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Title: The role of habitat heterogeneity and canyon processes in structuring sediment macrofaunal communities associated with hard substrate habitats in Norfolk Canyon, USA

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Abstract

Topographic and hydrodynamic complexity in submarine canyons promotes steep gradients in food availability and geophysical parameters which affect ecological assemblages and beta diversity. While habitat heterogeneity in submarine canyons is known to support diverse and abundant megafaunal communities, due to difficulty in sampling little is known about infaunal communities adjacent to hard substrate habitats, their contribution to canyon assemblages, and overall deep-sea diversity. Sediments were collected in three distinct habitat types: within Norfolk Canyon (western Atlantic) adjacent to the canyon walls, along the main axis of the canyon, and on the adjacent continental slope to quantify macrofaunal (>300 μm) density, diversity and community composition, and sediment geochemical parameters including grain size, organic content, and stable isotope composition. While macrofaunal densities were similar among habitats sampled at comparable depths, diversity was higher near the hard substrate environments. Discrete communities were present in each habitat type, while annelid functional composition was similar between adjacent to hard substrate and canyon axis habitats. Although diversity and abundance of hard substrate adjacent sediment communities did not change with depth, communities were driven by sediments with low organic matter content, whereas canyon and slope community assemblages were best explained by depth and higher organic content. Beta diversity among hard substrate adjacent sediments and canyon axis communities was high, with 27% of canyon taxa and 10% of regional taxa only occurring in hard substrate habitats. Given the thousands of submarine canyons worldwide, our results highlight the overall importance of substrate habitat heterogeneity within canyons in supporting deep-sea benthic diversity and suggest that both within-canyon and regional diversity are underestimated.

Keywords

Submarine canyon, macrofauna, community, functional trait, habitat heterogeneity

Introduction

Submarine canyons are morphologically complex features along continental margins, providing heterogeneous habitats and acting as conduits for the transport of sediment and organic matter from the productive continental shelves to food-deprived abyssal plains (Puig *et al.*, 2014). Habitat heterogeneity is created by the wide range of environmental conditions provided by variations in topography, hydrodynamic patterns, and sediment transport processes that support gradients in food resources and areas of sediment resuspension and deposition (De Leo *et al.*, 2010; Puig *et al.*, 2014) at both local (Huvenne *et al.*, 2011) and regional scales (De Leo *et al.*, 2014). Sediment transport and accumulation (García *et al.*, 2008) represent important influential ecological drivers. Locally enhanced organic matter concentrations (De Leo *et al.*, 2010; Duineveld *et al.*, 2001) combined with substrate heterogeneity (Levin and Sibuet, 2012) potentially explain higher faunal diversity, abundance, and benthic productivity found in canyon systems compared to surrounding areas (Cunha *et al.*, 2011; De Leo *et al.*, 2010; Escobar Briones *et al.*, 2008; Gunton *et al.*, 2015a; Gunton *et al.*, 2015b; Ingels *et al.*, 2009; Robertson *et al.*, 2020). However, the dynamic nature of canyons can result in rapid changes in composition of benthic assemblages on both small (1-100 m) and large (1-10 km) scales (Bernardino *et al.*, 2019; Campanyà-Llovet *et al.*, 2018; Gambi *et al.*, 2019; Gunton *et al.*, 2015a; Ingels *et al.*, 2009; Ingels *et al.*, 2011; McClain and Barry, 2010), which can make comparisons among areas location dependent.

In addition to the soft-sediment habitats that dominate canyon environments, hard substrates often occur in multiple forms, including outcrops of bedrock along canyon walls, as boulders previously deposited by turbidity flows, wall failures, or glaciers and icebergs, and along the upper rims of the canyon. Hard substrates are characterized by exposed rock or consolidated mud with steep slopes with elevated current conditions that minimize sedimentation (Huvenne *et al.*, 2011). The presence of hard substrates increases the habitat heterogeneity present in canyon systems by providing additional niches that can support more complex and diverse biological assemblages (Pierdomenico *et al.*, 2017). Rich and diverse coral and invertebrate communities often colonize canyon hard substrates (Huvenne *et al.*, 2011; Orejas *et al.*, 2009; Quattrini *et al.*, 2015), sustained by suitable current conditions for food delivery, with soft-sediment habitats at their base. The influence of hard substrates can extend to nearby habitats (e.g. Bourque and Demopoulos, 2018; Demopoulos *et al.*, 2014), with sedimentary areas adjacent to hard substrates acting as deposition zones and containing high amounts of organic matter that fall down the steep slopes (McClain and Barry, 2010).

Habitat heterogeneity at multiple spatial scales (from 10 m to 10 km) within a system is a major factor in structuring faunal assemblages and promoting higher diversity (Campanyà-Llovet *et al.*, 2018; De Leo *et al.*, 2014; Gambi *et al.*, 2019; McClain and Barry, 2010) by influencing organic matter spatial distribution (Campanyà-Llovet *et al.*, 2018). Hard substrates within submarine canyons have been studied primarily in the context of the presence of cold-water corals (e.g. Baker *et al.*, 2012; Mortensen *et al.*, 2005; Orejas *et al.*, 2009; Quattrini *et al.*, 2015) due to their status as critical and sensitive species and habitats; however, little research has been conducted on the adjacent sediment macrofaunal communities (but see Campanyà-Llovet *et al.*, 2018; McClain and Barry, 2010). In the Monterey submarine canyon complex, McClain and Barry (2010) found different patterns in macrofaunal density, diversity, and species richness relative to distance from canyon cliff faces at different locations, with high species turnover occurring within 30 m of the canyon walls. In addition, sediments adjacent to cliff faces had increased mass flux of organic carbon to the sea floor with larger sediment grain size and lower percent organic carbon compared to sediments located farther from the cliff face (McClain and Barry, 2010). Similarly, near-wall sediments in Barkley Canyon had a higher mean grain size and lower organic carbon content than similar depths within the main canyon axis (Campanyà-Llovet *et al.*, 2018). Further evidence of increased megafaunal activity (e.g. bioturbation) in near-cliff sediments suggests that sediment macrofauna residing adjacent to hard substrates are experiencing high levels of disturbance, resulting in distinct communities (McClain and Barry, 2010) that increase the overall biodiversity of submarine canyon systems.

Norfolk Canyon, located in the western north Atlantic Ocean, is a large shelf-incising canyon containing areas of steep-sided wall habitats (Obelcz *et al.*, 2014) colonized by cold-water corals and other invertebrates (Brooke *et al.*, 2017), and large areas of soft-sediments throughout the main axis (Robertson *et al.*, 2020). Norfolk Canyon exhibits relatively high current speeds and suspended sediment clouds are present at multiple depths (200-1200m) along the axis (CSA *et al.*, 2017). Macrofaunal density, diversity, and composition within Norfolk Canyon differed from adjacent slope habitats with sediment dynamics and organic enrichment disrupting generalized depth-related patterns within the canyon and supporting distinct communities at discrete depths (Robertson *et al.*, 2020). In particular, mid-canyon (800 m) and shallow slope (190-550 m) locations were identified as being areas of severely disturbed community structure due to enhanced deposition and erosion/winnowing respectively (Robertson *et al.*, 2020). However, the degree to which different canyon habitats, including hard substrate adjacent sediments, contribute to the overall regional diversity remains unknown.

Here we investigate the infaunal community structure and functional composition of sediment communities adjacent to hard substrates in comparison to main-axis habitats within Norfolk Canyon and sediments on the adjacent continental slope by addressing the following questions: 1) are sediment communities adjacent to hard substrates similar to canyon axis and slope soft sediment communities; 2) are any similarities among hard substrate adjacent and canyon axis sediment communities based on geographic proximity or depth regimes; 3) how do sediment communities residing near hard substrates contribute to overall canyon and regional diversity; and 4) what environmental factors drive the community structure and function among hard substrate adjacent and canyon axis sediment communities?

Methods

Sampling Procedures

Sediment samples were collected adjacent to hard substrate habitats in Norfolk Canyon in 2013 aboard the NOAA Ship *Ronald H. Brown* (2-18 May 2013) (Figure 1a, Supplemental Table 1). Push cores (6.35 cm diameter) were opportunistically collected at 11 individual locations, typically at the base of vertical walls or next to large boulders where soft sediment had accumulated (Fig 1b), during six dives using the ROV *Jason II* at depths ranging from 400-1342 m. At each sampling location 1-2 cores were collected for macrofaunal (>300 µm) analysis and one core for sediment geochemical analysis. Additional sediment samples (Figure 1a, Supplemental Table 1) were collected along the main axis of Norfolk Canyon (190 m, 550 m, 800 m, 1100 m, 1600 m) and at similar depths on the adjacent continental slope (190 m, 550 m, 800 m, 1100 m) using a NIOZ box corer in 2012 (NOAA Ship Nancy Foster, 19-28 Sept 2012, N=6) and 2013 (NOAA Ship Ronald H. Brown, 10-18 May 2013, N=24) with 3-4 replicate box cores per location. Although the inclusion of multiple year samples adds potential seasonal and/or interannual variability to the canyon axis and slope locations, similar analyses as those described below where the 2012 samples were excluded provided similar results and are thus included here to increase replication. Due to lower resolution local bathymetry available at the time of sampling, the 190 m slope cores technically occurred within the defined bounds of Norfolk Canyon (see Figure 1a) as later determined by higher resolution bathymetry, but are included as representative slope locations in comparison to the 190m axis cores.

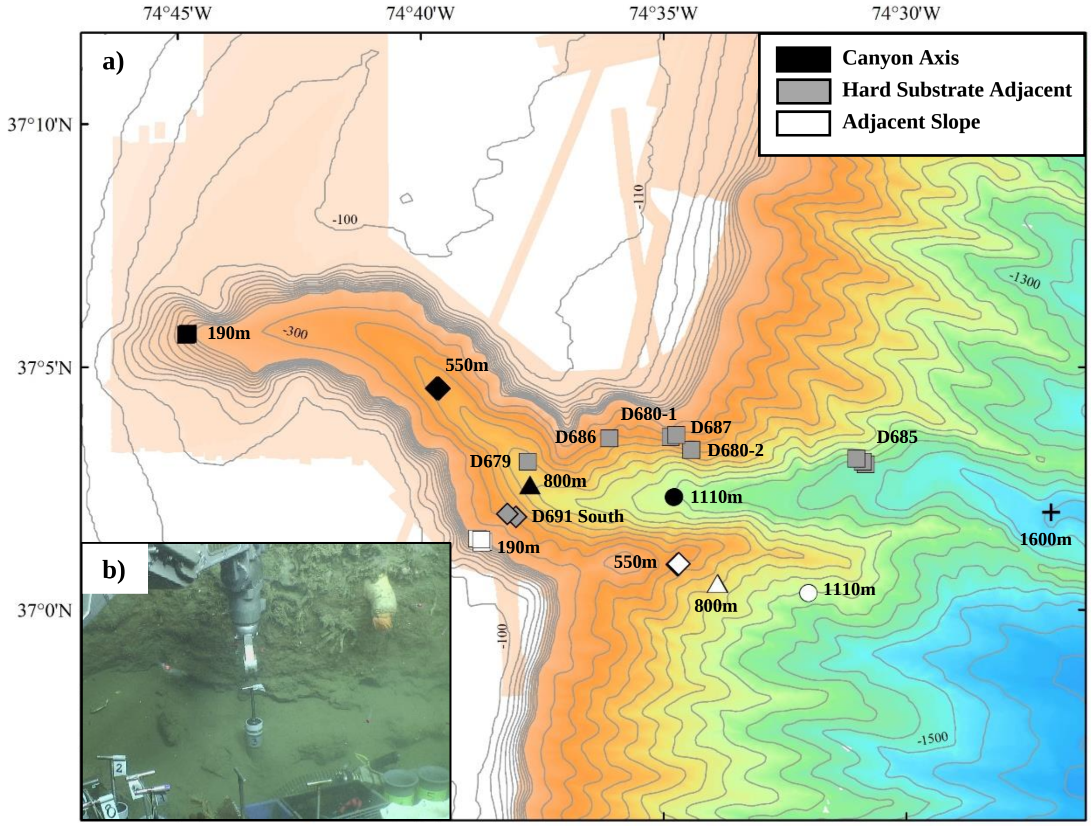


Figure 1. a) Map of sampling locations adjacent to hard substrate habitats (gray), in the main axis of Norfolk Canyon (black), and on the adjacent slope (white) with depth group or dive location labels. b) Example of sediment sampling adjacent to hard substrate habitats. Depth contours: 10 m (0-200 m) and 100 m (>200 m).

Box cores were subsampled with two polycarbonate push cores (6.35 cm diameter) identical to the ROV-deployed push cores, one each for faunal and sediment chemistry analyses. All push cores were sectioned vertically (0-2, 2-5, 5-10 cm) after recovery for either faunal or sediment geochemical analysis. Vertical distribution of fauna for canyon axis and slope samples was presented in Robertson *et al.* (2020). Faunal core sections were preserved whole in 8% buffered formalin solution until they were washed through a 300-μm mesh sieve to retain the macrofauna portion. Sediment geochemistry core sections were frozen whole in the field at -20°C.

Macrofauna were sorted with a dissecting microscope and identified to the lowest practical taxonomic level, including family level for polychaetes, oligochaetes, peracarid crustaceans, and molluscs. Homogenized subsamples of geochemistry cores were analyzed for the stable carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) isotopes, and percent organic carbon and nitrogen. Grain size analysis was performed on all hard substrate adjacent sediment geochemistry cores and a single replicate of canyon axis and slope cores using the Folk method (Folk, 1968). Station, community, and sediment geochemistry are presented in CSA *et al.* (2019) and Bourque *et al.* (2020). Data for the 0-5 cm vertical fractions from the 1600 m canyon axis stations were previously presented in Bourque *et al.* (2017).

Data Analysis

Macrofaunal Communities

Community structure was assessed using multivariate analysis and by examining the overall contribution of individual taxa to the community composition. Multivariate analysis of community structure across all samples was performed on presence/absence transformed data using Bray-Curtis similarities in PRIMER version 7 (Clarke and Gorley, 2015) with the PERMANOVA+ add on package (Anderson *et al.*, 2008). Cluster analysis (CLUSTER) combined with similarity profile analysis (SIMPROF) was used to determine similarity groupings among hard substrate adjacent sediment communities. Communities were examined using non-metric multidimensional scaling (nMDS) and permutational analysis of variance (PERMANOVA) to test for differences among habitats (hard substrate adjacent, canyon axis, slope) and their respective groupings as follows: CLUSTER-assigned groups for hard substrate adjacent sediments and depth for canyon axis and slope sediments. Similarity of percentages (SIMPER) was used to identify the taxa responsible for discriminating between habitats and groups and to assess the variability of the communities within groups. The RELATE function in Primer 7 was used to test for similarity in community structure with geographic distance within hard substrate adjacent sediment communities and among hard substrate adjacent and canyon axis sediment communities. A resemblance matrix was created with distances between sampling locations to remove the effect of co-located replicates and compared to the Bray-Curtis similarity matrix of community composition. An additional RELATE was performed using the Bray-Curtis similarity matrix of square-root transformed abundance with a Bray-Curtis similarity matrix of presence/absence transformed data to assess the influence of taxa density on the overall similarity results.

Diversity

Within habitat (alpha) and between habitat (beta) diversity were examined using the total number of taxa present in each core (Sp), Shannon diversity ($H' \log_e$), taxa richness estimated using Marglef’s index (d), and Pielou’s evenness (J’) based on untransformed abundance data using DIVERSE in PRIMER Statistical Software version 7 (Clarke and Gorley, 2015). Colonial organisms (e.g. Porifera and Bryozoa) were excluded from diversity calculations (H', J', and d) and multivariate community analysis but included in total taxa counts. Beta and regional (gamma, all habitats) diversity were examined using total taxa counts, shared taxa, and rarefaction curves calculated using the program EstimateS and plotted for each habitat type and for all samples combined. A Venn diagram was constructed to visualize the shared and unique taxa among habitats.

Univariate analyses

Density of macrofauna and univariate measures of biodiversity and sediment geochemistry were analyzed using one-way analysis of variance (ANOVA) with habitat and group as factors and individual cores as replicates, followed by post-hoc test Tukey's HSD for multiple comparisons. All data were tested for normality and heteroscedasticity using Shapiro-Wilk and Bartlett's tests (Zar, 1999) and $\log_e$-transformed when necessary. If transformation did not achieve normality, a non-parametric Kruskal-Wallis test was used on univariate measures. Sediment geochemical values were averaged across the vertical depth gradient per core prior to analysis. Depth relationships with abundance, diversity, and sediment geochemistry measures were tested using Spearman's rank correlation. A significance level of $p < 0.05$ was used in all tests. Univariate statistics were computed with the program R (R Development Core Team, 2018).

Functional composition

Annelid functional composition was assessed by assignment of individual families into four traits (feeding method, feeding location, motility, and living habit) with 15 total modalities based on published trait information. A trait matrix was created using a 'fuzzy coding' procedure (Chevenet *et al.*, 1994) which allows for flexibility in assigning taxa with a mixture of trait characteristics while capturing potential intraspecific variation in trait expression (Castella and Speight, 1996; Charvet *et al.*, 2000; Chevenet *et al.*, 1994; Demopoulos *et al.*, 2018). A station by trait matrix was created by multiplying taxa abundance by trait values and summing across each core, standardized, and a Bray-Curtis similarity matrix was created. The functional trait-weighted community data were analyzed using nMDS and PERMANOVA to test for differences among habitats and groups.

Relationship to environmental drivers

To further address the relationship of the environmental variables to the multivariate community and functional composition data, distance-based linear modeling (DistLM) and distance-based redundancy analysis (dbRDA) were performed using the PERMANOVA+ add on package. DistLM performs nominal tests of each variables explanatory power on community structure and builds a multivariate statistical model of explanatory power of a suite of variables when considered together. Community data were averaged for each sampling location due to the single grain size data available for each sampling location. Variables included were depth, mud content, percent organic carbon (%C), percent nitrogen (%N), stable carbon isotope composition ($\delta^{13}C$), stable nitrogen isotope composition ($\delta^{15}N$), and the carbon to nitrogen ratio (C:N). The explanatory variables used were not correlated to any other variable included in the model and were chosen due to their potential to structure and/or impact sediment communities.

Results

Hard substrate adjacent sediment communities

Cluster analysis of hard substrate adjacent sediment communities identified two significant community clusters (Figure 2 & 3a, SIMPROF p=0.029), with one group comprised of the sediment communities along the northern canyon wall (North), and the second group comprised of sediment communities along the southern canyon wall (South). North and South clusters had an average similarity of 36.1% (SIMPER), with higher abundances of Yoldiidae (Bivalvia), Scaphopoda, Thyasiridae (Bivalvia) in North samples and higher abundances of Tubificinae (Oligochaeta) and Cossuridae (Polychaeta) in South samples accounting for 26.1% of the dissimilarity. The North cluster had an average similarity of 46.7% (SIMPER) with Paraonidae (Polychaeta), Scaphopoda, Yoldiidae (Bivalvia), Tubificinae (Oligochaeta), and Cossuridae (Polychaeta) accounting for 56.6% of the similarity among samples. In contrast, the South cluster had a lower average similarity of 39.3% (SIMPER) with just two taxa, Paraonidae (Polychaeta) and Tubificinae (Oligochaeta) accounting for 58.4% of the similarity among samples. In comparison to presence/absence transformed similarities, the taxonomic composition had a significant effect on the overall similarity among samples (RELATE ρ=0.90, p=0.001). The North cluster was characterized by high proportions of Paraonidae (14.6%) and other Polychaeta (17.6%), scaphopods (6.8%), and bivalves (19.2%), but low proportions of

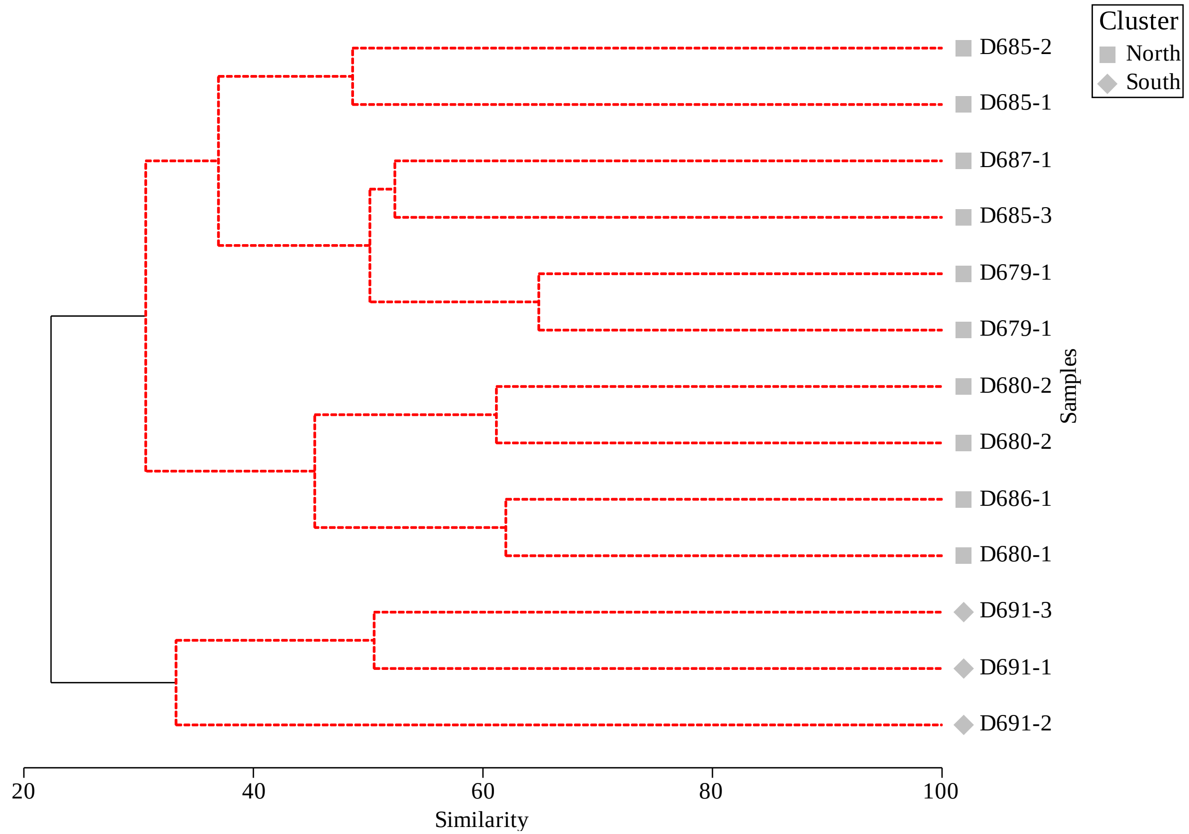


Figure 2. Dendrogram of hard substrate adjacent sediment communities from cluster analysis using Bray-Curtis similarities of square-root transformed abundance data. Solid black lines indicate significant differences among groups based on SIMPROF analysis.

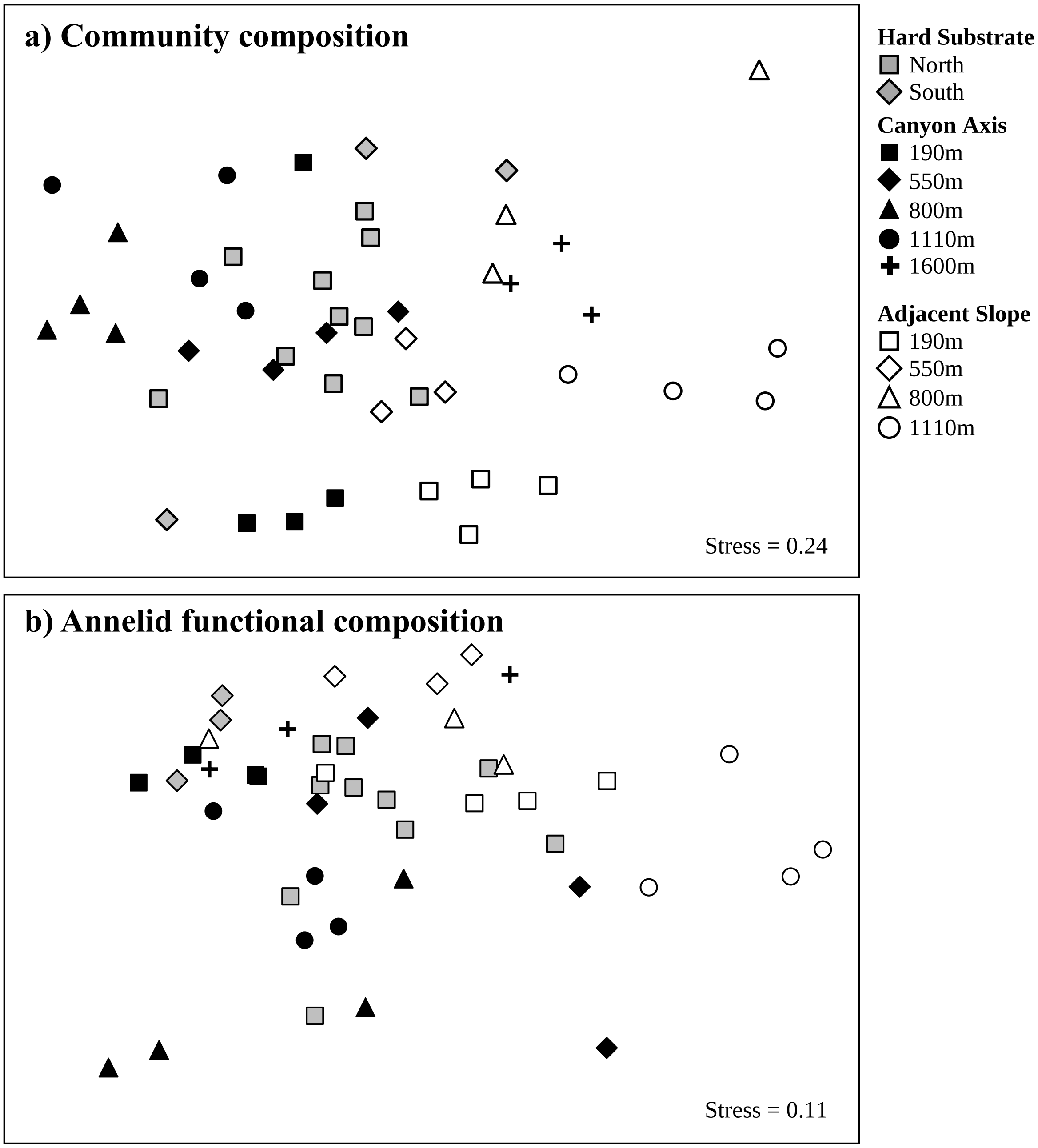


Figure 3. Non-metric multidimensional scaling of cores collected adjacent to hard substrate habitats (grey symbols), in the canyon axis (black) , and on the adjacent slope (white) a) based on Bray-Curtis similarities of square-root transformed abundance data and b) based on Bray-Curtis similarities of standardized annelid functional composition.

oligochaetes (5.0%) (Figure 3). The South cluster was characterized by high proportions of Cossuridae (22.7%) and Paraonidae (17.5%, Polychaeta) and oligochaetes (27.8%), but lower proportions of molluscs (2.1%) (Figure 4).

Macrofaunal density was similar between the North and South clusters (Table 1, Figure 5, ANOVA, F_{1-11}=2.89, p=0.15) and there was no relationship with depth either across all samples (Spearman correlation, ρ=0.121, p=0.69) or within the North cluster (Spearman correlation, ρ=-0.04, p=0.92). The South cluster exhibited a more even vertical density distribution of taxa (Table 1), while the North cluster had the major proportion of taxa in surface sediments. The total number of taxa was much lower in the South cluster (21) than in the North cluster (61); however, the South cluster consisted of only 3 samples while the North cluster was represented by 10. Overall the North and South clusters shared 17 of a total 65 taxa, with only 4 taxa unique to the South cluster. Both Shannon diversity (ANOVA, F_{1-11}=15.24, p=0.011) and species richness (d, ANOVA, F_{1-11}=7.92, p=0.016) were significantly lower within the South cluster while taxa evenness (J', ANOVA, F_{1-11}=1.93, p=0.19) was similar between North and South clusters. Similar to density, there was no correlation with any of the diversity metrics with depth for the North cluster (Spearman correlation: H'loge, ρ=-0.57, p=0.08; J', ρ=-0.085, p=0.81; d, ρ=-0.36, p=0.29).

Hard substrate adjacent sediment functional composition

Hard substrate adjacent sediment communities were composed primarily of subsurface dwellers (>65%), burrowers (>69%), motile species (>73%), and deposit feeders (>84%) with higher proportions of the above four traits within the South cluster (Figure 6). There was a significant difference in annelid functional composition between the North and South clusters

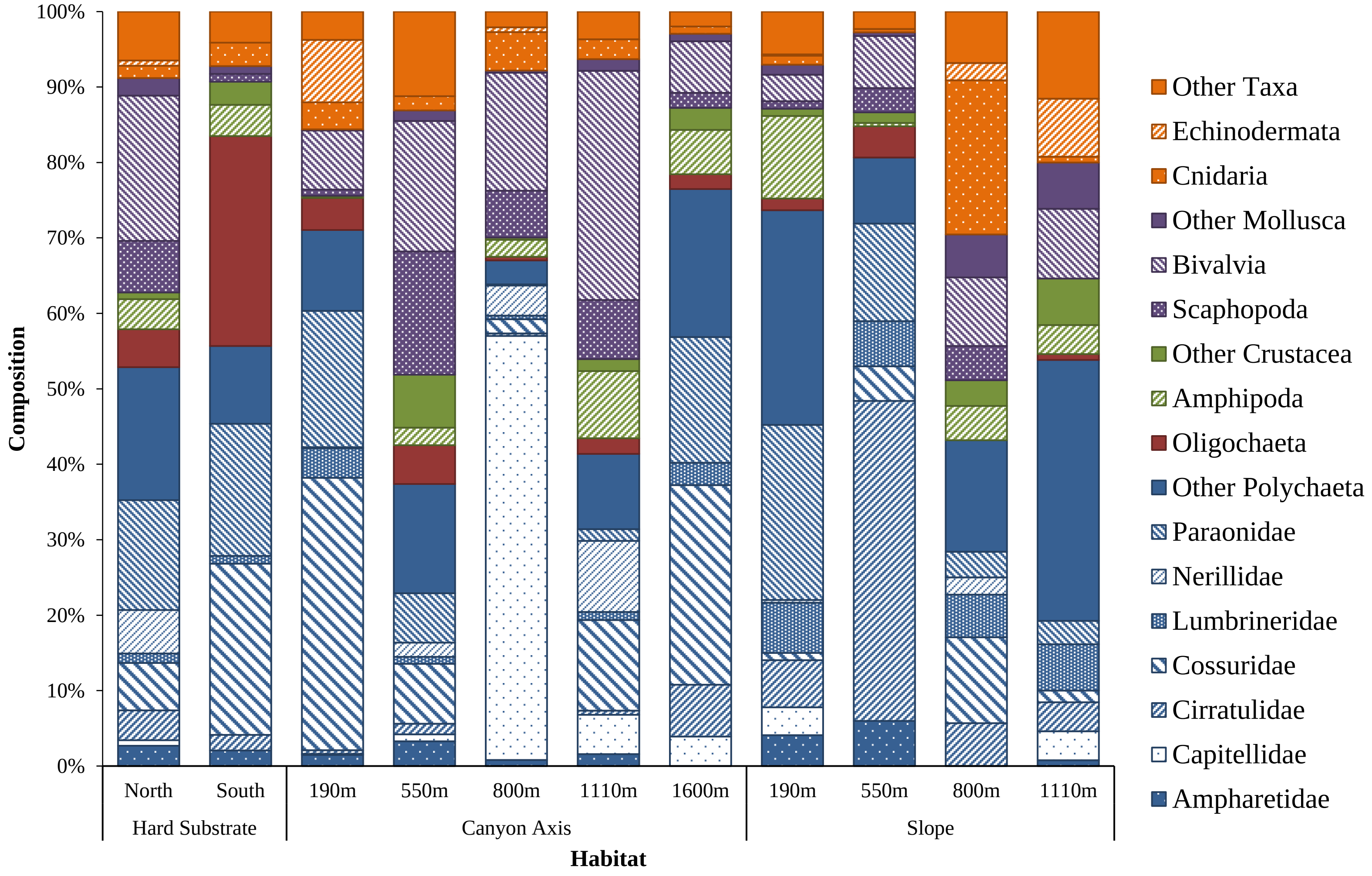


Figure 4. Major taxonomic composition of hard substrate adjacent, canyon axis and slope macrofaunal communities. Color represents major taxonomic groups: Polychaeta (blue), Oligochaeta (red), Crustacea (green), Mollusca (purple), all other groups (orange).

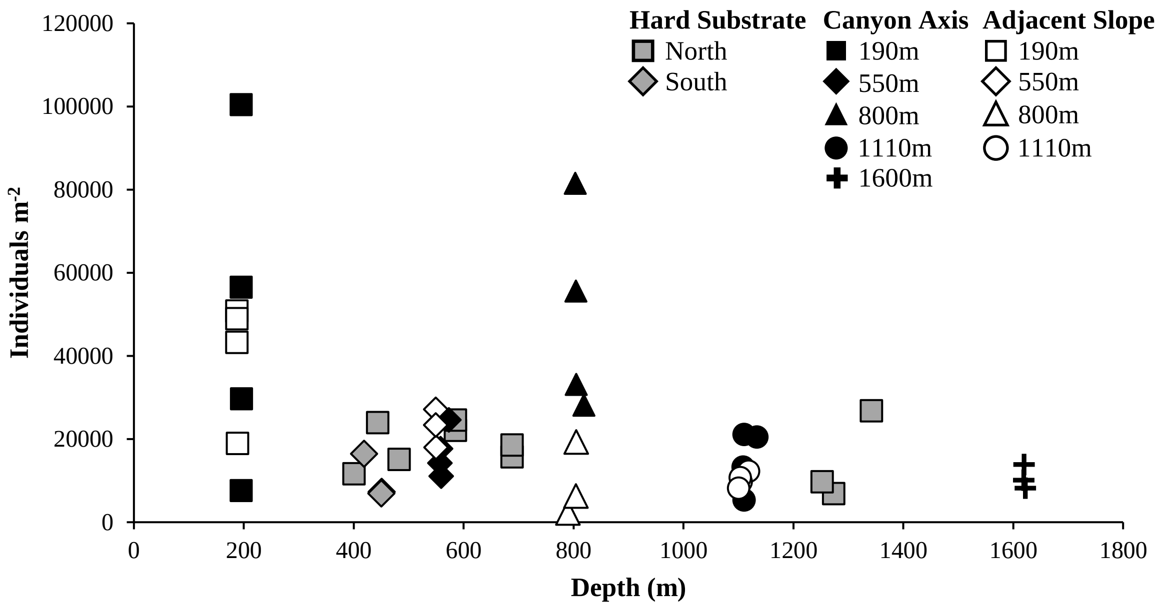


Figure 5. Scaled raw macrofaunal density in hard substrate adjacent, canyon axis, and slope sediments.

Table 1. Mean (± 1 S.E.) macrofaunal density and diversity in hard substrate adjacent, canyon axis, and adjacent slope sediments. Density=Individuals m^{-2}; d= Margalef's species richness; J'= Pielou's evenness; H'(log_e)=Shannon diversity; Taxa=Number of taxa. Values in parentheses represent one standard error.

Habitat	N	Density		0-2 cm	2-5 cm	5-10cm	d		J'		H'(log_e)		Taxa
Hard Substrate	**13**	**15871**	**(1960)**	**58.65**	**25.27**	**16.08**	**4.37**	**(0.40)**	**0.87**	**(0.02)**	**2.46**	**(0.11)**	**65**
North	10	17567	(2151)	63.67	23.02	13.31	4.86	(0.40)	0.88	(0.02)	2.62	(0.09)	61
South	3	10216	(3108)	29.90	38.14	31.96	2.71	(0.36)	0.83	(0.06)	1.91	(0.17)	21
Canyon Axis	**19**	**29101**	**(6034)**	**51.60**	**34.34**	**14.06**	**3.71**	**(0.22)**	**0.79**	**(0.04)**	**2.18**	**(0.11)**	**64**
190m	4	48578	(19987)	32.20	47.15	20.65	3.86	(0.64)	0.73	(0.02)	2.10	(0.13)	39
550m	4	16904	(2914)	71.03	18.22	10.75	4.54	(0.33)	0.90	(0.02)	2.62	(0.09)	33
800m	4	49605	(12199)	63.38	29.46	7.17	3.16	(0.48)	0.59	(0.12)	1.67	(0.37)	34
1110m	4	15087	(3701)	59.16	27.23	13.61	3.42	(0.30)	0.87	(0.04)	2.27	(0.12)	30
1600m	3	10742	(1672)	41.18	34.31	24.51	3.65	(0.52)	0.88	(0.06)	2.28	(0.23)	23
Adjacent Slope	**14**	**21395**	**(4237)**	**53.06**	**39.77**	**7.17**	**4.90**	**(0.37)**	**0.85**	**(0.03)**	**2.50**	**(0.12)**	**76**
190m	4	40521	(7366)	62.18	34.11	3.70	5.86	(0.68)	0.81	(0.03)	2.73	(0.22)	51
550m	3	22854	(2658)	36.41	54.84	8.76	4.06	(0.10)	0.73	(0.03)	2.12	(0.05)	31
800m	3	9268	(5141)	40.91	44.32	14.77	3.91	(1.26)	0.92	(0.04)	2.19	(0.36)	31
1110m	4	10269	(860)	53.08	33.85	13.08	5.32	(0.14)	0.94	(0.00)	2.80	(0.03)	40

Figure 6. Annelid functional composition a) feeding mode b) feeding location c) motility d) living habit

(Figure 3b; PERMANOVA, Pseudo-F=5.85, p=0.008) despite a high average similarity between the clusters (SIMPER, 83.7%). Average similarity was high within both the North (87.5%) and South (92.5%) clusters.

Comparisons of hard substrate adjacent communities to canyon axis and slope communities

Hard substrate adjacent sediment communities differed from both canyon axis (PERMANOVA, t=1.352, p=0.0293) and slope (PERMANOVA, t=1.919, p=0.0001) sediment communities (Figure 3a). Canyon axis and slope communities also differed (PERMANOVA, t=1.97, p=0.0002). Hard substrate adjacent sediment communities were overall more similar to canyon axis communities (SIMPER 38.3%) than to slope communities (SIMPER 32.6%) indicating a general canyon effect. Geographic distance between sampling locations adjacent to hard substrates and the canyon axis was not a significant factor in structuring sediment communities (RELATE, ρ=0.24, p=0.077). The North hard substrate adjacent communities were significantly different from the canyon axis 190 m (p=0.001), 800m (p=0.0006), 1110 m (p=0.01), and 1600 m (p=0.015) communities, while the South hard substrate adjacent communities were only significantly different from the canyon axis 800 m (p=0.011) communities. Differences in taxonomic composition (Figure 4) played an important role in structuring differences among hard substrate adjacent, canyon axis, and slope communities, with a significant correlation between abundance Bray-Curtis similarities and presence/absence Bray-Curtis similarities (RELATE, ρ=0.88, p=0.001).

Macrofaunal densities in hard substrate adjacent sediments were similar to densities observed in the canyon axis sediments at the closest comparable depths (550 & 1110 m, Figure 5). Hard substrate adjacent sediments collected at depths <700 m had much lower densities than their geographically closest 800 m canyon axis location, while hard substrate adjacent sediments collected at depths >700 m were similar to their closest geographic canyon axis location at 1600 m (Figure 5).

Comparisons of hard substrate adjacent communities to canyon axis and slope functional composition

While canyon and hard substrate adjacent sediment functional composition did not differ (Figure 3b, PERMANOVA, t=1.15, p=0.27), the functional composition differed between hard substrate adjacent sediments and slope habitats (PERMANOVA, t=2.82, p=0.0034). Canyon functional composition also differed from slope habitats (PERMANOVA, t=3.22, p=0.0004). Slope communities had lower proportions of deposit feeders (50-87%) and higher proportions of omnivores (2-26%), surface feeders (33-57%), motile (44-71%) and sessile (0.8-9.7%) fauna (Figure 6).

Within-canyon and regional diversity

A total of 653 macrofaunal individuals were collected from sediment cores adjacent to hard substrates. Individuals encompassed 65 taxa, including 31 polychaete families, 9 crustacean families, and 14 molluscan families. An additional 1,750 macrofaunal individuals were collected from the canyon axis and 948 in slope habitats. Slope habitats had 76 taxa encompassing 35 polychaete families, 18 crustacean families, and 14 molluscan families, while canyon axis had 64 taxa encompassing 30 polychaete families, 10 crustacean families, and 16 molluscan families. A total of 98 taxa were encountered across all three habitats.

Diversity differed among hard substrate adjacent, canyon axis, and slope communities (Figure 7). Shannon diversity (H') of hard substrate adjacent sediment locations on the north side of the canyon was higher than comparable depths (550 m & 1110 m) in the canyon axis and adjacent slope, while diversity of hard substrate adjacent sediments on the south side of the canyon were similar to those observed at 550 m in the canyon axis (Table 1). Rarefaction of all hard substrate adjacent sediment samples exhibited higher diversity than for all samples collected in the canyon axis across a wider depth range but was similar to the adjacent slope (Figure 7).

There was high beta diversity among hard substrate adjacent sediment habitats, canyon axis, and slope sediments (Figure 8). Canyon axis, slope, and hard substrate adjacent sediment habitats shared 38 taxa (38.8%), while 31 taxa were shared among any two habitats (31.6%) and 29 taxa (29.6%) were only found in a single habitat. Of the 29 unique taxa, 9 were found in canyon axis habitats and 10 each in hard substrate adjacent sediment and slope habitats. When considered together, hard substrate adjacent sediments account for 27% of all the taxa encountered within Norfolk canyon and 10% of the taxa encountered within the Norfolk Canyon/slope region as a whole.

Environmental drivers of macrofaunal communities

For hard substrate adjacent sediment habitats, only sediment C:N significantly increased with water depth (Spearman correlation, $\rho=0.656$, p=0.0.028 correlation). Compared to canyon and slope habitats, hard substrate adjacent sediments had significantly lower percent organic carbon than canyon habitats ($p=0.0026$), and significantly lower C:N than slope habitats ($p=0.0008$) (Table 2).

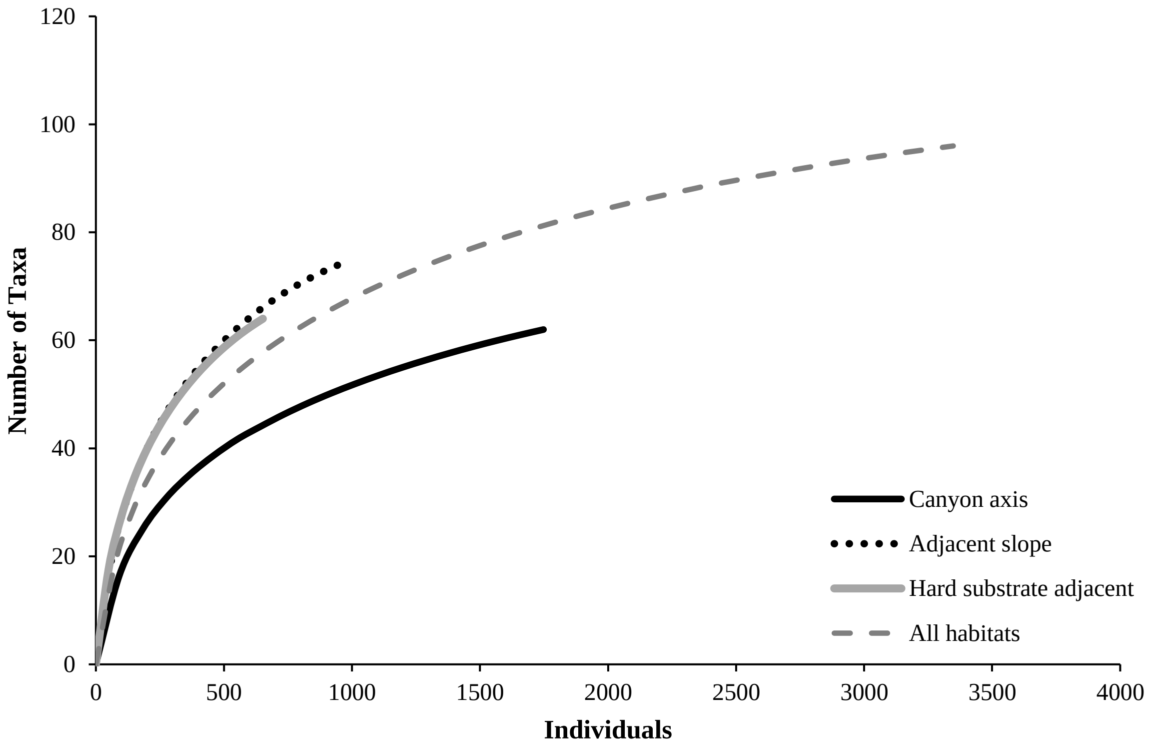
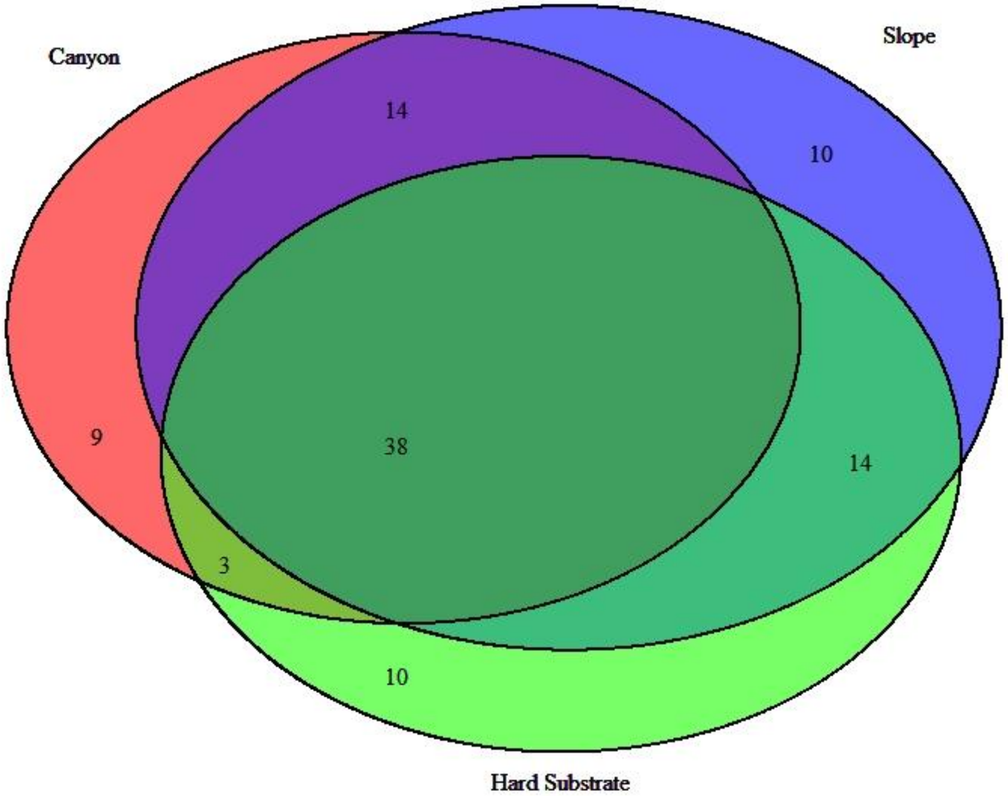


Figure 7. Rarefaction of hard substrate adjacent, canyon axis, and adjacent slope macrofaunal communities.



Polychaeta:
  Amphinomidae
  Pilargidae
Crustacea:
  Paramunnidae
  Diastylidae
  Cephalocarida
Mollusca:
  Cardiidae
  Periplomatidae
  Tellinidae
  Veneridae

Polychaeta:
  Aberrantidae
  Apistobranchidae
  Siboglinidae
Crustacea:
  Ampeliscidae
  Oedicerotidae
  Platyischnopidae
  Stenothoidae
  Armaturatanais sp.
Mollusca:
  Tornidae
  Buccinidae

Polychaeta:
  Aphroditidae
  Poecilochaetidae
  Sternaspidae
Crustacea:
  Mysidae
Other:
  Anthozoa
  Porifera
Mollusca:
  Columbellidae
  Limidae
  Propeamussidae
  Polyplacophora

Figure 8. Beta diversity of hard substrate, canyon axis, and slope habitats. Listed taxa are those exclusive to a single habitat.

Table 2. Mean sediment geochemical values for hard substrate adjacent, canyon axis, and slope habitats. Numbers in parentheses indicate the standard error of the mean.

Habitat	**% Mud**		**$\delta^{13}C$**		**%Corg**		**$\delta^{15}N$**		**%N**		**C:N**	
Hard Substrate	67.5	(3.5)	-21.1	(0.1)	0.9	(0.1)	6.3	(0.1)	0.2	(0.0)	6.0	(0.4)
North	67.7	(4.9)	-21.3	(0.3)	0.8	(0.1)	6.2	(0.1)	0.2	(0.0)	6.1	(0.5)
South	66.8	(2.6)	-21.1	(0.2)	0.9	(0.1)	6.5	(0.1)	0.2	(0.0)	5.5	(0.5)
Canyon Axis	73.6	(8.8)	-21.2	(0.1)	1.9	(0.2)	6.8	(0.2)	0.3	(0.0)	8.0	(0.5)
190 m	42.3	-	-21.4	(0.3)	1.3	(0.4)	6.5	(0.1)	0.2	(0.0)	7.0	(1.6)
550 m	63.0	-	-21.1	(0.3)	1.4	(0.3)	7.5	(0.9)	0.2	(0.0)	6.8	(0.1)
800 m	46.3	-	-21.0	(0.3)	2.3	(0.2)	6.8	(0.4)	0.3	(0.0)	10.4	(1.4)
1110 m	77.4	-	-21.3	(0.2)	2.2	(0.3)	6.6	(0.4)	0.3	(0.0)	8.1	(0.9)
1600 m	95.4	(0.4)	-21.2	(0.0)	2.3	(0.2)	6.6	(0.1)	0.4	(0.0)	7.5	(0.8)
Adjacent Slope	49.2	(17.2)	-21.6	(0.2)	1.7	(0.4)	5.6	(0.3)	0.2	(0.0)	11.2	(1.4)
190 m	20.6	-	-21.9	(0.4)	0.9	(0.4)	5.8	(0.7)	0.1	(0.0)	13.7	(4.6)
550 m	18.5	-	-22.1	(0.5)	0.9	(0.3)	5.6	(0.3)	0.1	(0.0)	11.3	(1.0)
800 m	77.3	-	-21.2	(0.2)	2.1	(0.7)	5.7	(0.4)	0.2	(0.1)	9.3	(1.1)
1110 m	80.5	-	-21.3	(0.3)	2.8	(0.9)	5.4	(0.8)	0.3	(0.1)	10.2	(1.4)

DISTLM analysis of macrofaunal communities indicated that four of the seven explanatory environmental variables individually explained a significant portion of the community variation (Table 3). The “best” model identified %Corg explaining 11.6% of the community variation and the second “best” model within 1 AICc identified both %Corg and depth explaining 21.6% of the community variation. Distance-based redundancy analysis (Figure 9a) of the “best” two-variable model indicates that hard substrate communities are predominantly separated from canyon and slope communities due to lower %Corg, while depth separates communities within all three habitat types. Seven additional models were within 1 AICc of the top model (Table 3), with 2-variable models that included %Corg combined with either depth (21.5%), percent mud (21.2%), or $\delta^{13}C$ (20.6%) serving as potential explanatory models. Environmental variables structured annelid functional trait composition differently than the macrofaunal communities. Of the seven explanatory variables only $\delta^{15}N$ composition explained a significant portion (16.5%, p=0.036) of the variation in functional composition (Table 4). The “best” model included $\delta^{15}N$ alone, while the “best” two-variable model (within 1 AICc unit of the top model) included both $\delta^{15}N$ and %Corg and explained 25.8% of the variation in functional trait composition (Table 4). The dbRDA of the two-variable model (Figure 9b) indicates that %Corg separates hard substrate adjacent sediment functional composition from both canyon axis and slope composition, while $\delta^{15}N$ separates individual locations of hard substrate adjacent habitats and canyon and slope communities.

Table 3. Results from the distance-based linear modeling (DISTLM) of environmental variables with macrofaunal communities in Norfolk Canyon axis, hard substrate adjacent, and slope environments.

Variable	**SS(trace)**	**Pseudo-F**	**P**	**Proportion**
δ^{13}C	3033.4	1.796	**0.027**	**0.091**
%C	3869.2	2.356	**0.001**	**0.116**
δ^{15}N	1685.5	0.956	0.551	0.050
%N	2691.1	1.576	0.078	0.080
C:N	2641.5	1.544	0.076	0.079
% Mud	2901.2	1.711	**0.031**	**0.087**
Depth	3131.2	1.860	**0.016**	**0.094**

AICc	**R^2**	**RSS**	**Selections**
150.68	0.11574	29562	%Corg
151.07	0.21585	26215	%Corg, Depth
151.15	0.21247	26328	% Mud, %Corg
151.17	0.093663	30300	Depth
151.23	0.090738	30397	δ^{13}C
151.31	0.20614	26539	δ^{13}C, %Corg
151.32	0.086781	30530	% Mud
151.46	0.080497	30740	%N
151.49	0.079013	30789	C:N
151.84	0.18504	27245	% Mud, %N
Total SS(trace)		33431	

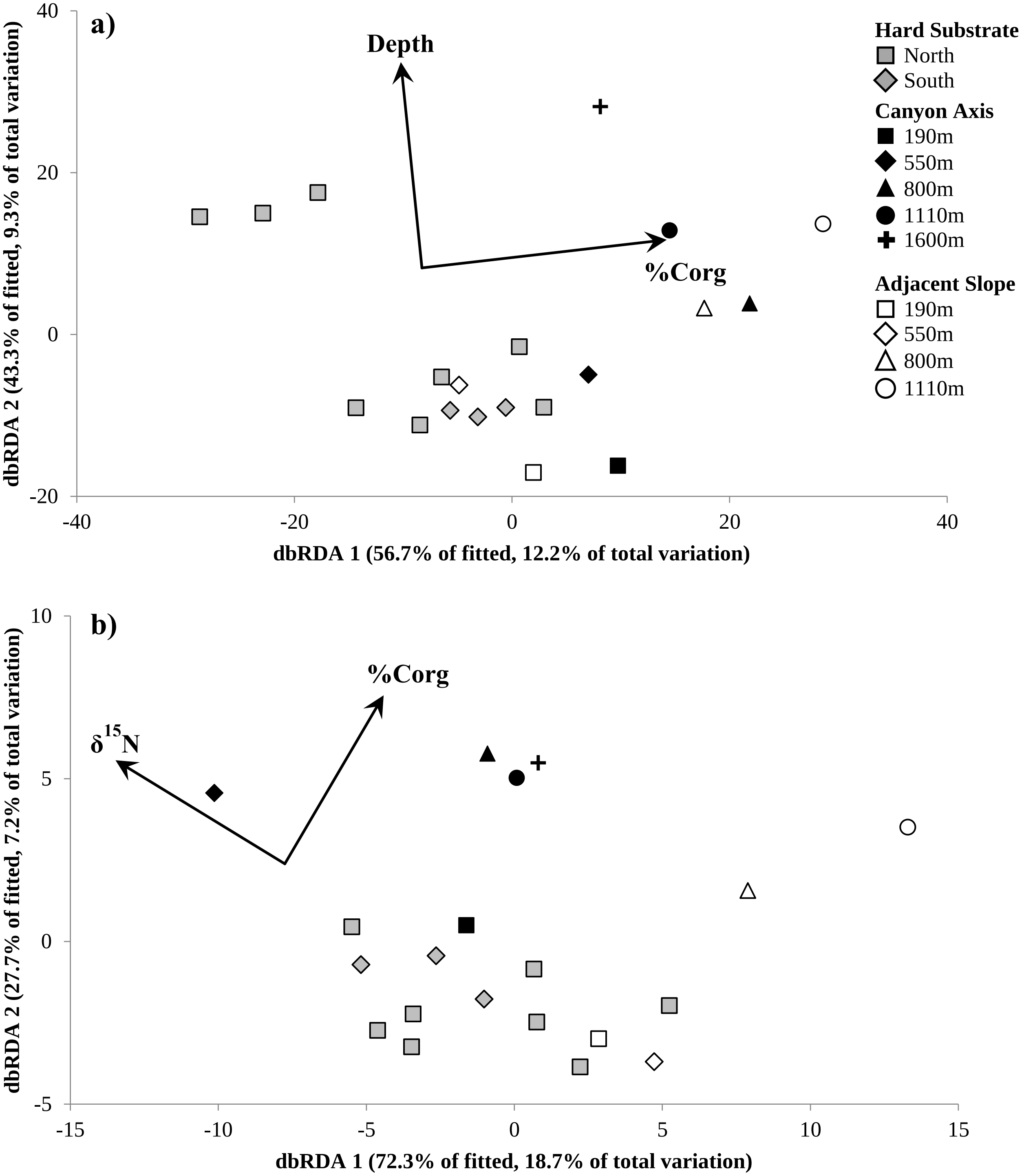


Figure 9. dbRDA of top two-variable DISTLM model of environmental variables for a) macrofaunal community; b) annelid functional composition.

Table 4. Results from the distance-based linear modeling (DISTLM) of environmental variables with annelid functional trait composition in Norfolk Canyon axis, hard substrate, and slope environments.

Variable	**SS(trace)**	**Pseudo-F**	**P**	**Proportion**
δ^{13}C	123.2	0.832	0.447	0.044
%C	187.4	1.297	0.267	0.067
δ^{15}N	281.6	2.023	0.127	0.101
%N	461.2	3.568	**0.036**	**0.165**
C:N	136.7	0.928	0.406	0.049
% Mud	325.0	2.376	0.098	0.117
Depth	157.57	1.078	0.342	0.057

AICc	**R^2**	**RSS**	**Selections**
99.833	0.16543	2326	δ^{15}N
100.27	0.25815	2068	%Corg, δ^{15}N
100.8	0.23825	2123	δ^{15}N, C:N
100.97	0.1166	2463	C:N
101.07	0.22782	2153	δ^{15}N, Depth
101.32	0.10103	2506	%Corg
101.36	0.21678	2183	%Corg, %N
101.37	0.33115	1865	%Corg, δ^{15}N, %N
101.5	0.2111	2199	δ^{15}N, %N
101.52	0.21033	2201	% Mud, δ^{15}N
Total SS(trace)		2788	

Discussion

Hard substrate adjacent habitats in Norfolk Canyon

Hard substrate adjacent sediment communities in Norfolk Canyon differed from both canyon axis and slope communities with differences based on depth and food availability (organic carbon content). Similar densities were observed between hard substrate adjacent and canyon axis habitats at similar depths, suggesting some canyon-specific processes may be influencing both habitats. Norfolk Canyon axis and slope communities are influenced by sediment grain size, organic matter enrichment, and depth (Robertson *et al.*, 2020) resulting in changes in macrofaunal density with sediment transport and food availability, similar to other canyons worldwide (Campanyà-Llovet *et al.*, 2018). Additional environmental factors affecting the fauna adjacent to canyon walls may be due to "edge effects" in hydrodynamic flow, by which different amounts of material are either deposited or winnowed by the currents and internal tides, as well as deposition from cliff faces that may alter the flux of nutrients delivered to sediments. Food availability (inferred from organic carbon content) was low but variable adjacent to hard substrates, consistent with the results from other canyons (Campanyà-Llovet *et al.*, 2018; McClain and Barry 2010). Geological composition of sediments collected at cliff bases in Monterey Canyon, characterized by low organic carbon content and coarse grain sizes, suggest that deposition is primarily from the canyon walls (McClain and Barry 2010), where sediments are influenced by high mass and carbon flux adjacent to cliff faces. McClain and Barry (2010) posit that there is increased deposition adjacent to cliffs but that the low carbon content in the sediments is the result of increased consumption by high densities of megafauna. However, a second possibility is that the organic-rich material observed in sediment traps located 15 m above the sea floor is not being deposited on the seafloor but remains in suspension and is transported away due to local hydrodynamics, resulting in winnowed organic-poor, coarse-grained sediments. Lastly, the presence of large grain sizes at the base of canyon walls alone supports increased oxygen exposure that enhances diffusion and oxidation of organic matter (Hedges and Keil, 1995). Canyon walls have a large influence on flow at mid and deep (917 and 1347 m) depths in Norfolk Canyon by forcing the dominant directions in flow within the canyon with general bottom flow up-canyon (CSA *et al.* 2017) and altering sediment and organic matter transport. As the hard substrates are topographically distinct locations compared to axis and slope habitats, further measurements of local near-bed hydrodynamics would help elucidate the effect of near-wall flows and water mass characteristics on both sediments and food supply.

For hard substrate adjacent sediment communities located on the north side of the canyon, diversity was generally higher than at similar or deeper depths in the canyon axis, which may be a function of the increased habitat heterogeneity provided by the hard substrates to adjacent sediments. In addition, diversity did not differ with depth among hard substrate adjacent sediments, suggesting similar influence of habitat heterogeneity on diversity across all the depths in hard substrate habitats. Multiple controls on canyon infaunal diversity have previously been identified, such as depth (Conlan *et al.* 2015), organic matter enrichment (Ingels *et al.* 2011, Bernardino *et al.* 2019), disturbance regimes (Robertson *et al.* 2020), and seafloor topography (De Leo *et al.* 2014, Bianchelli *et al.* 2010), with particular influence of slope and aspect. The steep slopes provided by the canyon walls and their location along the north wall likely influence the similarity in diversity. Our results were inconsistent with those of McClain and Barry (2010), where diversity was depressed adjacent to cliffs and overall declined with depth within Monterey Canyon; however diversity was enhanced adjacent to cliffs at their shallowest depth (595 m) suggesting non-uniform environmental controls across all their sampling locations.

The overall difference among hard substrate adjacent sediment and canyon axis communities was the result of high dissimilarities between the hard substrate adjacent sediments and the 190 m and 800 m canyon axis communities. While the 190 m canyon axis communities were located at the head of the canyon >10 km from all other sampling locations (Figure 1), both the 190 m and 800 m locations were typified by lower mud content than any of the hard substrate adjacent habitats. Robertson *et al.* (2020) observed that communities at 800 m within the axis of Norfolk Canyon are severely disturbed with high abundances of opportunistic taxa Capitellidae and Cirratulidae (Pearson and Rosenberg, 1978) and located in an area of high water column turbidity (CSA *et al.*, 2017), sediment deposition, and organic enrichment. Higher organic carbon and mud content was observed at the sampling location closest to the 800 m axis site (Figure 1, D679-1), suggest some influence of the turbidity plume extending across the canyon to the edges. High water column turbidity that occurs at 800 m depth can extend upwards to 700 m, with moderate levels up to 500 m depth (CSA *et al.* 2017) supporting our results. McClain and Barry (2010) hypothesized that cliff-adjacent sediments are experiencing high levels of disturbance through increased bioturbation by megafauna, resulting in reduced macrofaunal evenness, species richness, body size, and a lack of tube-building taxa and amphipods near cliff faces. Although we have no data for biomass or macrofauna size estimates, the increased diversity of taxa, presence of tube-builders and amphipods, and no dominance of opportunistic taxa suggests disturbance near Norfolk Canyon hard substrates may only be moderate. Given there is increasing evidence that no two canyons are alike (Cunha *et al.*, 2011), comparisons between Monterey Canyon and Norfolk Canyon may be limited; however, the results of McClain and Barry (2010) provide the only insight into other canyon hard substrate adjacent sediment communities. Monterey Canyon and Norfolk Canyon are morphologically and geologically different and likely have different particulate organic carbon regimes due to regional differences. McClain and Barry (2010) sampled within multiple sections of the larger canyon complex, with their shallowest station (Soquel Canyon, 595 m) exhibiting contrasting community patterns with distance from cliff faces compared to their deeper stations. Their sampling locations were at the bases of cliffs where there were large expanses (>100 m) of soft-sediments. In contrast, hard substrate adjacent sediments from Norfolk Canyon were collected opportunistically, typically in small patches of sediment along the canyon walls or large boulders. The contrasting results among the Monterey Canyon stations may reflect a higher variation in the hydrodynamic regimes and sediment transport among Monterey Canyon stations than among our study locations (Maier *et al.*, 2019) where there was high similarity among all depths.

Submarine canyons support distinct and functionally different annelid communities compared to the adjacent slope, contributing to our assessment that canyon-specific processes are the primary drivers influencing infaunal communities. Organic carbon content was one of the key components explaining both functional, as well as community, assemblages, again highlighting the importance of canyons acting as conduits and concentrators of organic matter. As many of the functional traits examined here were feeding characteristics (mode, location), the amount of food content in the sediments is a natural explanatory parameter. Despite lower organic carbon content, hard substrate adjacent habitats were dominated by deposit feeders which require organic matter to survive. Norfolk Canyon axis sediments are known to contain high quality organic matter based on pigment analysis (CSA *et al.*, 2017) and may provide the nutritional support for hard substrate adjacent communities. While corresponding quantitative observations on the Norfolk Canyon megafaunal communities are unavailable, the different topography adjacent to hard substrates in Norfolk Canyon compared to Monterey Canyon presents a lower likelihood of high densities of megafauna consuming organic matter resulting in the low %Corg observed, supported by our community results. Sediment $\delta^{15}N$ represents the quality of the food available and higher values were the primary driver for separating all canyon (axis and hard substrate) from slope functional assemblages. Higher $\delta^{15}N$ values occurring within the canyon suggests increased reworking of organic material. However, the similarity among hard substrate adjacent and canyon axis functional groups may be a result of assessing only annelid communities. Annelids represented 58-84% of hard substrate adjacent communities, and only 43-78% of canyon axis communities, leaving a large portion of the taxa and their functional role unassessed. For example, Thyasiridae bivalves, known to contain chemoautotrophic endosymbionts (Dando *et al.* 1994) and occupy organic-rich sediments, had high abundances at the 800 m canyon axis location and were also present in some hard substrate sediments, would add to the overall functional diversity. Additional assessment of feeding niche specialization by non-polychaete taxa will likely enhance our understanding of the functional role of both hard substrate adjacent and canyon axis habitats.

Although sampling was limited, differences between hard substrate adjacent sediment communities on the north side and the south side of Norfolk Canyon may be an indicator of localized differences in the hydrodynamic conditions. Anticyclonic circulation has been observed in Baltimore Canyon (Hunkins, 1988) and other submarine canyons (Durrieu de Madron, 1994; She and Klinck, 2000) resulting in differing directions in flow on opposite sides of a canyon. Spatially variable topography and related hydrodynamic regimes (e.g. current speed) on different sides of a submarine canyon likely result in differences in sediment deposition between inner and outer bends, analogous to river environments. . High current velocities have been reported from Norfolk Canyon (CSA *et al.*, 2017; Hecker *et al.*, 1983) and long-term in situ measurements of hydrodynamic flow indicated that canyon walls have a large influence on flow at mid- (917 m) and deep-canyon (1347 m) depths (CSA *et al.*, 2017). Lower proportions of surface feeders, density, diversity, and mud content suggest that the south side of Norfolk Canyon experiences higher current speeds than the north side or may be receiving sediment from a different source. Comparable data from Monterey Canyon indicated that organic carbon content and grain size composition differed between sides of the canyon (McClain and Barry, 2010), supporting potential hydrodynamic differences, although abundance and diversity were similar. However, additional replicate sampling would be required to fully assess for differences in biological and environmental parameters.

Within-canyon and regional biodiversity

Sediment communities adjacent to hard substrates contribute substantially to the biodiversity present in Norfolk Canyon. Given the limited and opportunistic sampling of hard substrate adjacent habitats, the slope of the rarefaction curves suggest much higher biodiversity is as yet discovered from these habitats. Despite the slightly lower sampling effort for hard substrate adjacent habitats (13 cores) versus the canyon axis (19 cores), a higher number of taxa were encountered in sediments adjacent to hard substrate habitats. Spatial turnover of taxa was also high among canyon communities. Within hard substrate adjacent habitats, communities only shared 12% of taxa across the entire depth range. These results further suggest the presence of different environmental niches adjacent to hard substrates, given that individual taxa preferentially occupy areas with a specific range of sediment biogeochemical parameters. While previous studies on canyon hard substrates have focused on the epi-megafaunal communities (e.g. deep-sea corals), our results highlight that they influence adjacent sediments to support distinct communities, although the scale of influence is yet unknown for Norfolk Canyon. The influence of hard substrate habitats on adjacent sediments presented here is consistent with results from deep-sea coral habitats (Bourque and Demopoulos, 2018; Demopoulos *et al.*, 2014), where adjacent sediment communities differed from other regional soft-sediment communities. It should be noted that our analysis is at the family level and higher, providing a very conservative estimate of the beta diversity within the Norfolk Canyon region. Thus beta diversity may be higher than represented here, however identification beyond family level would be required to confirm. There are an estimated 9500 submarine canyons worldwide (Harris *et al.* 2014), many of which contain steep walls and sediment habitat suitable for infauna at their base. The increased diversity associated with hard substrate adjacent habitats observed in Norfolk Canyon suggests that the biodiversity of submarine canyons is underestimated, with these additional heterogeneous habitats contributing significantly to both within-canyon and regional biodiversity.

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Supplemental Table 1. Location information for all hard substrate adjacent cores collected via ROV and canyon axis and adjacent slope cores collected via box core. MF indicates the number of cores used for macrofaunal analysis; SC indicates the number of cores used for sediment geochemical analysis; * indicates grain size analysis of the sediment geochemical core.

Date	**Station**	**Latitude**	**Longitude**	**Depth (m)**	**MF**	**SC**	**Group**
2-May-2013	ROV-2013-RB-679-1	37.0509	-74.6300	688	2	1	Hard Substrate North
5-May-2013	ROV-2013-RB-680-1	37.0593	-74.5809	443	1	1	Hard Substrate North
5-May-2013	ROV-2013-RB-680-2	37.0549	-74.5739	585	2	1	Hard Substrate North
11-May-2013	ROV-2013-RB-685-1	37.0500	-74.5140	1342	1	1	Hard Substrate North
11-May-2013	ROV-2013-RB-685-2	37.0508	-74.5148	1273	1	1	Hard Substrate North
11-May-2013	ROV-2013-RB-685-3	37.0516	-74.5174	1252	1	1	Hard Substrate North
13-May-2013	ROV-2013-RB-686-1	37.0590	-74.6020	482	1	1	Hard Substrate North
14-May-2013	ROV-2013-RB-687-1	37.0604	-74.5787	400	1	1	Hard Substrate North
18-May-2013	ROV-2013-RB-691-1	37.0316	-74.6340	451	1	1	Hard Substrate South
18-May-2013	ROV-2013-RB-691-2	37.0327	-74.6370	419	1	1	Hard Substrate South
18-May-2013	ROV-2013-RB-691-3	37.0316	-74.6342	450	1	1	Hard Substrate South
19-Sep-2012	NF-2012-159	37.0944	-74.7472	196	1	1	Canyon 190m
11-May-2013	RB-2013-046	37.0948	-74.7466	195	1	1*	Canyon 190m
11-May-2013	RB-2013-047	37.0948	-74.7466	195	1	1	Canyon 190m
11-May-2013	RB-2013-048	37.0948	-74.7466	195	1	1	Canyon 190m
19-Sep-2012	NF-2012-162	37.0760	-74.6612	573	1	1	Canyon 550m
11-May-2013	RB-2013-043	37.0760	-74.6606	559	1	1*	Canyon 550m
11-May-2013	RB-2013-044	37.0760	-74.6606	557	1	1	Canyon 550m
11-May-2013	RB-2013-045	37.0760	-74.6606	558	1	1	Canyon 550m
20-Sep-2012	NF-2012-164	37.0429	-74.6292	819	1	1	Canyon 800m
10-May-2013	RB-2013-040	37.0427	-74.6292	805	1	1*	Canyon 800m
10-May-2013	RB-2013-041	37.0428	-74.6292	803	1	1	Canyon 800m
10-May-2013	RB-2013-042	37.0428	-74.6293	804	1	1	Canyon 800m
28-Sep-2012	NF-2012-192	37.0387	-74.5799	1133	1	1	Canyon 1110m
10-May-2013	RB-2013-038	37.0386	-74.5799	1110	1	1*	Canyon 1110m
10-May-2013	RB-2013-039	37.0387	-74.5800	1110	1	1	Canyon 1110m
15-May-2013	RB-2013-077	37.0388	-74.5796	1108	1	1	Canyon 1110m

15-May-2013	RB-2013-078	37.0335	-74.4504	1622	1	1*	Canyon 1600m
18-May-2013	RB-2013-082	37.0334	-74.4503	1619	1	1*	Canyon 1600m
18-May-2013	RB-2013-083	37.0334	-74.4503	1620	1	1*	Canyon 1600m
24-Sep-2012	NF-2012-181	37.0234	-74.6452	188	1	1	Slope 190m
11-May-2013	RB-2013-049	37.0231	-74.6458	187	1	1*	Slope 190m
11-May-2013	RB-2013-050	37.0245	-74.6473	187	1	1	Slope 190m
11-May-2013	RB-2013-051	37.0242	-74.6459	187	1	1	Slope 190m
24-Sep-2012	NF-2012-183	37.0156	-74.5786	550	1	1	Slope 550m
12-May-2013	RB-2013-054	37.0158	-74.5782	549	1	1*	Slope 550m
12-May-2013	RB-2013-055	37.0158	-74.5782	549	1	1	Slope 550m
12-May-2013	RB-2013-056	37.0158	-74.5782	548	1	1	Slope 550m
13-May-2013	RB-2013-059	37.0090	-74.5648	790	1	1	Slope 800m
12-May-2013	RB-2013-060	37.0091	-74.5647	790	1	1	Slope 800m
14-May-2013	RB-2013-069	37.0090	-74.5650	804	1	1*	Slope 800m
14-May-2013	RB-2013-070	37.0090	-74.5650	805	1	1	Slope 800m
14-May-2013	RB-2013-071	37.0058	-74.5337	1118	1	1	Slope 1110m
15-May-2013	RB-2013-073	37.0058	-74.5337	1105	1	1*	Slope 1110m
15-May-2013	RB-2013-075	37.0059	-74.5337	1103	1	1	Slope 1110m
15-May-2013	RB-2013-076	37.0058	-74.5336	1100	1	1	Slope 1110m