PATTERNS IN BIODIVERSITY AND DISTRIBUTION OF BENTHIC POLYCHAETA IN THE MISSISSIPPI CANYON, NORTHERN GULF OF MEXICO

A Dissertation

by

YUNING WANG

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

December 2004

Major Subject: Oceanography

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Approved as to style and content by:

Gilbert T. Rowe (Chair of Committee)	Mary K. Wicksten (Member)
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ABSTRACT

Patterns in Biodiversity and Distribution of Benthic Polychaeta

in the Mississippi Canyon, Northern Gulf of Mexico. (December 2004)

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The distribution of benthic polychaetes in the Mississippi Canyon was examined to evaluate impacts of environmental variables on species assemblages. Environmental variables considered included depth, bathymetric slope, hydrographic features, sediment grain size, food availability and sediment contamination. Samples were collected using GOMEX boxcorer.

Density decreased with increasing depth exponentially. Diversity exhibited a unimodal pattern with depth with a maximum value in the intermediate depth range (about 1269 m). Deposit feeders were the most abundant feeding guild. Both the feeding guilds and faunal composition could be divided into three groups along the depth gradient: shallow (300 – 800 m), intermediate (800 – 1500 m) and deep (> 1500 m). Results of statistical analyses revealed that depth was the most important determinant in organizing polychaete assemblages in the study area.

The Mississippi Canyon and the Central Transect (a non-canyon area) were found not contaminated by trace metals or Polynuclear Aromatic Hydrocarbons (PAHs)

in sediments, although the highest PAHs concentration occurred at the head of the Canyon, MT1. The mean density was higher in the Mississippi Canyon (1668 N/m^2) than in the Central Transect (979 N/m^2), while the mean diversity in the Canyon (ES(100) = 26.9) was lower than the Central Transect (ES(100) = 33.1). Large amounts of terrigenous input from the Mississippi River to the Canyon could enhance polychaete density and accelerate competitive exclusion, and thus lead to lower diversity. The faunal composition was significantly different between the two transects, with higher species richness in the Mississippi Canyon (301 species). This could be attributed to structure complexity in the Mississippi Canyon. The distribution of feeding guilds was similar between two transects. The differences observed in polychaete assemblages between two transects may be largely due to high terrigenous sediment and organic matter input to the Mississippi Canyon by the Mississippi River.

DEDICATION

This thesis is dedicated to my loving parents for their wisdom, guidance and support from the very beginning of my life. Without their unconditional love, hope and encouragement, I would never had those dreams to try my best to make them come true. This thesis is dedicated to my beloved husband who has always been there for me. Although I am not a perfect wife, he has always tried to be a perfect husband. This thesis is also dedicated to my lovely son, Ranran, for bringing so much happiness into my life and keeping my company through such a long long journey without complaining.

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1. INTRODUCTION

1.1. Study Area

The Mississippi Canyon is a major cross-margin channel in the Northern Gulf of Mexico, which is located on the Louisiana continental shelf, off the western side of the Mississippi River Delta. It was probably originally directly excavated by river water during sea level lowering, and then subjected to modification and erosion by submarine flows, or avalanches, of silt-laden water, which are called "turbidity currents" (Shepard, 1943; Heezen, 1956). The Mississippi Canyon was cut into the sedimentary deposits on the continental slope, having relatively steep rock walls and trough-shaped profiles. The depth ranges from 50 m to about 1200 m, over a length of almost 37 km and with a width of 8 km to 16 km (Shepard and Dill, 1966). The topography of the upper and lower canyon is very different. Sediments in the lower canyon are fine-grained, which is mainly due to the low energy regime (Goodwin and Prior, 1989).

The Mississippi and Atchafalaya Rivers supply large amounts of terrigenous particulate matter, nutrients and sediments to the Louisiana continental shelf and into the wide, trough-shaped Mississippi Canyon. The Canyon can be expected to redirect the local flow down off the edge of the continental shelf (Klinck, 1989; Howard, 1992; Klinck, 1996). If large quantities of particulate material are transported to the deep ocean

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This dissertation follows the style of Deep-Sea Research I.

through the Mississippi Canyon, this could strongly influence the physical, chemical and geological features of the canyon, and associated benthic and pelagic communities.

Rowe (1971) and Ohta (1983) observed distinctive differences in populations of epibenthos in submarine canyons and non-canyon areas, possibly because canyons act as funnels for organic matter. Hubbard (1995) suggested more species were found in the Central region than that in the eastern region or in the western region in the Gulf of Mexico, and the mean polychaete density was higher than that in the Western region but lower than that in the Eastern region, probably due to organic matter enhancement by the Mississippi river outflow. The Mississippi Canyon and the Central Transect sampled in this study were both located in the central region of the Gulf of Mexico, and thus comparisons between the two transects were made to see if differences existing in polychaete assemblages can be attributed to canyon effects.

1.2. Benthic Polychaeta Community Structure

Polychaeta is a class of the phylum Annelida. It is probably the most abundant and diverse group in marine sediments from the intertidal to the deep-sea. Over 10,000 species have been described worldwide (Fauchald, 1977). On the continental slope and the deep ocean floor, polychaetes compose 40% to 80% of the infauna (Sanders et al., 1965). Polychaetes have developed different living strategies to help them adapt to various habitats, especially in sand and mud. Strategies involve large variations in morphology, feeding types and reproductive modes (Ruppert and Barnes, 1994).

Polychaetes, as one of the most dominant groups in benthic infaunal communities, are good indicators of habitat quality. Polychaetes include both sensitive and non-sensitive species. The presence/absence of certain species, reproduction, growth and mortality (Pearson & Rosenberg, 1978) can reflect changes in the environment, such as pollution, nutrient enrichment, etc. Species composition, diversity, abundance, biomass and trophic groups are also affected by environmental disturbances in shallow and deep water (Glover et al, 2001; Levin and Gage, 1998). In most cases, polychaete assemblages demonstrate the same distribution patterns as the benthic fauna taken in its entirety (Fauchald, 1973; Gettleson, 1976; Hubbard, 1977). Furthermore, in deep-sea sediments, "polychaetes are present in sufficient numbers to allow the use of valid statistical methods, other taxa are present either rarely or in widely separated aggregation, requiring a larger, costlier sampling effort be taken to insure a statistically valid sample" (Hubbard, 1995).

The polychaete worms are an important link in the marine food web. Due to the high caloric value and protein content, both adults and larvae are nutritious food sources for many economically important fishes (Yang and Sun, 1986). The movement and deposit-feeding mode of polychaetes can enhance bioturbation, decompose organic matter and recycling of nutrients (Fauchald and Jumars, 1979).

1.2.1. Density

Previous research on deep-sea macrofauna biomass and abundance suggested that they were linearly correlated with particulate organic carbon (POC) flux on the ocean

floor (Carney et al., 1983; Rex, 1977), and their great reduction was a function of both increased depth and distance from shore (Rowe, 1983). Based on six different sets of data from the north-west Atlantic, the Gulf of Mexico and off South America, Rowe (1971, 1974) suggested that the statistical relationships between macrofaunal biomass (or abundance) and depth could be expressed as $Y = ae^{-bx}$, where Y is abundance or biomass, x is depth and a is a coefficient that was related to euphotic zone primary production.

1.2.2. Diversity Concept, Measurement and Comparison

Diversity Concept

Diversity is one of the central themes in ecological studies. It has two components: species richness and species evenness. Species richness is the number of species in a given area; species evenness is the distribution of the number of individuals amongst the species (Whittaker, 1960; 1972). There are several levels of diversity. The α diversity is also called "local diversity" or "within-habitat diversity", that is the diversity calculated from all the samples of a "homogenous" assemblage. The β diversity is also called "difference diversity" or "species turnover", which is the difference along a gradient (transect) or between habitats in a landscape. It is related to zonation along the gradient. The γ diversity is "landscape diversity". It is the diversity from all the assemblages in a landscape, and often referred to as "species lists for geographic units" or "species richness" (Whittaker, 1960; 1972). The α diversity has

been studied intensively, while few studies have examined β diversity in the marine environment (Gray, 2000).

Diversity Measurement and Comparison

Although many methods are available to measure the species diversity, there is still considerable disagreement about which method is the best for the specific community. Diversity measures can be divided into two categories. One is univariate analysis, including species richness indices, species abundance models and those indices based on the proportional abundances of species (Magurran, 1988). The other is multivariate analysis.

The species richness indices are essentially a measurement of the number of species in a given area. This measurement appears to be straightforward, but the value depends on area sampled, may be vulnerable to high sampling variability, and can be affected by dominance relations (Walker, 1989). In order to compare species richness among different communities and habitats, or between two samples with unequal sample sizes, a technique called "Rarefaction" devised by Sanders (1968) and modified by Hurlbert (1971) has been employed widely. A major criticism of rarefaction is that some information will be lost after rarefaction, such as the number of species and the relative abundance (Williamson, 1973). Fager (1972) and Simberloff (1979) reported that the rarefaction method of Sanders overestimates the number of species. An alternative approach is to calculate species accumulation curves for randomized samples (Colwell, 1997). For example, Chao 2, a non-parametric method (Chao, 1984,) could be used to

provide the least biased estimates of species richness based on small sample sets (Colwell and Coddington, 1994).

The species abundance models describe the distribution of species abundance. Four models are mainly used in ecological studies: the log-normal distribution, the geometric series, the logarithmic series and MacArthur's broken stick model (Magurran, 1988). The best-fit model depends on the specific community. In the geometric series model, only a few species are dominant, while other species are just "rare". In the log normal and logarithmic models, most species have medium abundances, a few species are very abundant and a few species are very rare. In the broken stick model, species occurrences are nearly equal (Magurran, 1988). Thus, evenness in the geometric series is very low, whereas evenness is high in the broken stick model.

Some indices are based on the proportional abundances of species, such as the Shannon-Wiener index (Shannon and Weaver, 1963) and Simpson index (Simpson, 1949). These indices provide more information about the community structure, since they take both species richness and evenness into account (Magurran, 1988).

Each of these indices and models has strengths and weaknesses. Both methods can provide a visual interpretation of trends in the data (Magurran, 1988). However, two samples can have exactly the same diversity or distribution structure without having a single species in common (Clarke and Warwick, 1994). In order to get a better understanding of the complexity of an ecosystem, Underwood (1996) suggested species-dependent multivariate analysis of community structure is needed. Such analyses include cluster, ordination by non-metric multi-dimensional scaling (MDS) and principal

components Analysis (PCA) to summarize patterns in species composition and environmental variables. These methods are available in the ecological analysis software PRIMER (Plymouth Routines In Multivariate Ecological Research) and statistical analysis software SPSS (Statistical Package for the Social Sciences).

1.2.3. Feeding Guilds

The feeding guild of any organism is defined as "the set of relations among food particle size and composition, the mechanism involved in food intake, and the motility patterns associated with feeding" (Fauchald, 1979). In other words, feeding guilds, also called feeding types, refer to a group of animals using a common type of food in a similar way. Fauchald and Jumars (1979) summarized previous studies on the feeding guild of each polychaete family as herbivore, carnivore, surface filter-feeding, surface deposit-feeding, and scavengers. Ruppert and Barnes (1994) suggested that omnivores, browsers and nonselective deposit feeders also exist in the marine environment. Fauchald and Jumars (1979) proposed that studies on feeding guilds can help ecologists get a better understanding of the ecological function of each species and to predict if a region was capable of invasion by certain species.

The relationship between the feeding guilds and sediment particle size is very close. Particle size is a good measure of current energy and food variety, and it has long been recognized that benthic assemblages vary with particle size. For example, Pinnet (2000) suggested that organisms of the same feeding guild would dominate a particular type of substrate. Deposit feeders inhabited low- energy, muddy substrates, because such

substrate tended to have a high content of organic matter. The filter-feeding fauna would not get sufficient suspended food in muddy substrates, but they could be abundant on gravel and coarse-sand bottoms, since strong currents provided continuous supply of suspended organic detritus and plankton in swift-moving water. On fine sand and coarse silt bottoms, a mixed faunal assemblage is present, which is composed predominantly of deposit feeders, and some infaunal filter feeders along with a few surface filter feeders (Pinnet, 2000).

1.2.4. Species Distribution (Zonation)

"The understanding of gradient-controlled distribution is of principal interest in the growing field of zoogeographic ecology," (Pielou, 1980). In marine environments, although the causes of vertical zonation remain unclear, depth and its associated variables should be major factors that regulate the distribution of specialized organisms. These variables include physical parameters (temperature, current velocity, pressure and salinity), sediment type and change in availability of resources (Carney et al, 1983).

Four general approaches have been applied in the deep-sea zonation studies (Carney et al., 1983): examination of similarities with similarity indices (Sanders, 1960; Sanders and Hessler, 1969), classification and ordination procedures (Carney and Carey, 1982; Wigley and Theroux, 1981) and coincidence-of-range studies (Menzies et al., 1973). These approaches each may have their own merits and shortcomings. Classification (clustering) and ordination procedures are widely employed today. Anderson (1965) and Whittaker (1973) concluded that when the sampled gradient is very

long, clustering would produce a better initial subdivision; when a smaller part of a vertical gradient is sampled intensively, ordination affords a better way to relate the faunal change to environmental variables. The study of zonation along gradients has been applied as biocriteria and become a central focus of ecological assessments (Jackson and Davis, 1994).

1.2.5. Ecological Niche

Hutchinson (1958) suggested that the niche could be viewed as a multi-dimensional space in which a certain species could live, with each dimension representing the range of some environmental condition or resource that was required by the species. Resources can be defined in different ways, including food (foods types), habitat (biological or physical/chemical properties), etc. (Krebs, 1998). Niche breadth and niche overlap are two important aspects that have been studied. Niche breadth is used to measure how specialized the species is, and niche overlap is a measure of how two species share the common resources. Some indices that are commonly used for niche breadth are Levin's index *B* (1968) and Smith's measure *FT* (1982). Smith and Zaret (1982) suggested that Morisita's measure (1959) is the best index for measuring niche overlap with least bias at all sample sizes and also when there are many resources. Another index, the percentage overlap measure (Renkonen, 1938), is used commonly but subject to bias. Niche overlap usually is used to indicate interspecific competition, but Krebs (1998) considers the relationship between niche overlap and interspecific

competition to be very complicated, and prefers to take niche overlap simply as an index to indicate the community organization.

1.3. Potential Impacts of Submarine Canyons on Benthic Community Structure

Serving as passageways of sediment transfer from continental margins to deep-ocean basins, submarine canyons play an important role in global biogeochemical cycles (Nittrouer and Wright, 1994). Flows are usually very complex in submarine canyons, since they are affected both by deep-sea circulation and shelf dynamics. Therefore, submarine canyons are regions with enhanced mixing and transfer of physical, chemical and biological properties between continental shelves and continental slopes and rises (Hotchkiss and Wunsch, 1982). Such physical, chemical and geological phenomena in submarine canyons could affect the benthic community structure and functions.

Deep-sea sampling efforts and ecological studies have indicated higher species diversity in the deep-sea than in estuarine and coastal areas despite food-limited conditions (Hessler and Sanders, 1967; Grassle and Maciolek, 1992; Paterson et al, 1998). Many theories have been proposed to explain this phenomenon. Early theories like Sanders' Stability-Time Hypothesis (1969), Dayton and Hessler's Biological Disturbance (1972), Rex's Competition and Predation Mediated by Productivity (1976), Huston's Dynamic Equilibrium Model (1979), etc. are more focused on how local processes such as competition and predation regulate biodiversity in small-scale areas. However, improved sampling methods and expansion of sampled area have provided more knowledge of biodiversity and its causes in the deep-sea benthos. Levin et al.

(2001) reviewed the relationship between the variation in local species diversity and the regional-scale phenomena, such as boundary constraints, gradients of productivity, sediment heterogeneity, oxygen availability, hydrodynamic regimes, and catastrophic physical disturbance. They presented a conceptual model in which environmental gradients can form geographic patterns of diversity by influencing local processes such as predation, resource partitioning and competition that determine species coexistence. These environmental factors are not isolated from each other. "The present patterns of deep-sea biodiversity are the result of an integration of ecological and evolutionary processes that operate at different spatial and temporal scales" (Levin et al., 2001). In the case of the Mississippi Canyon, in order to get a better understanding of the abundance and diversity pattern of benthic polychaetes, the same environmental properties within the canyon should be considered.

Additional variables which could impact the abundance and diversity of benthic polychaetes in the Mississippi Canyon included depth, spatial and sediment heterogeneity, particulate organic matter flux, bottom current, sediment contamination and catastrophic disturbance.

Depth

Many recent studies indicate that depth is the primary habitat factor in organizing benthic polychaete communities (e.g., Hyland et al., 1991; Bergen et al., 2001). Rex (1983) suggests a unimodal pattern of species diversity in the deep-sea benthos, in which the 3000 m depth has the highest diversity.

Spatial Heterogeneity of Microhabitat

The Mississippi Canyon floor, like other canyons, is not homogeneous. Direct observations by submersibles and underwater cameras indicate that biogenic activity is intense in this environment (Stanley, 1971). Jumars (1975) proposed that biogenically-produced, small-scale heterogeneity may be important in maintaining diversity in the deep sea (reviewed by Etter and Mullineaux, 2001), including polychaete mudballs (Jumars, 1975; Thistle and Eckman, 1990), protozoan tests (Levin et al., 1986), sponge spicules (Jumars and Eckman, 1983), tubes (Gooday et al., 1992), burrows (Aller and Aller, 1986), pits (Schaff and Levin, 1994) and mounds (Levin, 1991). Relatively stable deep-sea sediments allow those structures to persist for a long period (Jumars, 1976; Kukert and Smith, 1992), providing distinct microhabitats for specialized macro- and meiofauna, which could enhance biodiversity.

Sediment Heterogeneity

Heterogeneity in sediment grain size may be important in terms of regulating species diversity, because it provides diverse food resources (Etter and Mullineaux, 2001). The morphology and sediment composition of the upper Mississippi Canyon are different from those of the lower canyon (Shepard and Dill, 1966, Burden, 1999). Coarse sediments are found in the upper canyon, while the lower canyon forms a broad trough filled with fine-grained sediments, leading directly to the head of the Mississippi fan (Goodwin and Prior, 1989). Previous studies have already shown that there is a strong positive correlation between species diversity of soft-sediment communities and sediment heterogeneity (Sanders, 1968; Gray, 1981), although the explanations for this

relationship are varied and may be controversial (Snelgrove and Butman, 1994). Etter and Grassle (1992) proposed that if deep-sea organisms partition sediments with respect to size, a greater range of particle sizes would permit coexistence of more species. Some infaunal studies (e.g., Snelgrove and Butman, 1994) found sediment type to be a primary factor, which is probably the case when many sites are at relatively small depth intervals across a broad depth range (Bergen et al., 2001).

Particulate Organic Matter Flux

The energy availability to organisms in a particular area is widely thought to be an important mechanism regulating the species diversity (reviewed in Rosenzweig, 1995). The deep-sea environment does not have in situ primary production to support food webs, except chemoautotrophic production around hydrothermal vents and cold seeps (Van Dover, 2000). Deep-sea communities have to depend on particulate organic matter (POC) sinking from surface water or lateral advection by various mechanisms (Etter and Mullineaux, 2001). The parabolic pattern of diversity-depth has been attributed at least in part to productivity and its potential mediation of biological interactions (Rex, 1973, 1976, 1981).

Deep-sea benthic productivity and food availability are hard to measure directly. Thus, surrogates, such as polychaete density (Glover et al, 2001) and sedimentary particulate organic content (Levin and Gage, 1998) have been used in previous studies. Biggs et al. (2003) argued that chlorophyll concentration in near surface water was also a proxy for POC flux to the ocean floor. He suggested that on average 10% of the primary

production sinks out of the photic zone, and 3-10% of this flux in turn reaches the seabed.

Terrestrial inputs of organic carbon to the Mississippi Canyon could be high compared with other deep-sea areas because of significant discharges from one of the world's largest river systems --- the combined inputs of the Atchafalaya and Mississippi rivers. This river system also supplies large amounts of nutrients that can enhance coastal productivity. Therefore, seasonal organic enrichment in the Mississippi Canyon could be possible. A Mississippi Canyon core collected at a depth of 1000 m has shown an increase over time in percent organic carbon (Nelson, et al., 1994). Vetter and Dayton (1998) found that within canyons (the La Jolla submarine canyon system), organic enrichment by macrophyte detritus enhanced infaunal density and biomass compared with reference stations which were outside of the canyons. Thus, polychaete species composition and abundance may be distinctly different between canyon and non-canyon areas. Some classic pollution indicator species, such as *Capitella capitata* (Pearson and Rosenberg, 1978), had high densities, and deposit feeders were dominant in the canyons (Vetter, 1998). Therefore, increased POC flux in the Mississippi Canyon could lead to higher density of benthic polychaetes than adjacent non-canyon areas.

Bottom Currents

Hydrodynamics in the deep sea may be an important factor regulating the benthic community structure (Jumars and Nowell, 1984). Typical velocity of deep-sea bottom current is a few cm/sec, too weak to erode the seabed (Munk, 1970; Tyler, 1995), often referred to as "physically quiescent" (Thistle and Wilson, 1987). But this is not always

the case. During episodic benthic storms bottom current speed can reach 15 - 40 cm/sec. Also, internal waves (tides), water column instability and storm-driven eddies may create strong erosional currents (Dickson & McCave, 1986, Gage, 1997). Complex interaction between topography and local hydrography can create intensified bottom flow in canyons (Shepard, et al., 1979; Gage, 1997). Such a difference in hydrodynamic regime could be reflected in soft-bottom fauna. For example, Thistle and Wilson (1987, 1996) compared the isopod fauna of the High Energy Benthic Boundary Layer Experiment (HEBBLE) site (Nowell and Hollister, 1985), which is exposed to erosive flows several times per year, to three quiescent locations in deep sea. They found that the HEBBLE isopod fauna had been modified by the energetic hydrodynamic regime.

Based on Burden's study (1999), currents in the upper Mississippi Canyon are oscillatory with alternating periods of up-canyon and down-canyon flow. Mean current speed was approximately 8 cm/sec, maximum speed was over 50 cm/sec. During a hurricane, maximum current speed reached 68 cm/sec. The high variability of bottom currents in the Mississippi Canyon may have complex effects on the benthos. For example, moderate currents may enhance the density and biodiversity by bringing more organic matter and oxygen, stimulating bacterial production (Aller, 1989), and by entraining larval and subadult organisms or by increasing sediment heterogeneity. On the contrary, strong currents (>20 or 25 cm/sec) may potentially reduce physical heterogeneity, disperse juveniles and subadults, or take away some epifaunal species, and therefore, reducing the biodiversity (Levin and DiBacco, 1995). Different speeds of bottom currents may also facilitate different species of benthic polychaetes. For example,

if a bottom current causes resuspension of sediments, it may facilitate filter feeders; otherwise, it will favor deposit feeders since the currents bring more detritus.

Hydrodynamic regime may regulate the benthic communities through different mechanisms, since sediment grain size (sediment heterogeneity), sediment organic matter content (proxy of food supply), stability, pore water chemistry (e.g., oxygen availability), larvae dispersion, etc., are all directly or indirectly correlated with near-bottom flow. The pervasive effects of the hydrodynamic regime on the benthic environment and organisms suggest that near-bottom currents exert a powerful force on the local soft-sediment communities structure and function (Snelgrove and Butman, 1994). This also suggests that hydrodynamic energy and availability of organic matter are more likely to be primary driving forces, with depth and sediment grain size as secondary correlates But the hydrodynamic energy environment is hard to measure (Schimmelmann et al., 1992; Posey et al., 1996). Therefore, depth and sediment grain size probably act as surrogates, integrating effects of the hydrodynamic environment over time (Bergen et al., 2001).

Catastrophic Disturbance

Deep-sea sediments are not as quiescent as once thought. They have been disrupted by gravity-driven mass movements, such as slumps, slides, debris flows, and turbidity currents over geological time scales (Masson et al., 1994, 1996). Turbidity currents were active during the formation of the Mississippi Canyon and destroyed the benthic fauna. But they also introduce long-lasting physical heterogeneity on large scales (Masson, 1996). Glover et al. (2001) found polychaetes exhibit lower abundance and

lower species richness and higher dominance in the area where a turbidite happened 1000 years ago compared to other abyssal NE Atlantics sites. The impact of turbidity currents in the Mississippi Canyon in terms of species diversity is still unknown.

Other Variables

Some related variables, such as bottom-water dissolved oxygen and the sediment C:N ratio (which indicates food quality), were also investigated in previous studies. In some cases, they could be the highest explanatory factors for taxa richness and density in shallow and deep water, respectively (Flemer et al., 1999; Levin and Gage, 1998).

Chemical contaminants or pollutants in the bottom water and the sediments may affect the density and biodiversity of benthic polychaetes. For example, Polynuclear Aromatic Hydrocarbons (PAHs) are typical components of asphalts, fuels, oils, and greases. Although very little is known of effects of PAHs on invertebrates, Erstfeld and Ashbrook (1999) suggested that abundance and diversity of invertebrates were positively or negatively associated with low levels of PAHs in the soil, depending on different ecological hierarchy: the microfauna, mesofauna, and macrofauna. Since the Mississippi Canyon is an oil-rich area, there is a possibility that PAHs may have some effects on benthic polychaetes. Trace Metals in sediments are found to have adverse effects on polychaete biomass, species composition, abundance and ecological indices (Belan, 2003; Mucha et al., 2003). Biological processes, such as intraspecies or interspecies competition and predation, can also affect the distribution and composition of the benthic polychaetes (e.g., Rex, 1976). The effects of abiotic variables on the benthic community (including polychaete worms) have been studied intensively, but the most important

factors are still unclear. Due to the complexity and unique properties of the Mississippi Canyon in terms of organic loading, hydrodynamics, heterogeneity, etc., community structure of benthic polychaetes may have different patterns from those in the adjacent non-canyon area.

2. HYPOTHESES TESTED

Patterns in polychaete diversity and distribution have been studied in shallow water and deep sea, but little emphasis has been given to the ecology of this important component of deep-sea communities in the Mississippi Canyon. This research was a study of the benthic polychaete community assemblages (density, diversity, feeding guilds, species composition and ecological niche) in the Mississippi Canyon to see if any patterns existed. Comparison was performed between the Mississippi Canyon and one of the non-canyon areas to see if the difference could be attributed to canyon effects.

Another objective was to determine if depth was the most important habitat factor in organizing polychaete assemblages in the Mississippi Canyon and the Central Transect. Hughes et al (1986) suggested that determining the most important habitat factors in organizing biological assemblages was essential for defining environmental conditions. Etter and Grassle (1992) pointed out that understanding what generated and maintained patterns of species diversity was a major focus of contemporary ecological research. Thus, relationships of environmental variables to depth were estimated to see if depth was the primary habitat factors in the study area. The environmental variables considered included depth, sediment grain size, sediment organic matter content, dissolved oxygen in bottom water, surface primary productivity, PAHs, and trace metals. The reasons for interest in these factors are justified by the discussion presented in section 1.3. Also, this research assessed the quality of the study area to see if it was contaminated by PAHs and trace metals, since the Mississippi Canyon is an oil-rich area.

Based on the above objectives, the following null hypotheses were tested:

(1) H_{01}: There was no significant difference in polychaete assemblages between different sampling years.

(2) $H_{02:}$ There was no significant difference in polychaete assemblages between the Mississippi Canyon and the Central Transect, which is a non-canyon area.

(3) $H_{03:}$ There was no significant difference in polychaete assemblages at different depths.

(4) H_{04}: Food availability had no significant impacts on polychaete assemblages.

Food availability to benthos were not measured directly in the project. Some surrogates, such as chlorophyll concentration in near surface water (Biggs et al., 2003), polychaete density (Glover et al, 2001), sedimentary particulate organic content (Levin and Gage, 1998) and meiofauna biomass (carbon weight) were used as proxies of food availability to benthic communities.

(5) H_{05}: There was no significant difference in polychaete assemblages among different sediment types (sediment grain size).

(6) H_{06}: Sediment contaminations, including trace metals and PAHs, had no significant impacts on polychaete assemblages.

(7) $H_{07:}$ Hydrographic features, including temperature and dissolved oxygen, had no significant impacts on polychaete assemblages.

3. MATERIALS AND METHODS

3.1. Sampling Stations

GOMEX box core was used for quantitative sample collecting (Boland and Rowe, 1991). The benthic polychaete and sediment samples were obtained from box-cores made on three cruises in three consecutive years from 2000 to 2002 (Fig. 1). In the Mississippi Canyon, six stations along the depth gradient were sampled (Table1): MT1, MT2, MT3, MT4, MT5, and MT6. Depth ranged from 481 m to 2750 m. The Central Transect, which is a non-canyon area, was sampled to assess the difference in polychaete assemblages between the canyon and non-canyon areas, since these two transects are very close geographically. In the central transect, five stations with similar water depth to those in the Mississippi Canyon were sampled: C1, C7, C4, C14 and C12. Depth ranged from 334 m to 2924 m. Sampling station C7 was considered as a cold-seep site. Station S5, with average depth 3314 m, was the deepest station in this study, and an extension of the Central Transect (Fig. 1.)

Three replicates from each station were analyzed. Some samples were discarded due to poor quality, such as damaged samples and partial samples.

Table 1. Sampling stations in the Mississippi Canyon and the Central Transect, Northern Gulf of Mexico.

Activity No.	Sampling Station	Cruise No.	Replicate No.	Sampling Date	Depth (m)	Longitude	Latitude
19	C1	1	1	May 30, 2000	334	-90.2489	28.0601
220	C1	1	2	May 30, 2000	336	-90.2491	28.0596
223	C1	1	5	May 30, 2000	336	-90.2562	28.0571
241	C4	1	1	May 31, 2000	1455	-89.7857	27.4594
242	C4	1	2	May 31, 2000	1452	-89.7795	27.4602
243	C4	1	3	May 31, 2000	1463	-89.7760	27.4524
230	C7	1	1	May 30, 2000	1080	-89.9796	27.7283
231	C7	1	2	May 30, 2000	1070	-89.9770	27.7329
232	C7	1	3	May 30, 2000	1066	-89.9835	27.7315
250	C14	1	1	June 1, 2000	2487	-89.5714	26.9296
251	C14	1	2	June 1, 2000	2487	-89.5704	26.9300
252	C14	1	3	June 1, 2000	2495	-89.5645	26.9298
261	C12	1	1	June 2, 2000	2922	-89.2414	26.3794
262	C12	1	2	June 2, 2000	2920	-89.2414	26.3829
263	C12	1	3	June 2, 2000	2924	-89.2431	26.3750
110	C7	2	1	June 16, 2001	1057	-89.9812	27.7351
111	C7	2	2	June 16, 2001	1045	-89.9849	27.7351
112	C7	2	3	June 16, 2001	1072	-89.9818	27.7299
427	MT1	1	3	June 17, 2000	482	-89.8271	28.5411
428	MT1	1	4	June 17, 2000	481	-89.8288	28.5406
429	MT1	1	5	June 17, 2000	481	-89.8250	28.5411
415	MT2	1	1	June 17, 2000	676	-89.6726	28.4511
416	MT2	1	2	June 17, 2000	677	-89.6703	28.4512
418	MT2	1	4	June 17, 2000	677	-89.6733	28.4503
405	MT3	1	1	June 17, 2000	983	-89.4961	28.2204
406	MT3	1	2	June 17, 2000	987	-89.4964	28.2192
407	MT3	1	3	June 17, 2000	990	-89.4918	28.2190
397	MT4	1	1	June 15, 2000	1401	-89.1659	27.8270
398	MT4	1	2	June 15, 2000	1401	-89.1647	27.8284
399	MT4	1	3	June 16, 2000	1401	-89.1679	27.8280
271	MT5	1	1	June 3, 2000	2275	-88.6678	27.3322
272	MT5	1	2	June 3, 2000	2290	-88.6696	27.3264
273	MT5	1	3	June 4, 2000	2267	-88.6622	27.3346
281	MT6	1	1	June 4, 2000	2745	-87.9978	27.0001
282	MT6	1	2	June 5, 2000	2750	-87.9882	27.0015
283	MT6	1	3	June 5, 2000	2743	-87.9987	26.9965
2	MT1	2	1	June 2, 2001	487	-89.8277	28.5381
3	MT1	2	2	June 2, 2001	490	-89.8256	28.5352
4	MT1	2	3	June 3, 2001	485	-89.8303	28.5388
20	MT3	2	1	June 4, 2001	980	-89.5126	28.2245
22	MT3	2	2	June 4, 2001	982	-89.5066	28.2244
23	MT3	2	3	June 4, 2001	984	-89.5058	28.2226
87	MT6	2	1	June 13, 2001	2740	-88.0140	26.9908
88	MT6	2	2	June 13, 2001	2733	-88.0145	27.0034
89	MT6	2	3	June 13, 2001	2742	-88.0113	26.9858
60	MT1	3	2	August 13, 2002	465	-89.8230	28.5542
61	MT1	3	4	August 13, 2002	465	-89.8209	28.5611
66	S5	3	33	June 13, 2002	3313	-88.2630	25.4912
65	S5	3	37	June 13, 2002	3316	-88.2708	25.4922

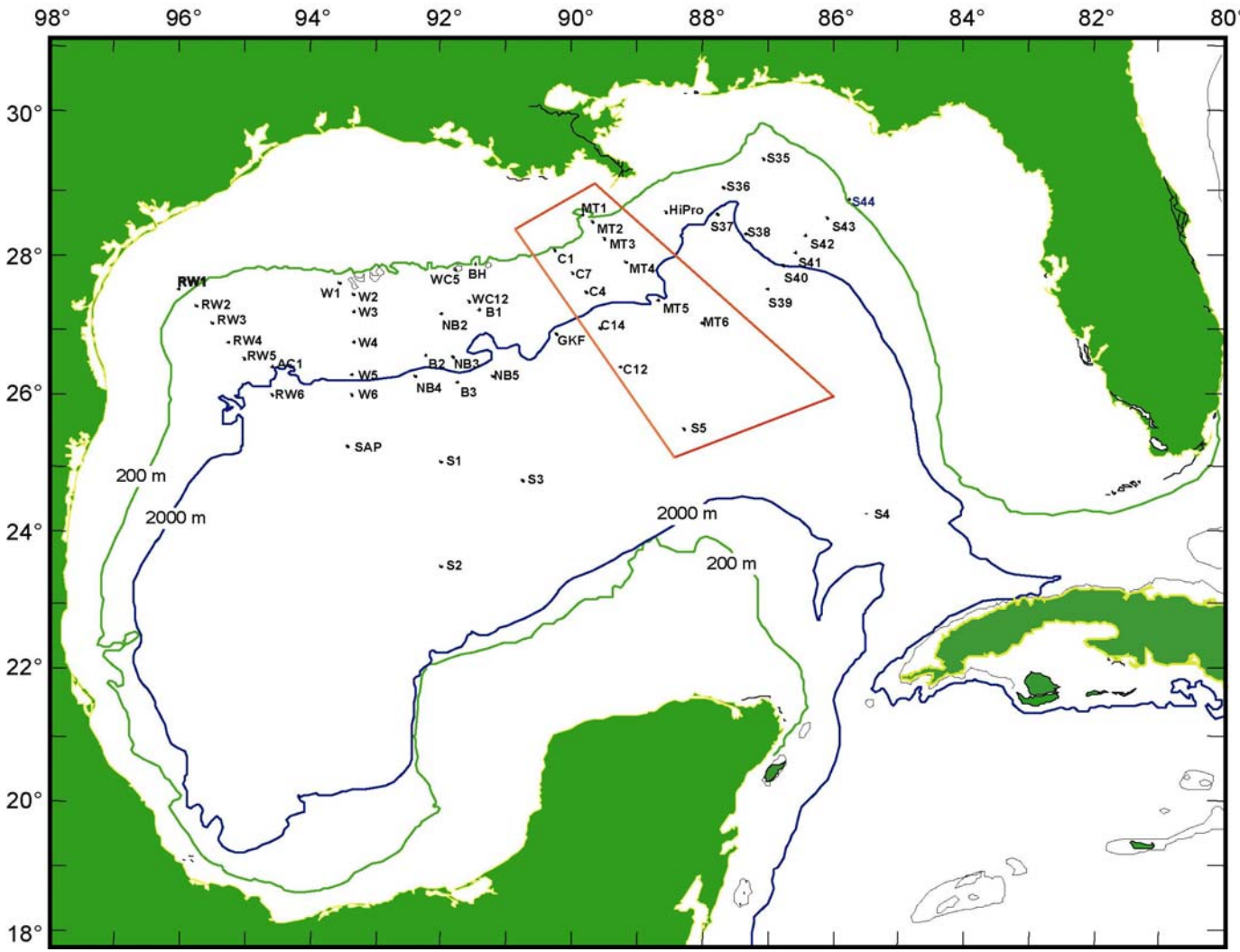


Fig. 1. Sampling stations in the Northern Gulf of Mexico (year 2000 – year 2002).

3.2. Sample Treatment

Samples collected from the Mississippi Canyon and the Central Transect were treated in the same way for the purpose of comparison. For macrofauna analysis, sieving was conducted using the gentle flotation method developed by Howard Sanders of the Woods Hole Oceanographic Institution. The boxcorer had a net macrofaunal sample area of 0.1725m^2. The top 15cm sediment of each corer was gently washed through 300μm sieves. Those sediments that were retained on the sieves were kept in the container and then fixed by 10% formalin buffered with seawater. After return to the lab, samples were stained with 5% Rose Bengal (an organic stain) for at least 24 hours, and then formalin and Rose Bengal were removed by rinsing with fresh water. The stain helped in sorting the macro-invertebrates to major taxonomic group. Sorted animals were transferred to 70% ETOH for permanent preservation. Finally, all individuals were identified to the lowest taxonomic level.

Environmental data were available at http://www.gerg.tamu.edu. The top 2 cm of subcores were used for analyses of sediment water content, grain size, porosity, geotechnical properties, total organic carbon content, total inorganic carbon content, etc. Three years mean chlorophyll concentrations (CHL) in near surface water in the Gulf of Mexico were provided by Biggs et al. (2003), and were used as a proxy for POC flux to the seabed. Other parameters, such as depth, temperature, salinity, sigma-theta and pressure, etc., were measured using CTD/rosettes and Acoustic Doppler Current profile (ADCP).

3.3. Data Analysis

A range of analytical methods was used to differentiate patterns and confirm the real trends in the data (Green, 1979; Clarke and Warwick, 1994; Underwood, 1997). A species-sample matrix was created that included each replicate sample, including species name, species abundance and species density. Also, a matrix of the corresponding hydrographic and sediment properties data was prepared. Once data were collated in a suitable matrix, very rare species were removed or retained depending upon the analysis and its results.

PRIMER V5 (distributed by Primer-E Ltd.) was mainly used for biodiversity measurements and matching biological data to environmental data. The other program used for biodiversity measurement was PAST (Paleontology Statistics) (Hammer, Harper and Ryan, 2004). SPSS V.11.0 was mainly used for regression and mean comparison. Ecosim 7 was used for ecological niche analysis (Gotelli and Entsminger, 2004). DPLOT (www.dplot.com) was used for producing graphs.

3.3.1. α Diversity Indices

Different diversity indices have different abilities to detect differences between samples, since they may have different assumptions or no assumptions at all. In this research, some widely used diversity indices were employed to find the most appropriate ones for showing the trends in the data. Those indices included Evenness (Pielou, 1969), Shannon-Wiener Index (H´), Simpson Index (D), Expected Number of Species E(Sn) (Sanders,1968; Hurlbert, 1971) and Cumulative Species richness (Chao, 1984).

3.3.2. β Diversity Indices (Species Zonation Analysis)

Univariate and multivariate methods were both available for zonation studies. Univariate methods were a starting point of multivariate methods. Univariate methods involve similarity indices. Although there are many similarity indices available, Bray-Curtis Similarity (Bray and Curtis, 1957) was the method of choice. Cluster method, a multivariate analysis, was mainly used for station classification and abundant species classification. This method is discussed in section 3.4.2 in detail.

3.3.3. Species Distribution Model

Before any analysis, distribution of species among individuals in a sample is the first thing we should know. Rank-abundance graphs were produced to examine the species distribution in a replicate sample, and were best used as a "first look" at the data. The species were arranged along the X-axis in decreasing order of abundance; the Y-axis was their abundance. The characteristic shape of the line can indicate which model is the best-fit model (Magurran, 1988). Three models were tested, the geometric series, the log series and the lognormal. The broken stick model was not tested since we know that the species distribution in the benthic sample will not be equal. It is very important to know which species contribute more than others to the differences observed in biological marine survey data, which could be determined by ranking species in terms of abundance.

3.3.4. ANOVA and Multivariate Analysis

Analysis of Variance (ANOVA) and Multivariate Analysis were mainly used to test five hypotheses (see section 2). Clarke and Warwick (1994) suggested that ANOVA (Analysis of Variance) could be used to determine if there was a significant difference between samples when only species abundance was concerned. ANOVA was also used to test the difference in biodiversity when biodiversity was represented by various indices.

A major method of classification used was cluster analysis. Results were shown as dendrogram. Some common methods of ordination include Principal Components Analysis (PCA) and Non-metric Multidimensional Scaling (MDS) (Olsgard and Gray, 1995). Using these methods for the same data sets could ensure that the patterns were consistent, and these methods were very powerful in detecting patterns (Olsgard and Gray, 1995). These methods were all available in the PRIMER software.

Multivariate analysis methods are widely used because of their power to detect patterns and trends in data sets. In this research, multivariate techniques were employed for both zonation analysis and diversity analysis, and help describe the relationship between the biological data and the environmental data (Clarke and Warwick, 1994). More specifically, BIO-ENV and BVSTEP procedures (stepwise multiple regression, available in PRIMER V5.) were carried out to link environmental variables to biological data, including species composition, species density and diversity indices. The purpose of this was to find out what the “best subset” variables were in terms of having high correlation with the biotic pattern, and examine the extent to which the biotic pattern was

"explained" by the environmental data, if there was such a pattern. Thus, determinant factors could be found through the correlation analyses. Field et al. (1982) suggested the steps of multivariate analysis of marine biological survey data. Those steps were followed, including data transformation, similarity measurement, classification and ordination.

3.4. Geographic Information Systems (GIS)

GIS was used to establish correlation between geographic features, such as bathymetry and slope, and biological data. ERMapper 6.4 was used for importing maps to ArcGIS, and ArcGIS 8.2 was used for Grid Analyst. Datum was defined as World Geodetic System (WGS) 84, and projection was Universal Transverse Mercator (UTM) 16 North. The bathymetry map of the Northern Gulf of Mexico was kindly provided by Dr. Bill Bryant.

4. RESULTS

4.1. Environmental Properties

More than 100 environmental variables were recorded during the course of Deep Gulf of Mexico Benthic project (DGoMB), including depth, longitude/latitude, dissolved oxygen in bottom water, particulate organic matter content in sediments, sediment grain size, trace metals and organic contamination in sediments. It is hard to assess the relationship of the polychaete assemblages to such a large group of environmental variables. To solve this problem, the following variables (Table 2) were chosen from the original DGoMB database (available at http://www.gerg.tamu.edu). The criteria were that variables should not have too many missing measurements (more than 10), and variables should not have very high statistical correlation with other variables within the same category, i.e., mutual Spearman rank correlation coefficient (ρ) should be less than 0.95. For example, the correlation coefficient (ρ) between pressure and depth was 0.996, thus, pressure was removed; the correlation between TRAHWP and TPAHNP was 0.998, since both were Polynuclear Aromatic Hydrocarbons (PAHs), thus, TPAHNP was removed; and the correlation between aluminum (Al) and iron (Fe) was 0.979, both being trace metals, thus, Fe was removed. According to the criteria above, trace metal variables were chosen from 30 variables. PAHs were chosen from 52 variables. Hydrographic feature variables were chosen from 26 variables. Correlation between each pair of abiotic variables within the same category was analyzed using Draftsman Plot (available in PRIMER) and represented by Spearman rank correlation coefficient (ρ).

Table 2. Physical and chemical properties for 12 sampling stations in the Mississippi Canyon and the Central Transect. No replication was available for most measurements. When there was a replication, mean value was used for analysis.

Variables		MT1	MT2	MT3	MT4	MT5	MT6	C1	C7	C4	C14	C12	S5
Depth		481	677	983	1401	2277	2746	335	1072	1457	2489	2922	3314
Longitude		-89.83	-89.67	-89.51	-89.19	-88.67	-88	-90.25	-89.98	-89.78	-89.58	-89.24	-88.26
Latitude		28.54	28.45	28.22	27.83	27.33	27	28.06	27.73	27.45	26.93	26.38	25.49
Temperature		9.24	6.27	5.05	4.25	4.25	4.30	11.67	4.95	4.33	4.27	4.32	4.37
Salinity		35.12	34.90	34.93	34.97	34.98	34.98	35.45	34.93	34.97	34.98	34.98	35.00
Sigma-theta		27.18	27.44	27.61	27.74	27.76	27.76	27.00	27.64	27.73	27.76	27.76	27.74
CHL		2.47	2.13	0.75	0.41	0.24	0.19	0.50	0.28	0.22	0.19	0.20	N/A
POC		18.4	28.5	19.3	8.2	5.4	23.9	48.9	19.1	18.6	25.7	8.8	N/A
PON		5.7	4.4	3.4	2.0	2.3	4.5	5.5	2.9	3.0	4.0	1.8	N/A
C/N		3.6	7.7	7.4	7.2	5.4	6.7	9.9	8.6	8.0	7.9	8.1	N/A
DO		2.46	3.05	4.13	4.31	5.54	4.39	2.53	3.71	4.21	4.39	4.45	7.20
Grain Size	% Sand	2.0	2.7	4.1	9.0	64.3	29.7	4.3	8.00	10.8	4.8	24.6	N/A
	% Silt	33.0	40.1	40.7	45.5	15.3	26.9	35.0	40.5	36.3	22.8	40.7	N/A
	%/Clay	65.0	57.1	55.2	45.5	20.4	43.4	60.7	51.5	52.9	72.4	34.7	N/A
Trace Metals	Ag	0.04	0.05	0.06	0.10	0.08	0.05	0.05	0.13	0.10	0.04	0.06	N/A
	Al	65450	60300	68050	58500	34400	51900	58200	60500	55300	56900	43000	45700
	As	22.7	19.4	19.7	13.8	8.3	10.9	16.9	12.1	9.1	11.8	7.1	N/A
	Cd	0.08	0.18	0.31	0.21	0.13	0.10	0.16	0.24	0.18	0.13	0.14	N/A
	Co	11.9	12.8	13.2	11.0	5.4	9.2	12.2	11.5	10.2	15.4	9.4	N/A
	Cu	19.9	19.7	24.2	27.8	16.9	26.0	19.7	25.9	29.6	36.2	30.6	59.9
	Hg	0.05	0.03	0.05	0.03	0.02	0.04	0.02	0.03	0.03	0.03	0.03	N/A

Table 2. ─ Continued

	Variables	MT1	MT2	MT3	MT4	MT5	MT6	C1	C7	C4	C14	C12	S5
Trace metals	Mg	13650	13200	13900	13300	8500	12750	14800	14000	14000	15000	12100	14780
	Mn	8492	12441	7350	2657	786	863	10774	4389	2151	5722	1347	1774
	P	681	690	709	790	503	575	644	657	628	618	543	N/A
	Pb	26.1	26.8	19.2	18.7	10.5	11.8	23.8	23.2	17.1	14.4	13.1	N/A
	S	3071	3020	2695	2836	1396	1587	3953	3035	2849	1963	2237	N/A
	Sb	0.86	1.11	1.24	0.64	0.55	0.50	1.04	0.72	0.65	0.71	0.62	N/A
	Si	196000	185000	201000	179000	187000	196500	182000	184000	181000	194000	157000	146200
	Sr	159	176	204	476	624	460	258	392	546	491	738	12640
	Zn	104	98	102	85	69	70	89	94	80	91	62	60.6
PAHs	TPAHWP	733.2	N/A	718.6	121.1	60.1	59.2	611.3	37.7	15.2	91.6	31.26	47.3
	NAPH	29.6	N/A	90.4	10.5	2.8	3.1	14.9	6.8	3.9	4.4	5.45	2.20
	PHENAN	24.4	N/A	15.2	8.7	2.3	2.5	37.2	2.1	1.6	4.2	2.4	2.5
	ANTHRAC	11.3	N/A	7.1	3.5	0.8	0.8	62.6	1.1	0.6	5.2	2.3	0.5
	DIBEN	2.3	N/A	1.3	1.2	0.3	0.2	2.2	0.9	0.2	0.3	0.3	0.2
	FLUORAN	31.8	N/A	15.5	7.3	2.4	2.1	40.4	2.5	1.9	6.5	2.5	2.6
	PERYL	109.9	N/A	26.8	23.7	12.6	14.9	49.7	2.7	3.7	7.8	8.7	6.4

Note:

- Units for all the environmental variables are: Depth (m), Pressure (decibars), Temperature (degree), Conductivity (S/m)), Salinity (PSS), Sigma-theta (kg/m^3), CHL (mg/m^3), POC (ug C/L), PON ((ug N/L), Trace Metal (μg/L), PAHs (ng/L), DO (mg/L).

- Abbreviation: CHL (three-year average of chlorophyll concentration in surface water); POC (Particulate Organic Carbon in sediments); PON (Particulate Organic Nitrogen in sediments); C/N (Carbon/Nitrogen ratio); % Sand (Percentage of sand in sediments); % Silt (Percentage of silt in sediments); % Clay (Percentage of clay in sediments); DO (Dissolved Oxygen in the bottom water); PAHs (Polynuclear Aromatic Hydrocarbons); NAPH (Naphthalene); PHENAN (Phenanthrene); ANTHRAC (Anthracene); DIBEN (Dibenzopyrene); FLUORAN (Fluoranthene); PERYL (Perylene)

After removal of those "unqualified" variables, a group of environmental variables were listed in Table 2 to describe the environmental properties of the 12 sampling stations. Among all the sampling stations in the study area, station MT1 had the highest chlorophyll (CHL) concentration in near surface water, 2.47 mg/m^3, followed by MT2, 2.13 mg/m^3. Station C1 had the highest particulate organic matter content, including both PON and POC in sediments. At C7, which was considered as a cold seep site, higher sulphur (S) content was observed, while high organic matter (POC or PON) were not found.

Aluminum (Al), magnesium (Mg), manganese (Mn), phosphorus (P), sulphur (S), and silicon (Si) were abundant compared with other trace metals, while copper (Cu), cobalt (Co), lead (Pb) and zinc (Zn) were observed with relative low concentrations. In previous studies, Cu, Co, Pb and Zn were considered as contaminants in sediments and could have adverse effects on benthic organisms. Among PAHs, TPAHWP was relatively abundant; DIBEN is one of the most toxic and best studied of the PAHs, but was found at low concentrations in these samples. MT1 had highest PAH concentrations (all PAHs combined) compared with other stations. MT1 is an area with strong interest of offshore oil & gas exploration and production.

Correlations among Selected Environmental Variables

Correlations between each pair of variables in Table 2 were evaluated. Due to limited space, only selected variables were analyzed and significant correlations were displayed ($p < 0.10$) (Table 3). Results of Spearman Rank Correlation test indicated that most variables in Table 2 were not highly correlated, since correlation between each two

pairs of variables was less than 0.95. Depth was positively correlated with dissolved oxygen concentration in bottom water ($\rho = 0.92$) and percent sand in sediment ($\rho = 0.67$). Depth was negatively correlated with CHL concentration in near surface water ($\rho = -0.90$), which could be interpreted as negative correlation between CHL in surface water and the distance from coastal area. CHL concentration was also observed to negatively correlated with percent sand or dissolved oxygen, and positively correlated with temperature and some trace metals. I think those correlations were probably due to high correlation between CHL and depth. No significant correlations were also observed between depth and POC, PON and the C:N ratio in sediments ($p > 0.10$). Most log-transformed trace metals and PAH concentrations in sediments were negatively correlated with depth except for Log Sr ($\rho = 0.87$). Thus, concentrations of most trace metals decreased with increasing depth. Percent sand was negatively correlated with percent clay ($\rho = -0.88$). Significant positive correlations were observed between percent clay in sediments and particulate organic matter content in sediments, including POC ($\rho = 0.64$) and PON ($\rho = 0.70$).

Table 3. Spearman rank correlation coefficients for selected environmental variables from Table 2.

	Depth	Temp.	Salinity.	DO	% Sand	% Silt	% Clay	CHL.	POC	PON	C:N	LogCd	LogP	LogPb	LogS	LogSr	LogZn	LogTPAHW	LogNAPH
Depth		-0.69	**	0.92	0.67	**	-0.51	-0.90	**	**	**	**	-0.69	-0.89	-0.86	0.87	-0.81	-0.84	-0.80
Temp.			0.13	-0.72	-0.78	**	0.62	0.68	**	**	0.67	**	**	0.84	0.83	-0.67	**	**	0.61
Salinity				**	**	**	**	**	**	**	**	-0.71	**	**	**	**	**	***	**
DO					0.65	**	**	-0.78	**	-0.62	**	**	-0.75	-0.92	-0.93	0.92	-0.85	-0.65	-0.84
% Sand						**	-0.88	-0.77	**	**	**	**	-0.71	-0.90	-0.73	0.72	-0.78	-0.70	-0.67
% Silt							**	**	**	**	**	0.75	0.62	**	**	**	**	**	**
% Clay								**	0.64	0.62	**	**	**	0.66	0.56	-0.54	0.65	**	**
CHL									**	**	**	**	0.73	0.84	**	0.79	0.72	0.78	0.78
POC										**	**	**	**	**	**	**	**	**	**
PON											**	**	**	**	**	*8	**	**	**
C:N												**	**	0.62	0.71	**	**	**	0.62
LogCd													0.58	**	**	**	**	**	**
LogP														0.76	0.61	-0.70	0.75	0.65	0.79
LogPb															0.91	-0.85	0.81	0.77	0.87
LogS																-0.67	0.58	0.60	0.71
LogSr																	-0.90	-0.84	-0.83
LogZn																		0.78	0.86
LogTPAHW																			0.76
LogNAPH																			

Note: Only significant correlations were presented ($p < 0.10$). Variables were selected from Table 2 due to limited space available. ** means correlations were not significant ($p > 0.10$).

Pattern within Environmental Data

Two multivariate analysis methods, the Non-metric Multi-Dimensional Scaling (MDS) and Principle Component Analysis (PCA), were employed to investigate patterns existing in the environmental data (Table 2) from the Mississippi Canyon and the Central Transect. Both indicated that environmental properties of the 12 sampling stations were different from each other. Dissimilarity of environmental properties between each pair of stations was measured based on normalized Euclidean distance, and was represented by the distance between any two points on Fig. 2. Results of MDS and PCA revealed the same pattern within environmental data, that is, the 12 sampling stations on Fig. 2 were arranged along the depth gradient. Stations at intermediate depth (800 – 1500 m) had similar environmental properties, such as C4 and MT4, MT2, MT3 and C7. Further analysis suggested that depth and percent sand (combined) could explain 85.5% of the variation in dissimilarities among the 12 sampling stations in the study area. Other environmental variables, such as temperature, salinity, POC, PON, trace metals and PAHs were not as important as depth and percent sand in the study area.

In the MDS plot, stress equals 0.03 (< 0.05) (Fig. 2 (a)). The high-dimensional relationship between stations could be represented by this MDS two-dimensional plot faithfully with no prospect of misinterpretation (Clarke and Gorley, 2002). In the PCA plot, 76.1% of the variation was explained by this two-dimensional PCA model (Fig. 2 (b)). Both MDS and PCA analysis could reveal the pattern within the environmental data faithfully.

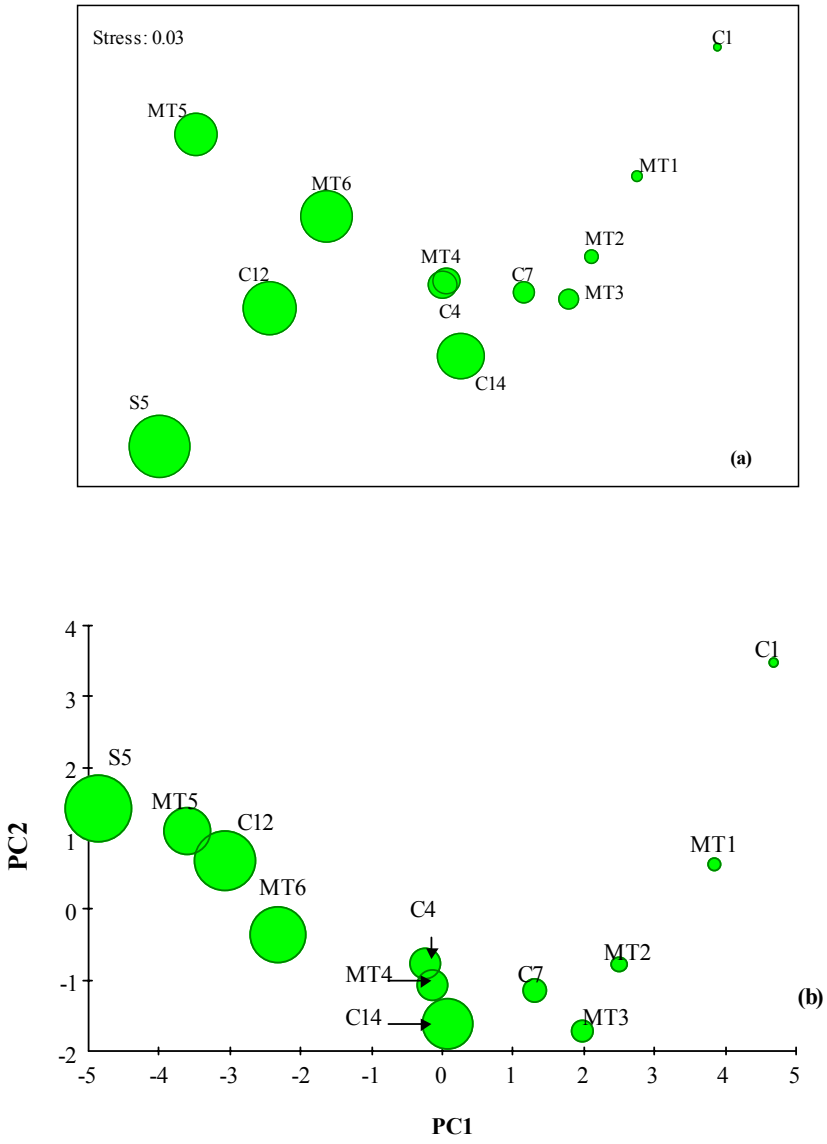


Fig. 2. Multivariate analysis of the pattern existing in environmental data (Table 2) using (a) Multi-Dimensional Scaling (MDS) and (b) Principle Component Analysis (PCA). The distance between any two points represents the dissimilarity between two sampling stations in terms of environmental properties Dissimilarities were measured using normalized Euclidean distance. Green circles represent the 12 sampling stations, and scale of green circle represents the scale of depth. (a) stress equals 0.03. (b) 76.1% of the variation is explained by this two-dimensional PCA model.

Comparison between the Mississippi Canyon and the Central Transect

In general, environmental properties were not significantly different between the two transects (ANOSIM test, R = 0, p = 0.47) (Table. 4), including hydrographic features (bottom-water temperature, salinity, and DO), sediment grain size (percent sand, percent silt and percent clay), sediment contamination (trace metals and PAHs), surrogates for food availability to benthic consumers (Chlorophyll concentration in near surface water, particulate organic matter content in sediments, and meiofaunal biomass). The only significant difference was in the C:N ratio. The C:N ratio in the Central Transect was 8.6 ± 0.8, which was significantly higher than in the Mississippi Canyon (C:N = 6.8 ± 0.9) (p = 0.02). The C:N ratio is the relative percentage of carbon to that of nitrogen in the organic matter. High C:N indicated lower food quality in the Central Transect.

4.2. Density

4.2.1 General Information about Polychaete Density

Polychaete density at each sampling station was calculated from three replicates that were collected during the same sampling year (2000-2002) with unit as Number of Individuals per Square Meter (N/m^2) (Table 5). Density decreased with increasing depth on both transects. In the Mississippi Canyon, density decreased from the highest value 3049 ± 323 N/m^2 at MT2 (mean depth = 677m; year 2000) to the lowest value 166 ± 74 N/m^2 at MT6 (mean depth = 2742 m; year 2000). In the Central Transect, density

Table 4. Comparison of statistical means and standard deviation of selected environmental variables between the Mississippi Canyon and the Central Transect.

Transect		Temp.	Salinity	DO	% Sand	% Silt	% Clay	CHL	POC	PON	C:N
Central Transect	Mean	5.65	35.05	4.41	9.8	36.0	54.2	0.28	24.21	3.53	8.6
	Std. Deviation	2.95	0.19	1.54	7.6	6.8	12.3	0.12	15.08	1.58	0.8
Mississippi Canyon	Mean	5.55	34.97	3.94	18.6	33.5	47.7	1.03	17.28	3.32	6.8
	Std. Deviation	1.96	0.07	1.21	24.6	11.1	15.5	1.00	8.91	1.16	0.9
	Sig. F	0.95	0.41	0.59	0.42	0.65	0.44	0.13	0.36	0.82	0.02

Transect		Log Ag	Log As	Log Cd	Log P	Log Pb	Log S	Log Sr	Log Zn	LogTPAHW	LogNAPH
Central Transect	Mean	-1.17	0.86	-0.78	2.79	1.25	3.43	2.91	1.89	1.88	0.78
	Std. Deviation	0.21	0.44	0.11	0.03	0.12	0.12	0.61	0.08	0.57	0.35
Mississippi Canyon	Mean	-1.22	1.17	-0.81	2.81	1.24	3.36	2.48	1.93	2.20	1.01
	Std. Deviation	0.15	0.17	0.21	0.07	0.17	0.15	0.25	0.07	0.46	0.57
	Sig. F	0.61	0.14	0.75	0.52	0.98	0.43	0.15	0.34	0.34	0.44

Table 5. Polychaete density in the Mississippi Canyon and the Central Transect from year 2000 to 2002.

Transect	Sampling Station	Depth ± stdv (m)	Year_2000 Density ± std (N/m^2)	Year_2001 Density ± std (N/m^2)	Year_2002 Density ± std (N/m^2)
The Mississippi Canyon	MT1	481 ± 0	2692 ± 885		
	MT1	487 ± 3		2390 ± 650	
	MT1	465 ± 0			2514 ± 357
	MT2	677 ± 1	3049 ± 323		
	MT3	987 ± 4	2332 ± 118		
	MT3	982 ± 2		1042 ± 271	
	MT4	1401 ± 0	1314 ± 187		
	MT5	2277 ± 12	455 ± 161		
	MT6	2746 ± 4	166 ± 74		
	MT6	2738 ± 5		172 ± 44	
The Central Transect	C1	335 ± 1	1399 ± 599		
	C7	1072 ± 7	1407 ± 329		
	C7	1049 ± 14		1115 ± 281	
	C4	1457 ± 6	1277 ± 167		
	C14	2489 ± 5	539 ± 146		
	C12	2922 ± 2	483 ± 203		
	S5	3314 ± 3	467 ± 119		

decreased from 1399 ± 599 N/m^2 at C1 (mean depth = 335 m; year 2000) to 467 ± 119 N/m^2 at S5 (mean depth = 3314 m; year 2000).

Results of Multiple Linear Regression indicated that a combination of depth, transect, sediment grain size, particulate organic content in sediments, and CHL concentration in near surface water could explain 100% of the variation in polychaete density ($r^2 = 1.00$, d.f. = 7, F = 2787.24, p = 0.02). Thus, these variables were considered as significant habitat factors in terms of determining polychaete density in the study area. Correlations between density and these variables are discussed in detail as below.

4.2.2. Variation in Polychaete Density with Sampling Year

Polychaete density data from station C7, MT1, MT3 and MT6 were used to test effects of sampling year using a single factor analysis of variance (ANOVA) (Table 6), because only those stations were sampled in both year 2000 and 2001. The mean density in year 2000 was 1649 ± 1098 N/m^2, and the mean density in year 2001 was 1180 ± 888 N/m^2. Although the sample mean was higher in year 2000, ANOVA indicated the mean polychaete density was not significantly different between two sampling years (d.f. = 1, F = 1.33, P > 0.05, power = 0.20). Only 5.7% variation in polychaete density data could be explained by the factor SAMPLING YEAR.

Table 6. Statistical means and standard deviation for the polychaete density in year 2000 and year 2001. Data were collected from four sampling stations C7, MT1, MT3 and MT6.

Sampling Year	Mean	N	Std. Deviation	Sig.	Observed Power
Year_2000	1649	12	1098		
Year_2001	1180	12	888	0.26	0.20
Total	1415	24	1006		

4.2.3. Variation in Polychaete Density with Transect

The mean density on each transect was estimated from all the sampling stations in the Mississippi Canyon and the Central Transect. ANOVA indicated that the mean density varied significantly with transect (d.f. = 1, F = 5.54, p < 0.05, power = 0.64) (Table 7). In the Mississippi Canyon, the mean density was 1668 ± 1241 N/m^2. In the

Central Transect, the mean density was 980 ± 489 N/m^2. Thus, higher polychaete density was found in the Canyon. 10.5% of the variation in polychaete density data was explained by the factor TRANSECT.

Table 7. Statistical means and standard deviation for the polychaete density on two transect, the Mississippi Canyon and the Central Transect. Data were collected from all the sampling stations on both transect.

Transect	Mean	N	Std. Deviation	Sig,	Observed Power
Central Transect	980	20	489		
Mississippi Canyon	1668	29	1241	0.02	0.64
Total	1387	49	1053		

4.2.4. Variation in Polychaete Density with Depth

Curve Estimation Regression (available in SPSS) was conducted to determine the best fit to describe the statistical relationship between polychaete density and depth. In addition, in order to compare the Mississippi Canyon and the Central Transect, Curve Estimation Regression was also carried out on density data from each transect to see if different trends existed.

Variation in Polychaete Density with Depth in the Study Area

Results of Curve Estimation Regression indicated that LINEAR, QUADRATIC, CUBIC and EXPONENTIAL models were the best four models (Table 8). The LINEAR

model was the simplest model to describe the mathematical relationship between polychaete density and depth, and the polychaete density decreased with increasing depth linearly (Adjust R^2 (r^2) = 0.60, d.f. = 48, F = 72.29, P < 0.05). The QUADRATIC and CUBIC models fit better than the LINEAR model, since Adjust R^2 (r^2) were higher (r^2 = 0.62) and more variations could be explained. But the calculations for the QUADRATIC and CUBIC models were more complicated, and more variables were introduced, such as X^2 and X^3. Thus, the best-fit model was the exponential model (EXPONENTIAL), which had the highest Adjust R^2 (r^2) and fewer variables compared with the QUADRATIC and CUBIC model (Table 8). The statistical relationship between depth and polychaete density could be expressed as (Fig. 3):

$$\mathbf{Y = 3497.6e^{-0.000856X}};\ \text{where: Y = Polychaete Density, X = Depth}$$

(r^2 = 0.71, d.f. = 48, F = 119.59, P < 0.05).

Table 8. Curve estimation regression to assess the statistical relationship between polychaete density and depth in the study area. The best four models and associated parameters were listed as below.

Model	r^2	d.f.	F	Sig.F	Expression
LINEAR	0.60	48	72.29	0.00	$Y = 2680.9 - 0.86X$
QUADRATIC	0.62	48	40.74	0.00	$Y = 3282.6 - 1.9X + 0.000296X^2$
CUBIC	0.62	48	27.52	0.00	$Y = 2850.9 - 0.7X - 0.000521X^2 + (1.59E\text{-}07)X^3$
EXPONENTIAL	0.71	48	119.59	0.00	$Y = 3497.6e^{-0.00086\ X}$

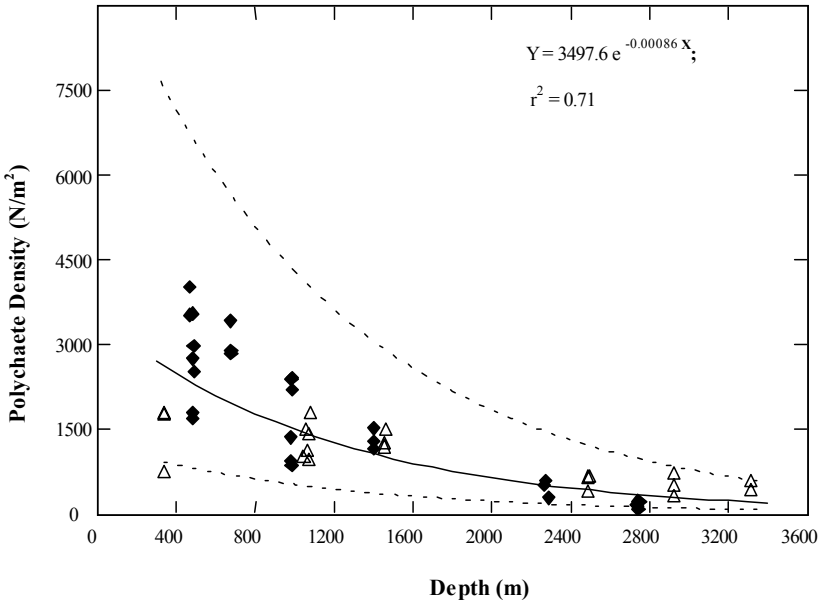


Fig. 3. Exponential relationship between polychaete density and depth in the study area. Exponential model was the best-fit model: $Y = 3497.6\ e^{-0.00086X}$ ($r^2 = 0.71$, $P < 0.05$). Dashed lines represent 95% upper or lower confidence level respectively. Solid line represents the predicated polychaete density from the exponential model. Solid diamonds represent observed density from the Mississippi Canyon, and triangle represents observed density from the Central Transect.

Comparison between the Mississippi Canyon and the Central Transect

The results of Curve Estimation indicated that the exponential model was also the best-fit model for density-depth relationship in the Mississippi Canyon or the Central Transect, which could be expressed as $Y = ae^{bX}$, where Y represents polychaete density (N/m^2) and X represents depth (m), a and b are constants. As shown in Fig. 4, different trends may exist between these two transects. In the Mississippi Canyon, the statistical relationship of polychaete density with depth was $Y = 5586.9e^{-0.0012X}$ ($r^2 = 0.90$, d.f. =

27, F = 241.95, P < 0.05). In the Central Transect, the relationship was Y = 1855.5e $^{-0.00045X}$ (r^2 = 0.64, d.f. = 19, F = 34.93, P < 0.05).

Based on the exponential models on Fig. 4, polychaete density in the Mississippi Canyon decreased more sharply than in the Central Transect. When depth was less than 800 m, polychaete density was expected to be higher in the Mississippi Canyon than in the Central Transect. When depth was greater than 1400 m, polychaete density was expected to be higher in the Central Transect rather than in the Mississippi Canyon.

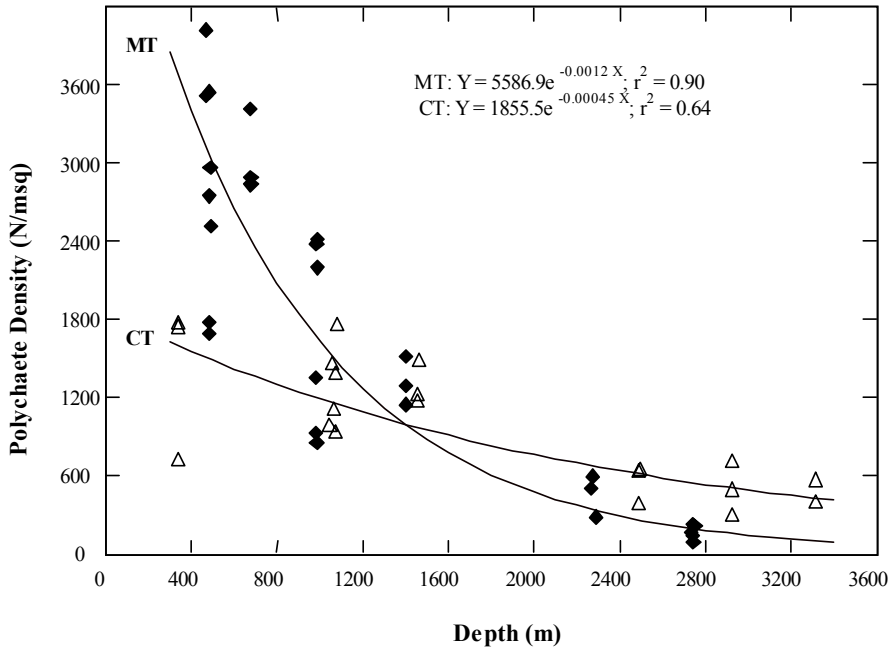


Fig. 4. Comparison of exponential relationship of polychaete density with depth between the Mississippi Canyon and the Central Transect. In the Mississippi Canyon (MT), the relationship was Y = 5586.9e $^{-0.0012X}$ (r^2 = 0.90, P < 0.05). In the Central Transect, the relationship was: Y = 1855.5e $^{-0.00045X}$(r^2 = 0.64, P < 0.05). Solid line represents the predicated polychaete density from the exponential model. Solid diamonds represent observed density from the Mississippi Canyon, and triangle represents observed density from the Central Transect.

4.2.5. Variation in Polychaete Density with Food Availability

To test effects of food availability on polychaete density, particulate organic matter content (POC and PON) and C:N ratio in sediments, meiofaunal biomass (carbon weight), and a 3-year average of remotely-sensed chlorophyll (CHL) concentration in near surface water (SEAWIFS data, summarized by Biggs et. al., 2003) were used as direct and indirect proxies for food availability to benthos. Regression of the polychaete density on the indirect proxy (mean CHL concentrations in surface water) was significant; and the first-order fit was $Y = 1050.4 + 592.8X$ ($r^2 = 0.82$, d.f. = 9, $F = 45.13$, $P < 0.05$) (Fig.5). Station MT1 has the highest mean CHL concentration, followed by MT2, and these two stations had the highest polychaetes densities. Polychaete density then decreased more or less linearly with decrease in mean surface CHL concentration.

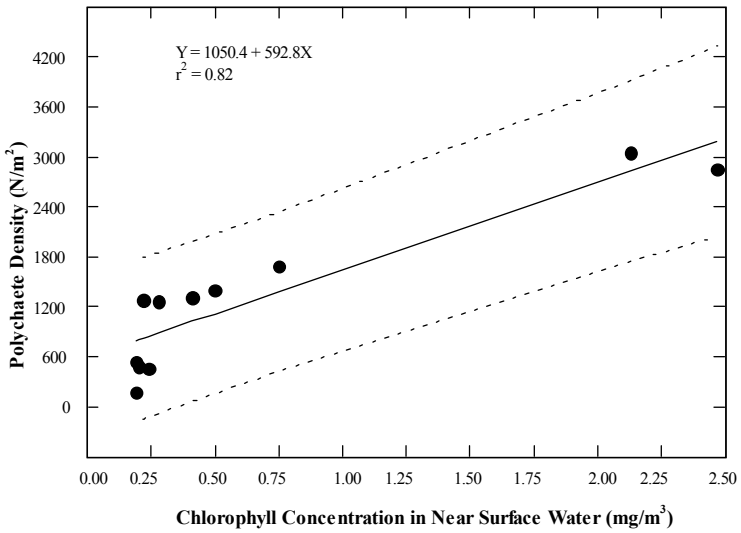


Fig. 5. Relationships of polychaete density to CHL concentration in near surface water. Dashed line represents 95% confidence level. Solid line represents predicted density. Circles were observed polychaete density data from the 12 sampling stations.

Spearman rank correlation analysis was conducted to evaluate the correlation between polychaete density and biomass of 16 meiofaunal groups. Significant positive correlations were found between polychaete density and meiofaunal biomass (gC/m^2) of isopods, kinorhynchs, ostracods, polychaetes (meiofauna), and nematodes ($p < 0.05$). The total meiofaunal biomass (gC/m^2) had the highest correlation with polychaete density ($\rho = 0.91$, $p = 0.00$), and the polychaete density varied with the total meiofaunal biomass exponentially ($r^2 = 0.89$, d.f. = 9, $F = 79.76$, $p = 0.00$). Meiofaunal biomass decreased with depth linearly ($r^2 = 0.91$, d.f. = 9, $F = 98.87$, $p = 0.00$), which suggests that potential food availability decreased linearly with increasing depth. However, summary measurements of organic content in the sediment such as POC, PON and C:N ratio in sediments were not significantly correlated with polychaete density ($P > 0.05$).

To focus on effects of food availability, depth effects were removed. In order to remove depth effects from data, each variable was regressed with DEPTH first, and then if any significant correlation existed, this trend was removed from data. The residuals were used for further regression analysis. Levin and Gage (1998) discussed the similar method. Depth effects were removed from meiofaunal biomass (gC/m^2) data as a linear model, and removed from CHL concentration and polychaete density data as an exponential model, since it was the best-fit model for their relationships with depth. After removal of depth effects, regression of polychaete density residuals on meiofaunal biomass (gC/m^2) residuals was no longer significant. Regression of density residuals on CHL concentration however remained significant ($p < 0.05$). Regressions of residuals on POC and the C:N ratio became significant (Fig.6). 57.8% of the variation in density

residuals was explained by POC (r^2 = 0.58, d.f. = 8, F = 5.49, p = 0.03), and 66.4 % of the variation was explained by the C:N ratio (r^2 = 0.66, d.f. = 8, F = 5.92, p = 0.04). Since POC and C:N ratio had no correlation with depth, there was no need to remove depth effects from POC and C:N ratio data.

Therefore, among the surrogates for food availability, CHL concentration had the highest correlation with polychaete density, so I regard CHL as an indirect proxy for food availability to benthos. Meiofaunal biomass (gC/m^2) was not a significant factor. POC and the C:N appear to have some effects on density, but the effects are confounded by depth effects.

4.2.6. Variation in Polychaete Density with Dissolved Oxygen, Temperature, Sediment Grain Size

Non-linear regression on percent sand, temperature and DO were significant ($p < 0.05$), while the other two sediment grain size properties, percent clay and percent silt, were found not significantly correlated with density ($p > 0.05$). The relationship of polychaete density with temperature, DO and percent sand could be fit well by a second-order polynomial (QUADRATIC model). The relationship between density and DO was $Y = 5670.9 - 1527.1X + 97.6X^2$ (r^2 = 0.49, d.f. = 7, F = 5.30, $P < 0.05$). Regression on percent sand in sediments was expressed as $Y = 2325.5 – 118.2X + 1.4X^2$ (r^2 = 0.50, d.f. = 8, F = 5.99, $P < 0.05$). Y refers to polychaete density (N/m^2) and X refers to bottom-water temperature, bottom-water DO and percent sand in sediments respectively.

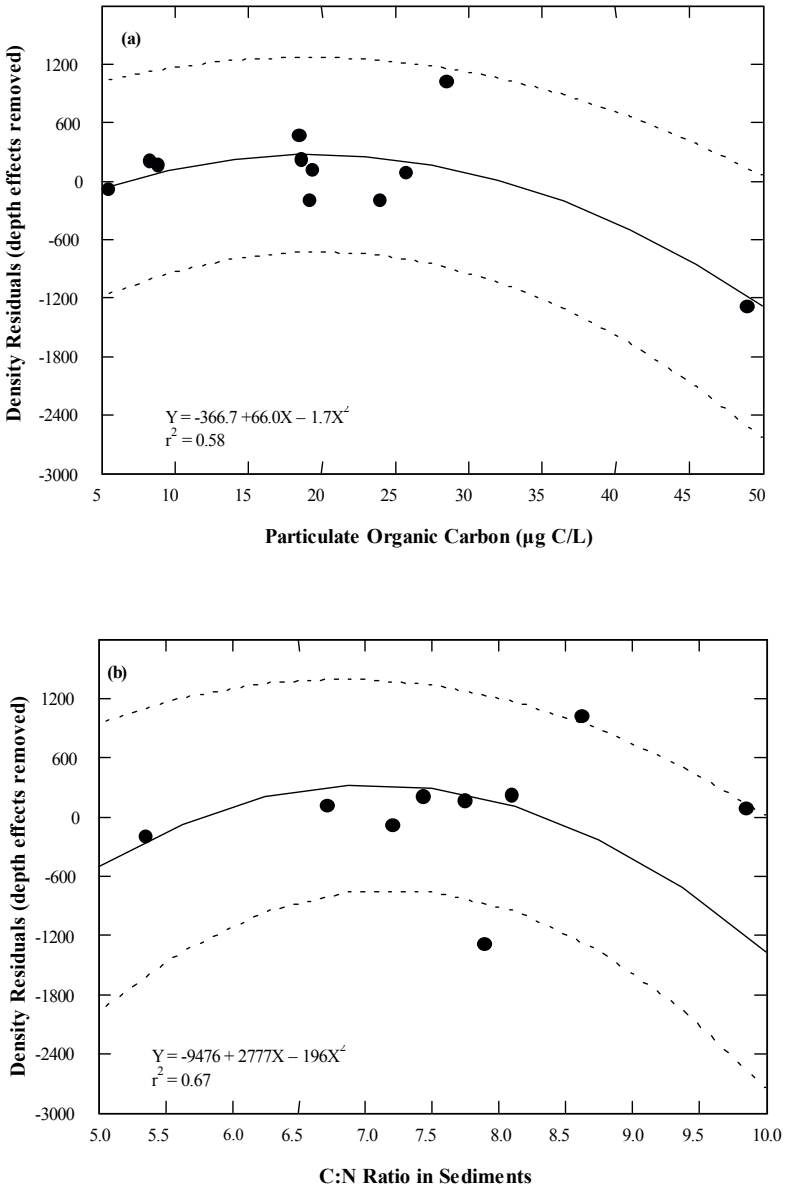


Fig. 6. Relationship of polychaete density residuals to (a) POC content and (b) the C:N ratio in sediments after depth effects removed as an exponential model ($p < 0.05$).

After removal of depth effects, regression of density residuals on temperature residuals, DO residuals, sediment grain size residuals were no longer significant ($p > 0.05$). Depth effects were removed from temperature and DO data as the QUADRATIC model ($p < 0.05$), since it was the best-fit model. Depth effects were removed from percent sand data as a positive linear function. Results indicated that effects of temperature, DO and percent sand on polychaete density depended on depth. They were depth-related parameters, and had no significant effects on polychaete density.

4.2.8. Variation in Polychaete Density with Sediment Contamination

Effects of Trace Metals on Polychaete Density

Many metals in sediments can adversely affect marine benthos according to previous studies (e.g., Long et al., 1995). These include Cd, Cr, Cu, Pb, Ni, and Zn. In the study area, trace metals were not correlated with polychaete density ($p > 0.05$), including Ag, Cd, Co, Cu, Hg, Mg, and TI.

Significant positive correlations were found between polychaete density and log-transformed concentrations of Al, As, Mn, P, Pb, S, Sb, and Zn ($p < 0.05$). The reduction in polychaete density was not detected with other trace metals. The exception was Sr, which was found to negatively correlate with density. The relationship between Log Sr and density was $Y = 10277.4 – 3495.3X$ ($r^2 = 0.74$, d.f. = 9, $F = 26.08$, $p < 0.05$). Y was polychaete density (N/m^2) and X was log-transformed concentration of Sr in sediments.

After depth effects were removed from trace metal data, regressions of density residuals on trace metal residuals were no longer significant ($p > 0.05$). Thus, trace metals were not significant factors. Depth effects were removed from trace metal data as a negative linear function ($p < 0.05$). The study area probably was not trace-metal contaminated, since polychaete density was not adversely affected by those trace metals in sediments in most cases.

Effects of Organic Contamination on Polychaete Density

Low levels of Polycyclic Aromatic Hydrocarbons (PAHs) were found in the study area. Polychaete density exhibited positive associations with log-transformed concentrations of TPAHWP, NAPH, PHENAN, and PERYL ($p > 0.05$). The non-linear regression of density on Log PERYL was fit well by the QUADRATIC model, while others were fit by the linear model. No significant correlations with polychaete density were found for other PAHs, such as ANTHRAC, DIBEN and FLUORAN ($p > 0.05$)

After removal of depth effects, regressions of density residuals on PAH residuals were no longer significant ($p > 0.05$). The exception was the regression on ANTHRAC, which was fit well by the QUADRATIC model ($r^2 = 0.60$, d.f. = 8, $F = 5.93$, $p = 0.02$). Depth effects were removed from PAH data as a negative linear function, since it was the best-fit model for PAH variations with depth.

4.2.9. Multivariate Analysis of Effects of Environmental Factors On Density

Patterns in environmental data (Fig. 3) were compared to that in the polychaete density data (Fig. 7 (a)) using BIO-ENV/BVSTEP procedures (available in PRIMER). Herein, the word "pattern" refers to variations in similarity or dissimilarity between sampling stations with respect to environmental/biological data. The purpose of this was to examine the extent to which the pattern of environmental data could match that of the polychaete density data and find the subsets of the environmental variables whose pattern could "best" match that of the polychaete density data. Depth and CHL concentration in near surface water were found to be the best subset of the environmental variables that could explain most variations in the polychaete density pattern (Spearman correlation coefficient $\rho = 0.91$, $p < 0.001$). Transect, hydrographic features, particulate organic matter content, sediment grain size, trace metals, and PAHs, are not as important. Thus, depth and CHL concentrations were essential factors in terms of determining the polychaete density pattern in the study area. The MDS plots were made for the 11 sampling stations in the Mississippi Canyon and the Central Transect except for S5 (Fig. 7) due to too many missing measurements at S5. The MDS plots were based on the polychaete density and the best subset of environmental variables that could match the polychaete density pattern ($p < 0.001$). Stress was less than 0.01, i.e., the two-dimensional MDS plot gave excellent representation of the high-dimensional relationship between stations with no real prospect of misinterpretation (Clarke and Gorley, 2002). Depth was negatively correlated with the density pattern, while CHL concentration was positively correlated with the density pattern (Fig. 7).

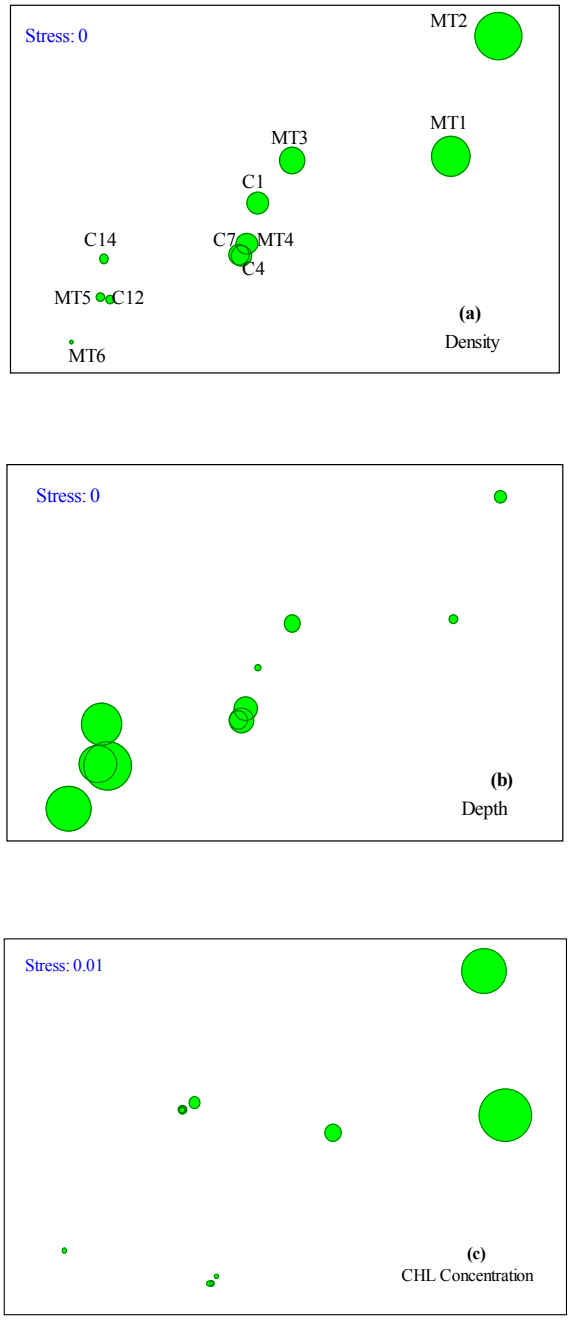


Fig. 7. MDS plots for the 11 sampling stations in the study area based on (a) polychaete density. (b) and (c) are the same MDS but with superimposed variables' values (Green circles). The scale of green circles represents the scales of depth and CHL concentration. Both could best match the polychaete density pattern ($p < 0.001$).

4.3. Diversity

4.3.1. General Information about Polychaete Diversity

Species Level

Species diversity was measured using a group of diversity indices, including Margalef (d), Fisher α, Shannon-Wiener (H′), Simpson (D), Expected Number of Species ES(n) (Rarefaction) and Evenness (J′). ES(100) was used to ensure the same sampling size for diversity comparison, which means the number of species expected from 100 individuals.

Species diversity varied with sampling station, sampling year and depth (Table 9). Diversity indices had different discriminant ability between samples (Fig. 8). ES(100), Fisher α and Marglef (d) showed changes in species diversity dramatically. Shannon-Wiener (H′) had moderate discriminant ability, and Simpson (D) had relatively low ability. Simpson index (D) was considered to be more sensitive to the common species in the sample (Peet, 1974). It is usually used as an index of relative dominance. As shown in Table 9 and Fig. 8, sampling stations C7, C4, MT3 and MT4 had higher species diversity than others. They were all at intermediate depth (800 – 1500 m).

The highest species evenness (J′) in the Mississippi Canyon occurred at MT5 and MT6, the deepest stations on this transect, while the highest J′ in the Central Transect was at C7 and C4 at intermediate depth. Distribution of individuals among species (evenness) therefore could have different trends on those two transects, which could be

regulated not only by depth, but also other factors, such as organic matter input, since C7 is considered to be a seep site.

Table 9. Measurement of polychaete biodiversity in the Mississippi Canyon and the Central Transect using different diversity indices (species level).

	Station	Total species (S)	No. of Individual (N)	Margalef (d)	Evenness (J')	Fisher α	Shannon-Wiener H' (loge)	Simpson (D)	Expected No. of Species (ES(100))
The Central Transect	C1	91	591	14.1	0.83	30.0	5.4	0.94	42.7
	C7	95	427	15.5	0.86	37.8	5.7	0.97	47.9
	*C7	104	396	17.2	0.88	45.9	5.9	0.97	51.5
	C4	97	408	15.9	0.87	40.2	5.7	0.96	50.1
	C14	45	231	8.0	0.85	16.6	4.6	0.93	33.6
	C12	49	185	9.1	0.80	21.7	4.5	0.91	36.8
	**S5	34	131	6.7	0.80	14.9	4.0	0.90	29.5
The Mississippi Canyon	MT1	107	1184	14.9	0.77	28.5	5.2	0.95	37.2
	*MT1	63	1049	8.9	0.75	14.7	4.5	0.93	27.5
	**MT1	56	976	7.9	0.71	12.9	4.1	0.89	25.6
	MT2	106	1152	14.9	0.76	28.4	5.1	0.95	35.8
	MT3	132	978	19.0	0.81	41.1	5.7	0.96	46.6
	*MT3	87	456	14.0	0.83	31.9	5.3	0.96	41.5
	MT4	103	480	16.5	0.88	40.2	5.9	0.97	51.0
	MT5	49	139	9.7	0.90	26.9	5.0	0.96	41.7
	MT6	26	56	6.2	0.92	18.8	4.3	0.95	26.0
	*MT6	35	62	8.28	0.91	33.2	4.6	0.95	35.0

Notes: *stations were sampled in year 2001. **stations were samples in year 2002. Other stations were sampled in year 2000.

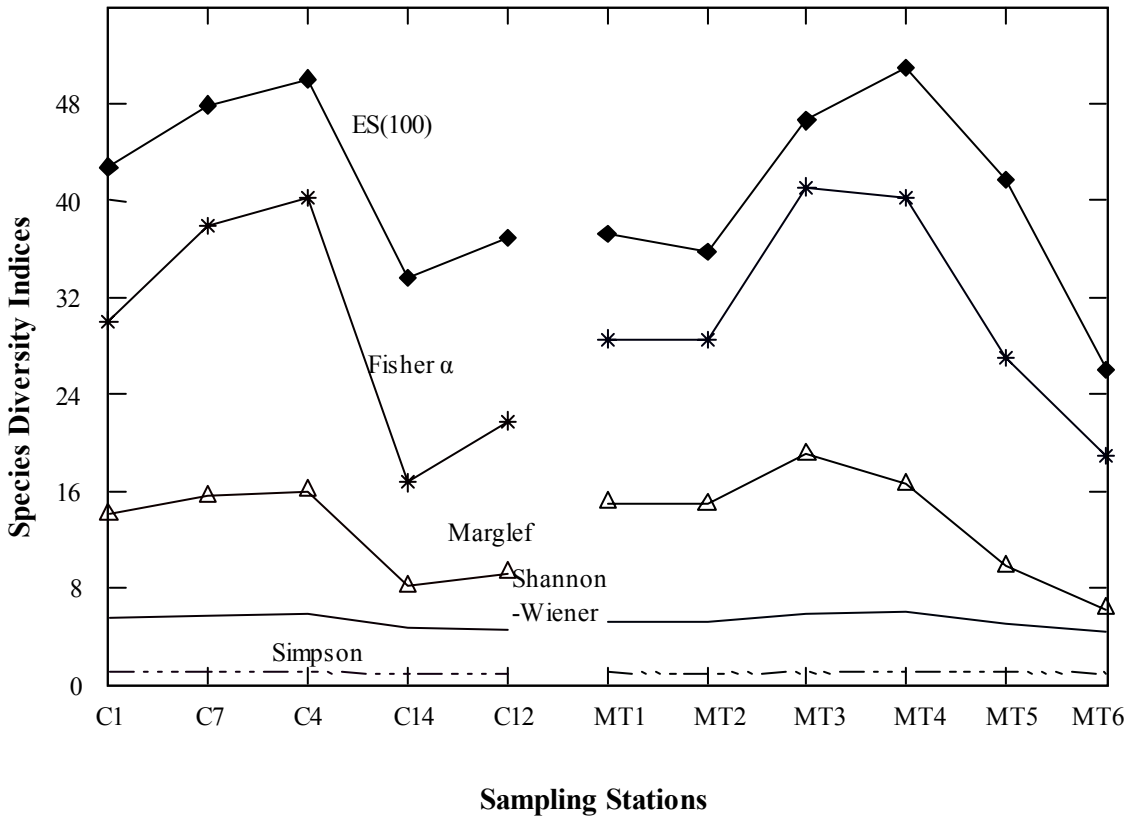


Fig. 8. Species diversity in the Mississippi Canyon (MT) and the Central Transect (C). Species diversity was calculated using a suite of diversity indices. Those indices may have different discriminant ability between sampling stations. In this study, (ES(100), Fisher α and Marglef (d) could show the trends dramatically.

Family level

The diversity indices were formatted in the same order for comparison at the family level and the species level (Table 10). Similar to the species level diversity, the family level diversity was relatively higher at MT3, MT4, MT5, C7 and C4. EF(100) (expected number of families from 100 individuals), Fisher α and Marglef (d) were the best indicators of the diversity at family level.

Table 10. Measurement of biodiversity in the Mississippi Canyon and the Central Transect using different diversity indices (family level).

	Station	Total Family (F)	No. of Individual (N)	Margalef (d)	Evenness (J')	Fisher α	Shannon-Wiener H' (ln)	Simpson (D)	Expected No. of Family (EF(100))
The Central Transect	C1	34	724	5.0	0.70	7.4	3.5	0.86	19.8
	C7	38	728	5.6	0.74	8.5	3.9	0.89	23.0
	*C7	36	577	5.5	0.78	8.5	4.0	0.91	23.1
	C4	40	661	6.0	0.69	9.3	3.7	0.87	21.7
	C14	23	279	3.9	0.73	5.9	3.3	0.84	17.9
	C12	24	250	4.1	0.74	6.5	3.4	0.85	18.4
	**S5	24	161	4.5	0.77	7.8	3.5	0.85	20.7
The Mississippi Canyon	MT1	27	1392	3.5	0.54	4.7	2.5	0.72	13.7
	*MT1	27	1237	3.6	0.57	4.8	2.7	0.77	12.6
	**MT1	22	1301	2.9	0.52	3.7	2.3	0.71	10.8
	MT2	34	1578	4.4	0.67	6.1	3.4	0.85	17.7
	MT3	33	1207	4.5	0.73	6.2	3.6	0.88	19.4
	*MT3	29	539	4.4	0.79	6.5	3.8	0.90	20.4
	MT4	32	680	4.7	0.75	6.9	3.7	0.89	20.4
	MT5	26	231	4.5	0.78	7.5	3.7	0.88	20.7
	MT6	17	86	3.5	0.84	6.3	3.4	0.88	17.0
	*MT6	22	89	4.6	0.79	9.3	3.5	0.86	22.0

Note: *stations were sampled in year 2001. **stations were samples in year 2002.
Other stations were sampled in year 2000.

4.3.2. Species Distribution Model

A rank-abundance graph was plotted to examine species distributions at the 12 sampling stations on the two transects. The species were arranged along the X-axis in decreasing order of abundance; the Y-axis was their abundance. The characteristic shape of the line indicates which is the best fit (Magurran, 1988). Three models tested were geometric series, log-series and log-normal. The log-normal model and the log-series model were the best fit ($p > 0.05$) (Fig. 9), which means that most species have medium abundances with few species very abundant and few very rare. The null hypothesis was there was no significant difference between polychaete distribution and the log-normal (or log-series) distribution. Since p was greater than 0.05, the null hypothesis was not rejected.

4.3.3. Variation In Polychaete Diversity With Sampling Year

Similarly to the analysis of density, diversity data from C7, MT1, MT3 and MT6 were used to test effects of sampling year on polychaete diversity, since those stations were sampled in both year 2000 and year 2001. Species diversity was represented by Expected Number of Species (ES(100)), Shannon-Wiener index (H′), Simpson index (D) and Evenness (J′) respectively. Each diversity index has its own strength and weakness, and the best understanding is obtained by using a combination.

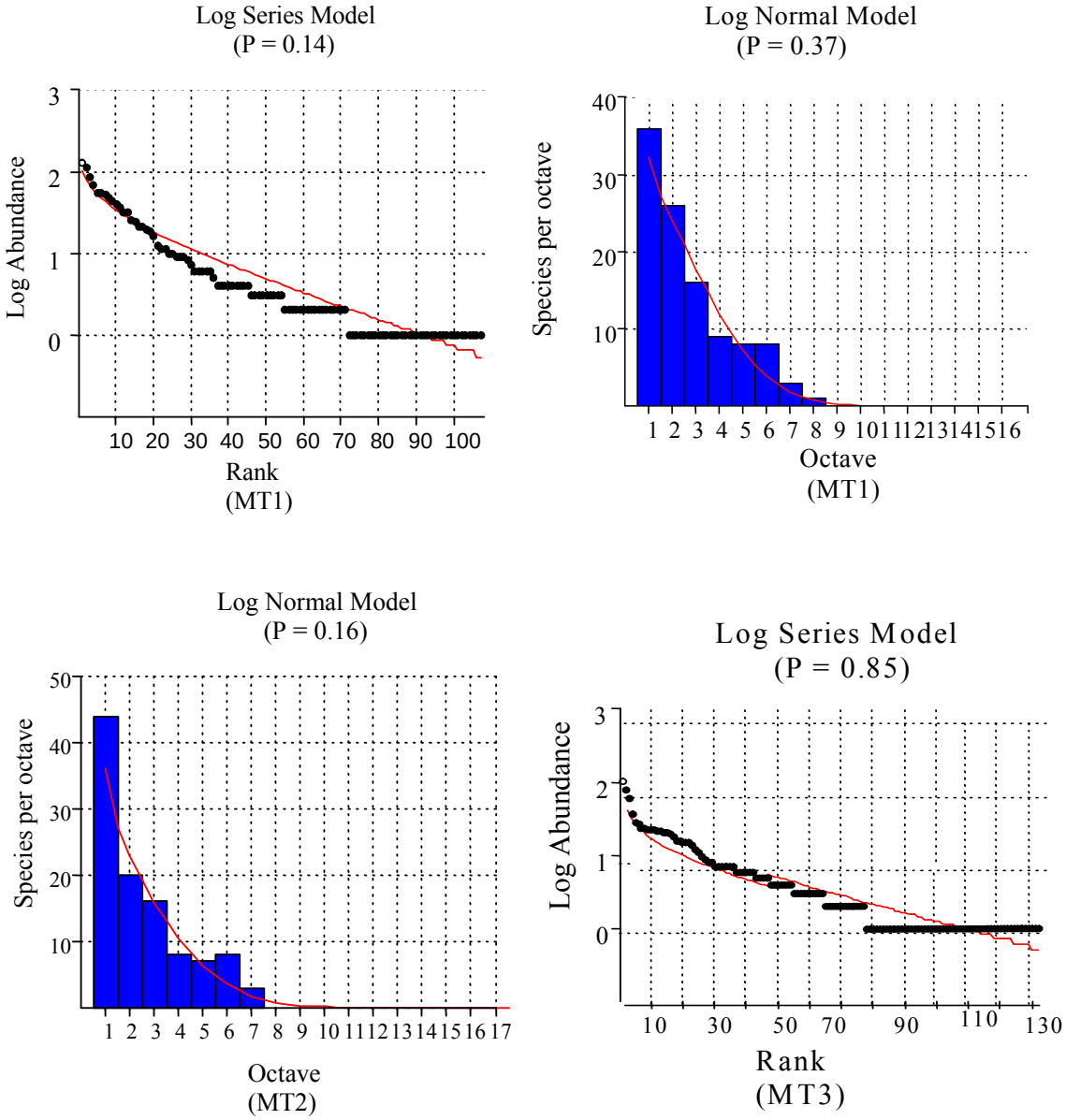


Fig. 9. Rank Abundance Graph to examine the species distribution at 12 sampling stations in the Mississippi Canyon and the Central Transect. The species were arranged along the X-axis in decreasing order of abundance; the Y-axis was their abundance. The log-series and the log-normal model were the best-fit models ($p > 0.05$).

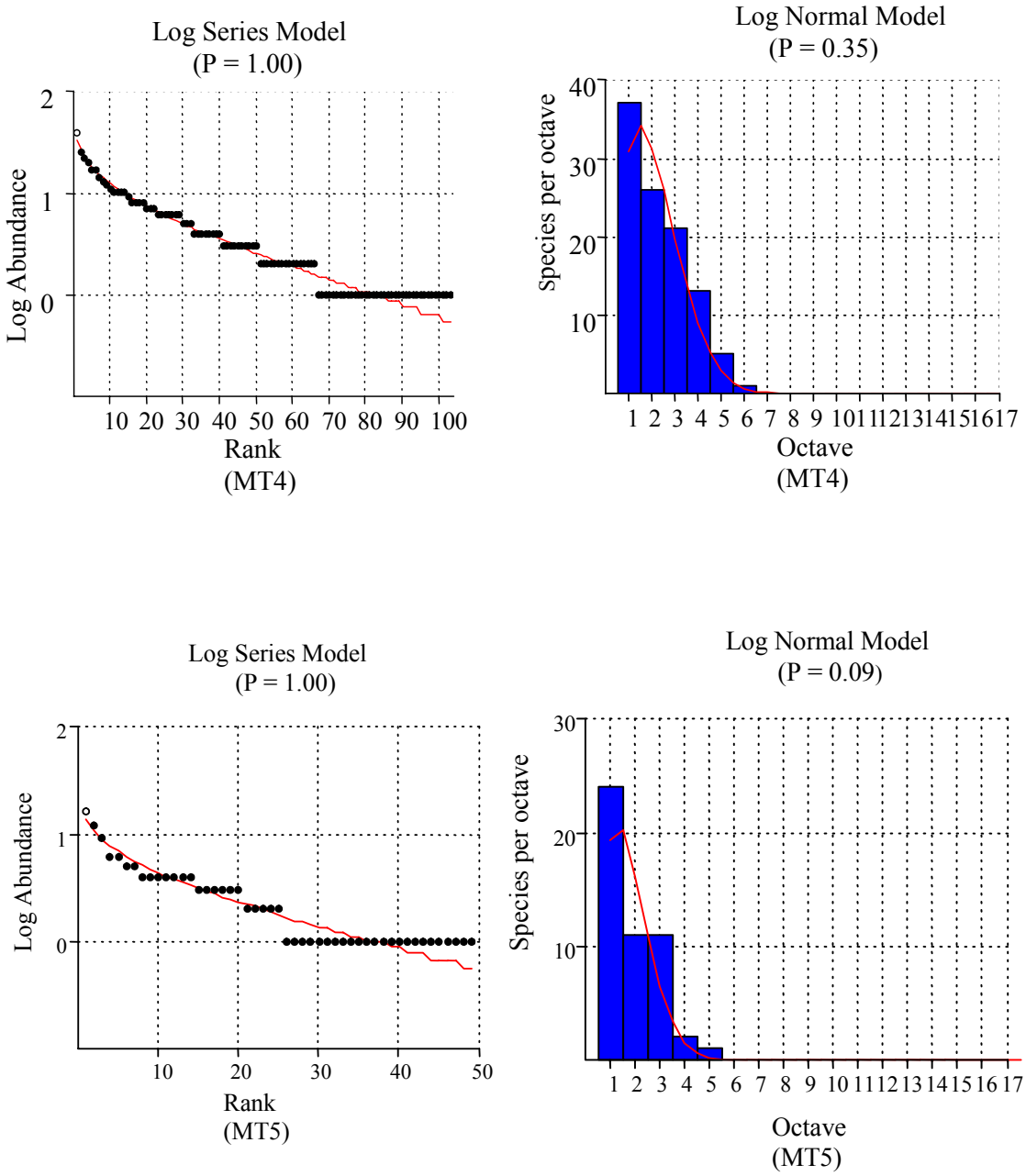
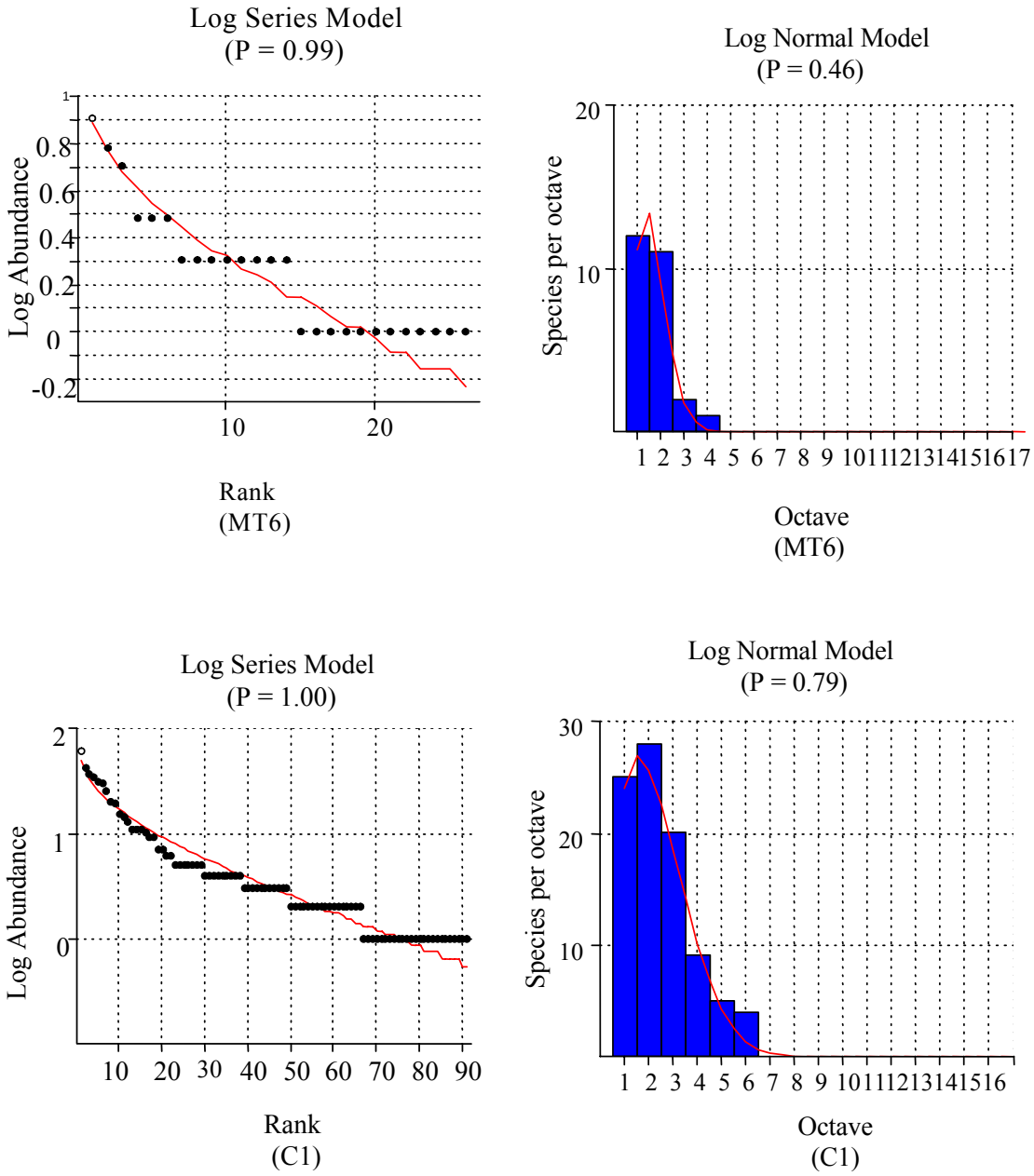


Fig. 9. — Continued.



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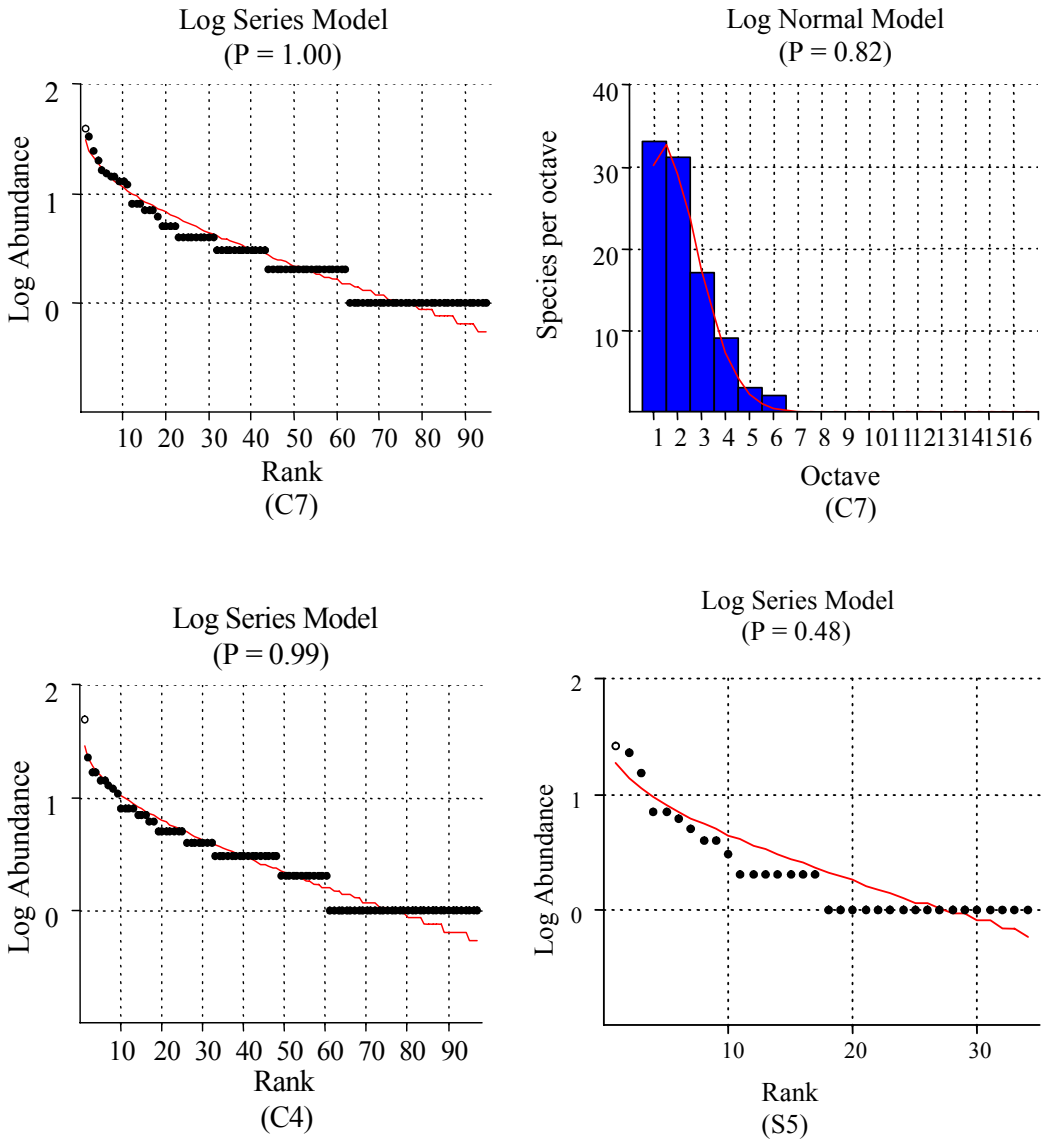


Fig. 9. — Continued.

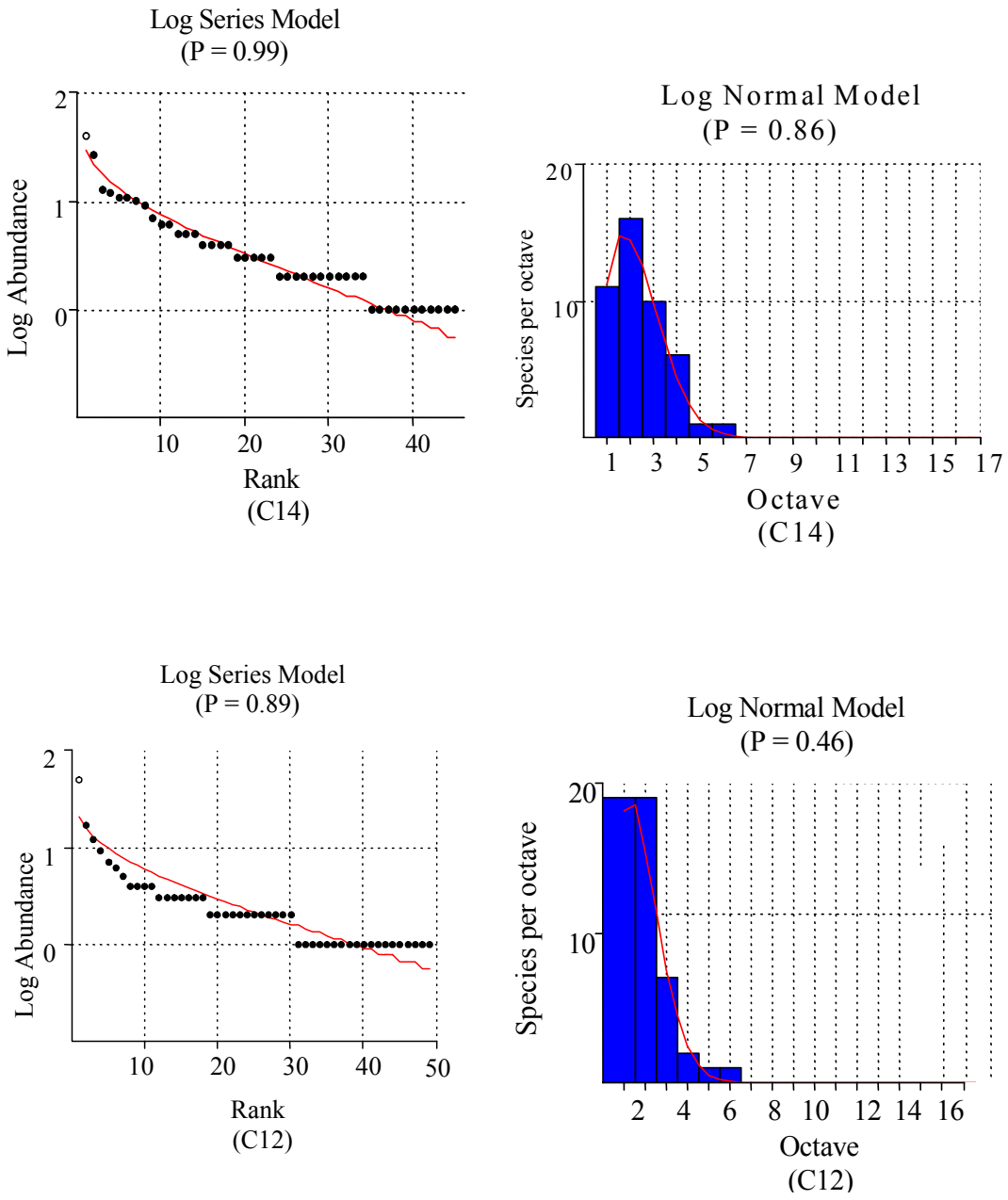


Fig. 9. — Continued.

The results of ANOVA indicated that SAMPLING YEAR was not a significant factor ($p > 0.05$) on polychaete species diversity, ES(100) (d.f. = 1, $F = 0.00$, $p > 0.05$, power = 0.05), Shannon-Wiener (H′) (d.f. = 1, $F = 0.19$, $p > 0.05$, power = 0.07), Simpson (D) (d.f. = 1, $F = 1.51$, $p > 0.05$, power = 0.22), or Evenness (J′) (d.f. = 1, $F = 2.35$, $p > 0.05$, power = 0.31). As a comparison, effects of sampling year on the family-level diversity EF(100) were also tested (Table 11). EF(100) was used because it was considered more informative than the other three indices. The mean EF(100) in year 2000 was 16.3 ± 5.7, and the mean EF(100) in 2001 was 16.9 ± 4.7. Statistically there was no significant difference in EF(100) between year 2000 and 2001 (d.f. = 1, $F = 0.10$, $p > 0.05$, power = 0.06). Hence, the species-level and the family-level diversity revealed similar trends as to the effects of sampling year, i.e., SAMPLING YEAR was not a significant factor to polychaete diversity.

Table 11. Statistical means and standard deviation for polychaete species/family level diversity in year 2000 and year 2001.

Sampling Year	Parameters	ES(100)	Shannon-Wiener	Simpson	Evenness	EF(100)
Year_2000	Mean	29.1	2.9	0.91	0.84	16.3
	N	12	12	12	12	12
	Std. Deviation	12.8	0.7	0.11	0.08	5.77
Year_2001	Mean	29.3	3.1	0.95	0.89	16.9
	N	12	12	12	12	12
	Std. Deviation	11.1	0.4	0.02	0.07	4.6
Total	Mean	29.1	3.0	0.93	0.89	16.6
	N	24	24	24	24	24
	Std. Deviation	11.7	0.6	0.08	0.07	5.1
Sig.		0.97	0.67	0.23	0.14	0.76
Observed Power		0.05	0.07	0.22	0.31	0.06

4.3.4. Variation in Polychaete Diversity with Transect

In order to investigate variations in polychaete diversity with transect, three analyses were carried out, ANOVA, rarefaction and the Species Accumulation Curves. ANOVA was employed to test effects of transect statistically. Rarefaction and Species Accumulation Curves were used to demonstrate trends in diversity between the Mississippi Canyon and the Central Transect. Comparisons between the two transects is tantamount to testing how the canyon alters non-canyon fauna.

ANOVA Test

ES(100) varied with transect significantly (d.f. =1, $F = 5.07$, $p < 0.05$, power = 0.60). The mean ES(100) in the Central Transect was 33.1 ± 8.4 expected species from 100 individuals, and the mean ES(100) in the Mississippi Canyon was 26.6 ± 10.1 expected species from 100 individuals (Table 12). Higher mean ES(100) was found in the Central Transect. No significant difference in diversity was found between transects using other indices. The mean EF(100) was also estimated (Table 12) as a comparison. The mean EF(100) in the Mississippi Canyon was 15.4 ± 4.1 expected families from 100 individuals, which was significantly lower than that in the Central Transect (d.f. =1, $F = 13.08$, $p < 0.05$, power = 0.94). The mean EF(100) in the Central Transect was 19.5 ± 3.2 expected families from 100 individuals. Hence, the species-level diversity (ES(100)) and the family-level diversity (EF(100)) demonstrated similar effects of transect: polychaete diversity was significantly higher in the Central Transect than in the Mississippi Canyon ($p > 0.05$).

Table 12. Statistical means and standard deviation for polychaete species/family level diversity on two transects, the Mississippi Canyon and the Central Transect.

Transect	Parameter	ES(100)	EF(100)
Central Transect	Mean	33.1	19.6
	N	18	18
	Std. Deviation	8.4	3.2
Mississippi Canyon	Mean	26.6	15.4
	N	29	29
	Std. Deviation	10.1	4.1
Total	Mean	29.1	17.1
	N	47	47
	Std. Deviation	9.9	4.2
Sig.		0.03	0.00
Observed Power		0.59	0.94

Comparison of the α Biodiversity among Stations Using Rarefaction Method

When ES(100) was plotted on EF(100), the slope is about 2 ($p = 0.01$) (Fig. 10). The ES(100):EF(100) ratio was the highest at the head of the Canyon, MT1 (2.1), and the lowest value occurred at S5 (1.0), the deepest station. The mean ES(100):EF(100) ratio was higher in the Canyon (1.7) than the Central Transect (1.5), and it was higher in the shallow and intermediate depth ranges (1.9) than the deep (1.2). Therefore, the ES(100):EF(100) ratio could be correlated with organic matter input to the sediments. The higher organic matter input, the higher ES(100):EF(100) ratio.

No rarefaction curve reached its asymptote, although all the individuals were taken into account at each station (Fig. 11). In the Mississippi Canyon, MT4 showed the highest species-level diversity (ES(100) = 51.1), followed by MT3 (ES(100) = 46.6). MT1 and

MT2 had similar levels but lower than MT3 and MT4, and higher than MT5 and MT6. In the Central Transect, C7 had the highest diversity (ES(100) = 51.5) followed by C4 (ES(100) = 50.1).

In the Mississippi Canyon, MT6 showed the highest family-level diversity (EF(100) = 21.8), followed by MT5 (EF(100) = 20.7). Station MT1 had the lowest family-level diversity (EF(100) = 12.7). In the Central Transect, C7 showed the highest family-level diversity (EF(100) = 23.8) and C14 showed the lowest family-level diversity (EF(100) = 17.9).

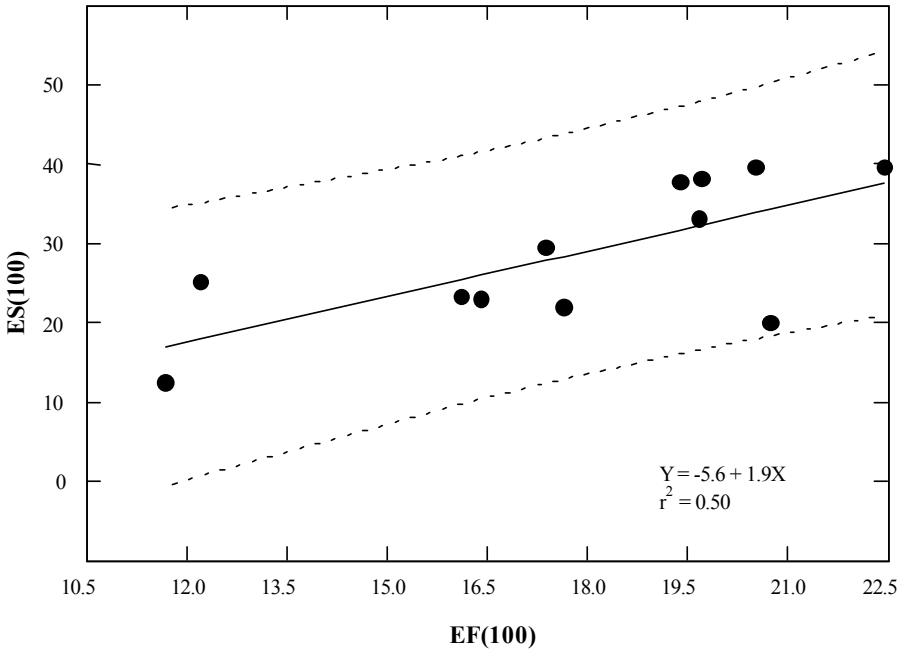
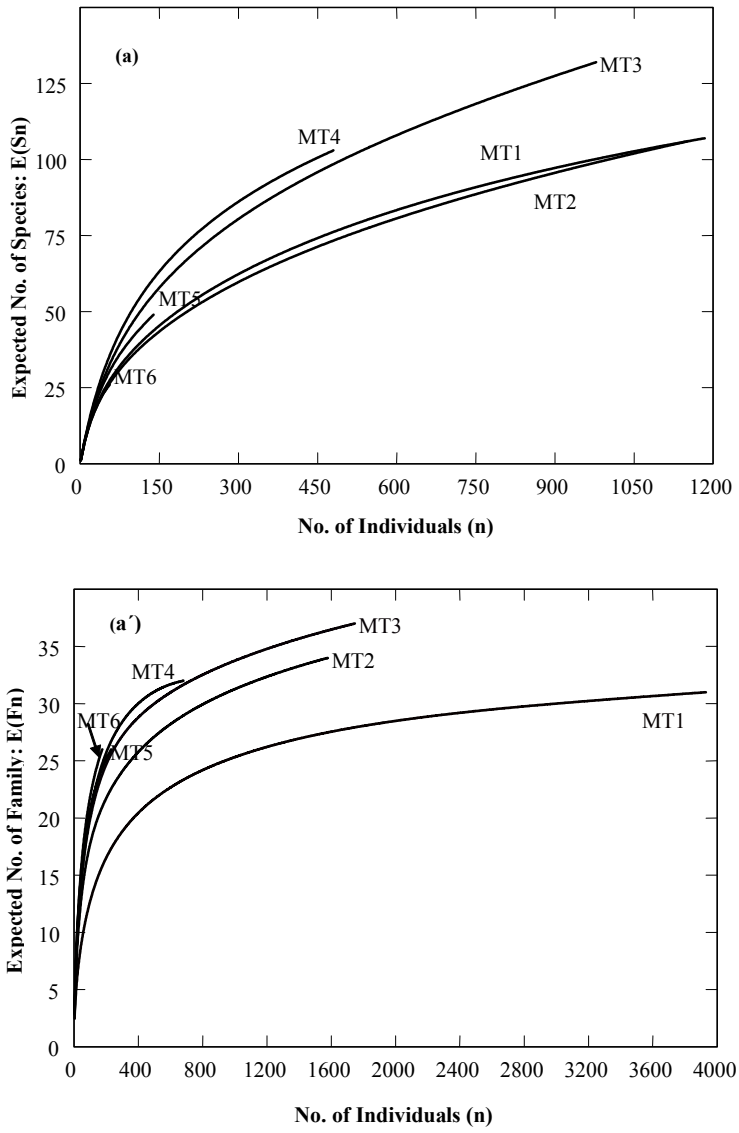
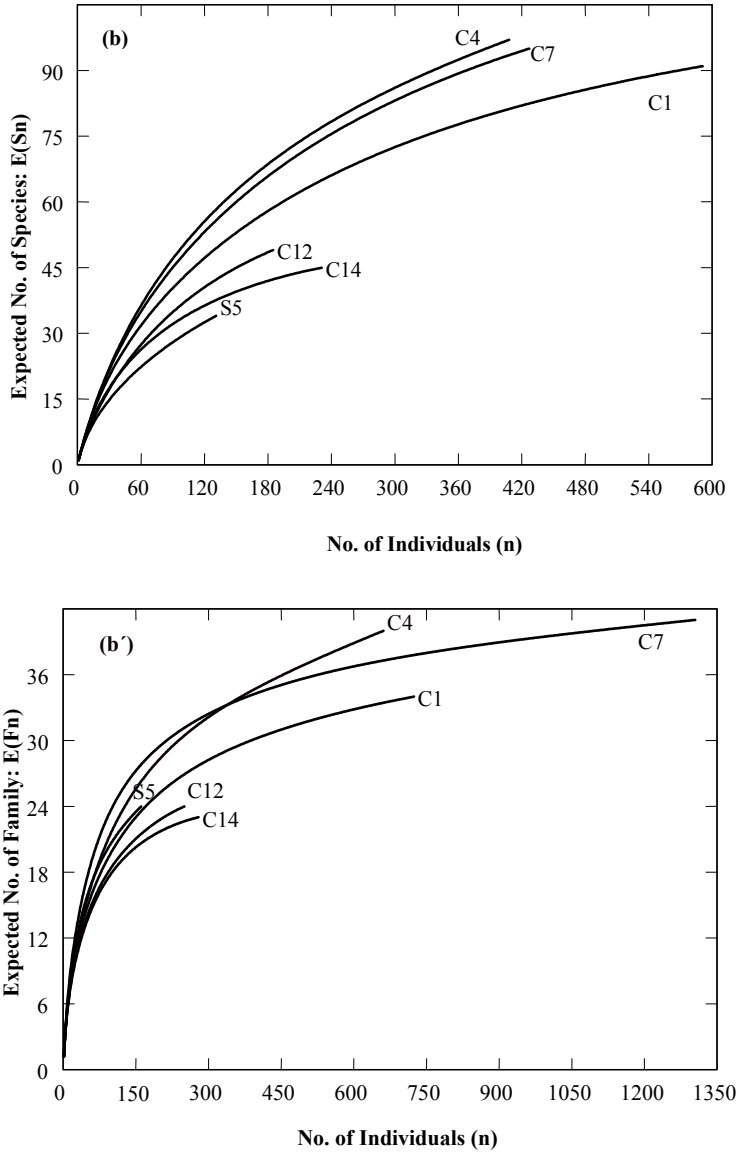


Fig. 10. Relationship between the species-level diversity ES(100) and the family-level diversity EF(100) in the study area.



Mississippi Canyon

Fig. 11. Rarefaction curves for the comparison of α biodiversity at both species-level and family-level among sampling stations in the Mississippi Canyon and the Central Transect.



Central Transect

Fig. 11. – continuted

Comparison of the α Biodiversity between the Mississippi Canyon and the Central Transect Using Rarefaction and Species Accumulation Curves

Rarefaction and Species Accumulation Curves were plotted from polychaete diversity data to compare the biodiversity between the Mississippi Canyon and the Central Transect (Fig. 12). In addition, both species-level and family-level diversity were considered to see if they revealed the same trends in the polychaete data in the study area.

The results of rarefaction analysis indicated that when lower levels of E(Sn) were used (n <= 2400 individuals), the species-level diversity was slightly higher in the Central Transect than that in the Mississippi Canyon (Fig. 12 (a1)), which was also confirmed by E(Fn) (family-level diversity) at lower levels of sampling size (n < 3400 individuals) (Fig. 12 (a2)).

Species (family) accumulation curves provided a better way to reveal diversity trends (Fig. 12). It is very clear when smaller areas were sampled (< 2.0 m^2), both the species-level and the family-level diversity were higher in the Central Transect due in large part to C7, a cold seep site (Fig. 12 (b1)). If the sampling area continued to increase, the Mississippi Canyon would have a higher diversity at both species and family levels (Fig. 12 (b2)).

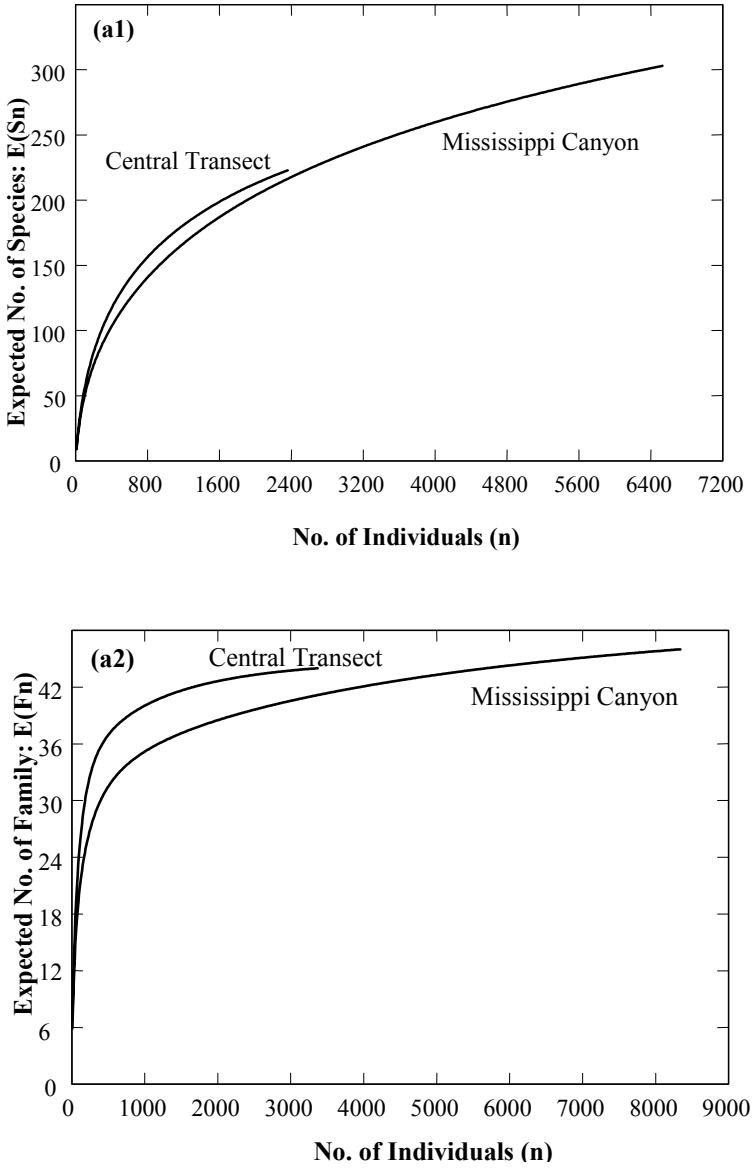
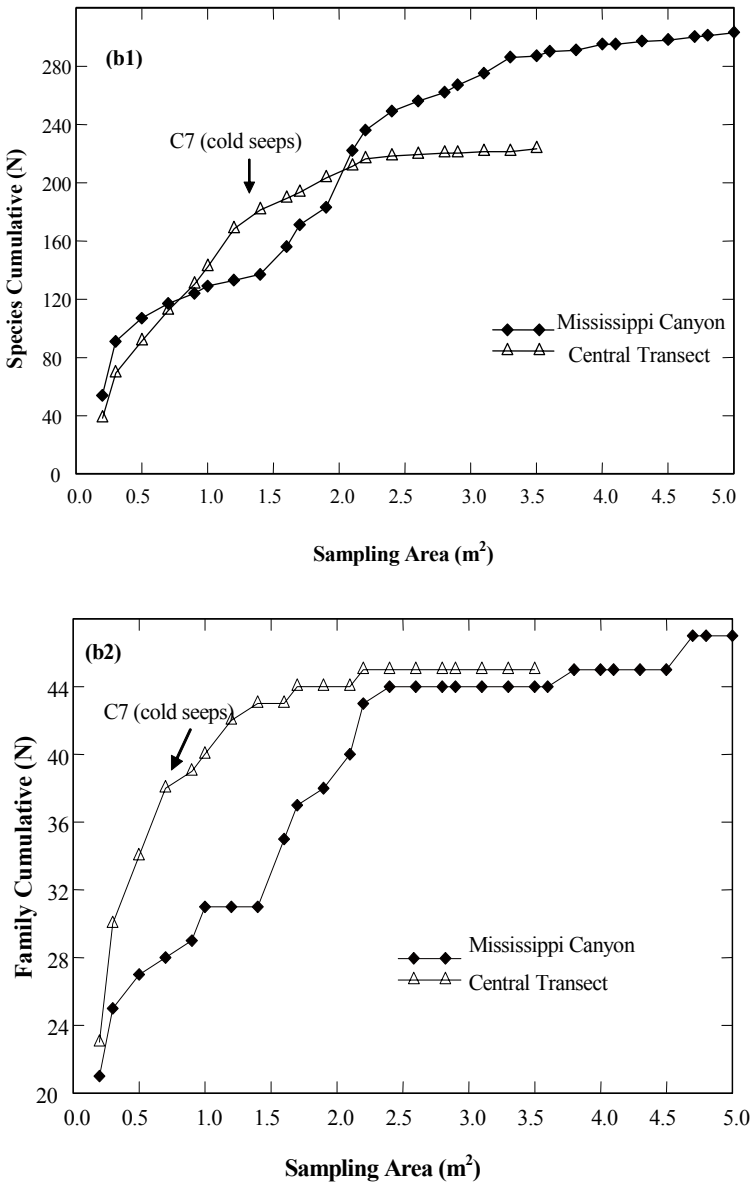


Fig. 12. Rarefaction curves (a) and species cumulative curves (b) for the comparison of biodiversity at different taxonomic levels and between the Mississippi Canyon and the Central Transect.



Species Cumulative Curves

Fig. 12. – Continuted.

4.3.5. Variation in Polychaete Diversity with Depth

Curve Estimation Regression was conducted to find the best-fit model to describe the statistical relationship between polychaete diversity as a function of depth. In order to examine the difference between the Mississippi Canyon and the Central Transect, Curve Estimation Regression was also conducted on diversity data from each transect to see if difference existed.

Variation in Polychaete Diversity with Depth in the Study Area

Curve Estimation Regression Analysis presented three best models: LINEAR, QUADRATIC and CUBIC. The QUADRATIC model, a second-order polynomial, was taken as the best-fit model, since it had higher Adjusted R^2 (r^2) and fewer variables (Fig. 13) compared with other models. Expected Number of Species (or Families) (ES(100) or EF(100)) was the best indicator that could be used to evaluate the relationship between depth and diversity, since it had the highest Adjusted R^2. The relationship of ES(100) to depth was as $Y = 23.9 + 0.02X - (6.7E\text{-}06)X^2$ ($r^2 = 0.51$, d.f. = 46, $F = 25.47$, $p < 0.05$) (Fig. 13 (a)). The relationship of EF(100) to depth was $Y = 9.4 + 0.02X - (5.0E\text{-}06)X^2$ ($r^2 = 0.55$, d.f. = 46, $F = 30.00$, $p < 0.05$) (Fig. 13 (d)). Herein, Y refers to polychaete diversity, and X refers to depth (m).

Shannon-Wiener (H′) also had a high Adjusted R^2 ($r^2 = 0.47$, d.f. = 46, $F = 22.34$, $p < 0.05$) (Fig. 13 (b)). Evenness (J′) Adjusted R^2 was much lower ($r^2 = 0.30$, d.f. = 46, $F = 11.13$, $p < 0.05$) (Fig. 13 (c)). Regression of Simpson (D) on depth was not significant ($p > 0.05$).

The polychaete species diversity seemed to exhibit a unimodal pattern with depth: the highest value was expected at intermediate depth (about 1269 m), and lower diversity was found at both shallower and deeper depths (Fig. 13). Theoretically, the maximum ES(100) occurred at 1269 m (ES(100) = 35.1), and the minimum ES(100) was at 3400 m (ES(100) = 4.9) (Fig. 13 (a)). The maximum H′ occurred at 1269 m (H′ = 3.3) and the minimum H′ was at 3400m (H′ = 1.88) (Fig. 13 (b)). Therefore, ES(100) and H′ displayed similar trends. Evenness (J′) was different. The minimum of Evenness (J′) occurred at 300 m (J′ = 0.78) and the maximum was at 2043 m (J′ = 0.91) (Fig. 13 (c)). Not unexpectedly, families varied in a similar fashion: EF(100) was highest at 1527 m (EF(100) = 20.9), while the minimum EF(100) occurred at 3400 m (EF(100) = 3.4).

Observed data however indicated that ES(100) and H′ were highest at MT3 (983 m), and lowest at MT6 (about 2743 m). Evenness (J′) again was different. MT1 (about 483 m) had the lowest evenness (J′ = 0.71) and the highest values occurred at MT5 (2290 m) (J′ = 0.98). The highest EF(100) was observed at C7 (about 1072 m) (EF(100) = 24.2) and the lowest EF(100) was found at S5 (about 3314 m) (EF(100) = 3.1).

Sampling station S5 was the deepest station in the study area, but did not have the lowest species diversity. Observed species diversity at S5 was higher than predicted diversity, which is peculiar.

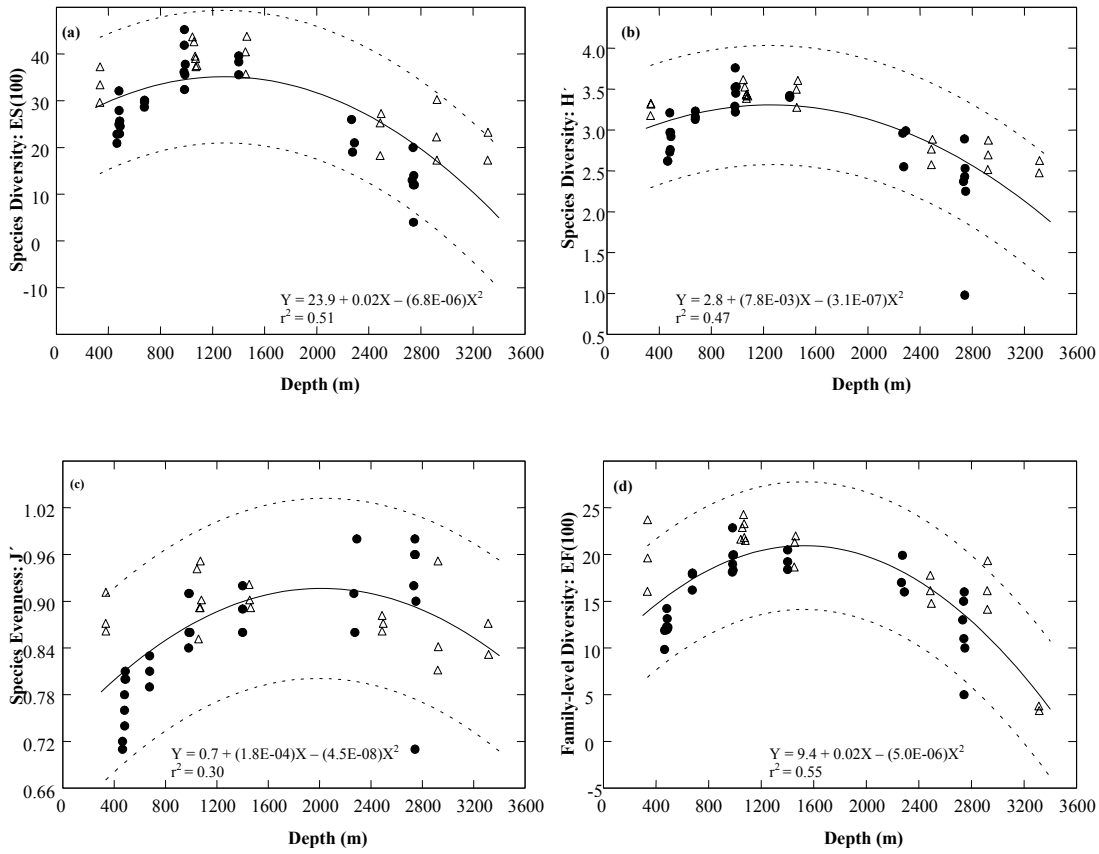


Fig. 13. QUADRATIC model as the best-fit model to describe the statistical relationship between depth and polychaete diversity (a) ES(100), (b) Shannon-Wiener (H´), (c) Evenness (J´) and (d) EF100. Variations in ES(100), Shannon-Wiener (H´) and EF(100) were explained well by the QUADRATIC model. Evenness (J´) was not fit by the QUADRATIC model as well as the other indices, since r^2 was only 0.30. They all exhibited a unimodal pattern with depth. Regression of Simpson (D) on depth was not significant ($p > 0.05$). Dashed lines represent the 95% confidence level, and solid lines represent predicted diversity. Circles represent observed diversity data from the Mississippi Canyon and triangles were observed data from the Central Transect.

Comparison between the Mississippi Canyon and the Central Transect

Comparison of diversity as a function of depth was made between the Mississippi Canyon and the Central Transect (Fig. 14). The species diversity was represented by ES(100), Shannon-Wiener (H′), Simpson (D) and Evenness (J′). Regressions were all fit by the QUADRATIC model. ES(100) and H′ were fit well by the QUADRATIC model with higher Adjusted R^2 (Fig. 14 (a) and (b)). Linear or non-linear regressions of Simpson (D) and Evenness (J′) on depth were not significant at least on one transect. For example, regression of Simpson (D) was not significant in the Mississippi Canyon, and regression of Evenness (J′) was not significant in the Central Transect. Thus, depth was not an important factor to Simpson (D) and Evenness (J′).

ES(100) and H′ followed a similar trend: species diversity was highest at intermediate depth on both transects. The species-level diversity was higher in the Central Transect than in the Mississippi Canyon at shallow and deep depths, while the species-level diversity at intermediate depth in the Central Transect was similar to that in the Mississippi Canyon.

The QUADRATIC model of EF(100) was presented as a comparison with the species-level diversity (Fig. 14 (e)). Again, EF(100) and ES(100) revealed a similar unimodal relationship with depth on both transects.

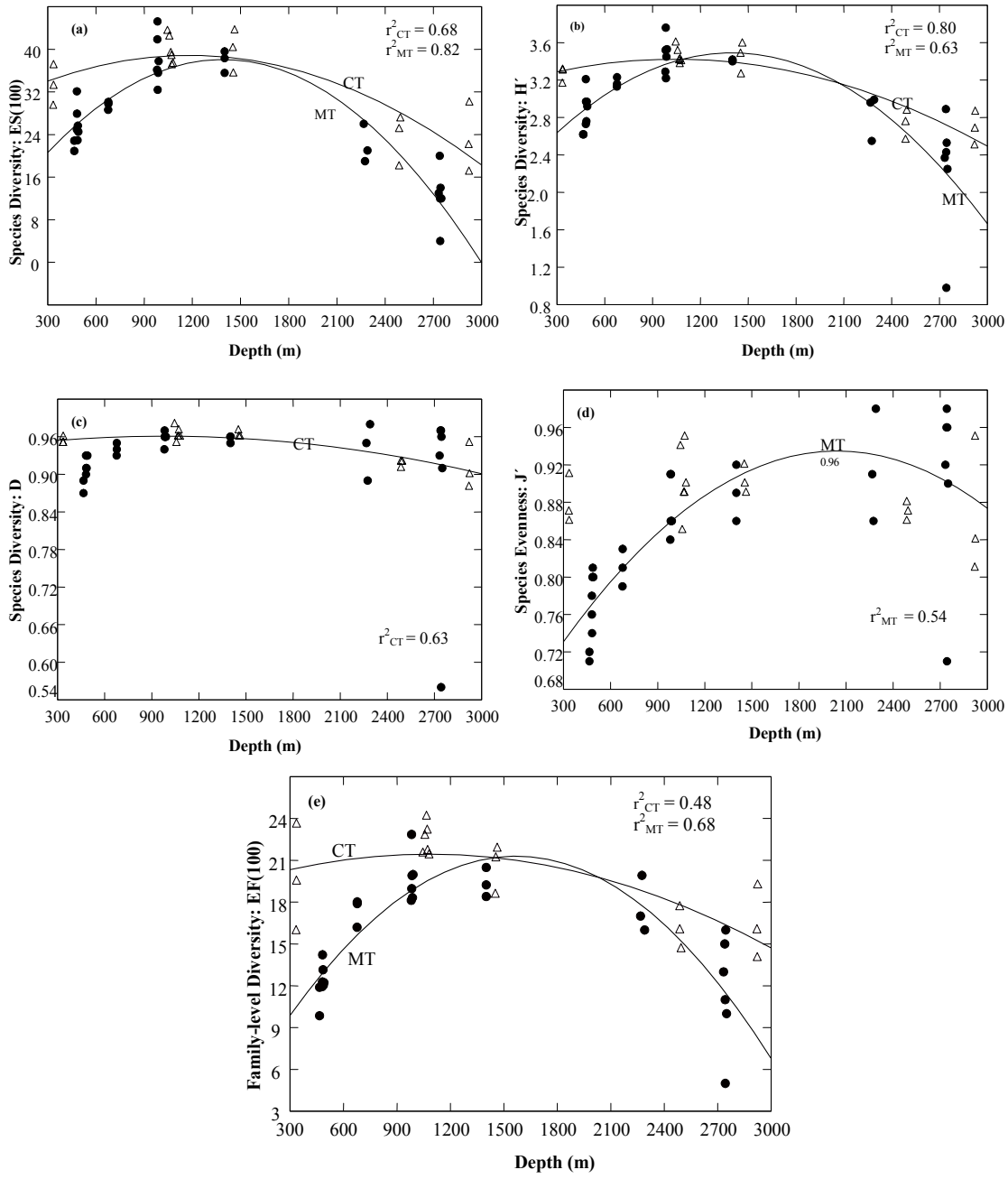


Fig 14. Comparison of the relationship of polychaete diversity to depth between the Mississippi Canyon and the Central Transect, (a) ES(100), (b) H′, (c)D, (d) J′ and (e) EF(100). They were all fit by QUADRATIC model ($p < 0.05$). Regressions of D and J′ on depth were not significant at least on one transect. ES(100), H′ and EF(100) showed the similar trends that the polychaete diversity had the highest diversity at intermediate depth on either transect, and diversity was higher in the Central Transect than in the Mississippi Canyon at shallow and deep depths.

4.3.6. Variation in Polychaete Diversity with Food Availability

Regressions of polychaete diversity on CHL concentration in near surface water, particulate organic matter contents and the C:N ratio in sediments were not significant ($p > 0.05$), which means they did not affect polychaete diversity considerably. Regressions on the polychaete density and meiofaunal biomass (gC/m^2) were both significant ($p < 0.05$). ES(100), H′, D, and EF(100) all exhibited a unimodal pattern with the polychaete density (Fig. 15) and meiofaunal biomass (Fig. 16) obtained at the same set of sampling stations.

After depth effects were removed, regressions of diversity measure residuals on the polychaete density and meiofaunal biomass (gC/m^2) residuals were no longer significant ($p > 0.05$). On the other hand, regressions of ES(100) and EF(100) residuals on the C:N ratio became significant (Fig.17). Thus, the C:N ratio might have some influences on polychaete diversity ES(100) and EF(100), but the influences were confounded by depth effects. The species-level diversity (ES(100)) and the family-level diversity (EF(100)) also varied unimodally with food availability.

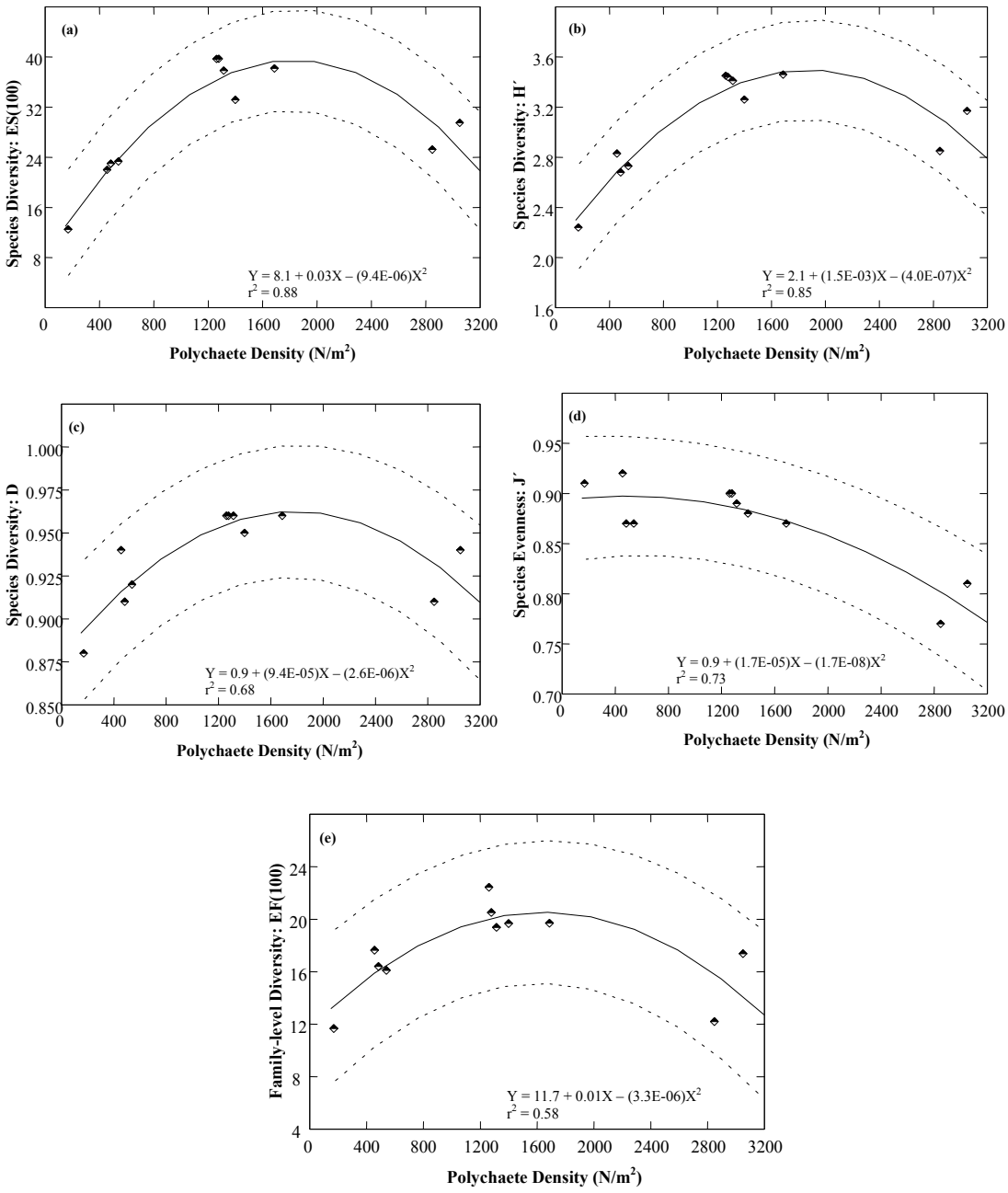


Fig 15. Statistical relationship of polychaete diversity to the polychaete density which was used as a proxy of food availability to the ocean floor, (a) ES(100), (b) H′, (c) D, (d) J′ and (e) EF(100). They were best fit by the QUADRATIC model ($p < 0.05$). They all exhibited a unimodal pattern with the polychaete density before depth effects were removed.

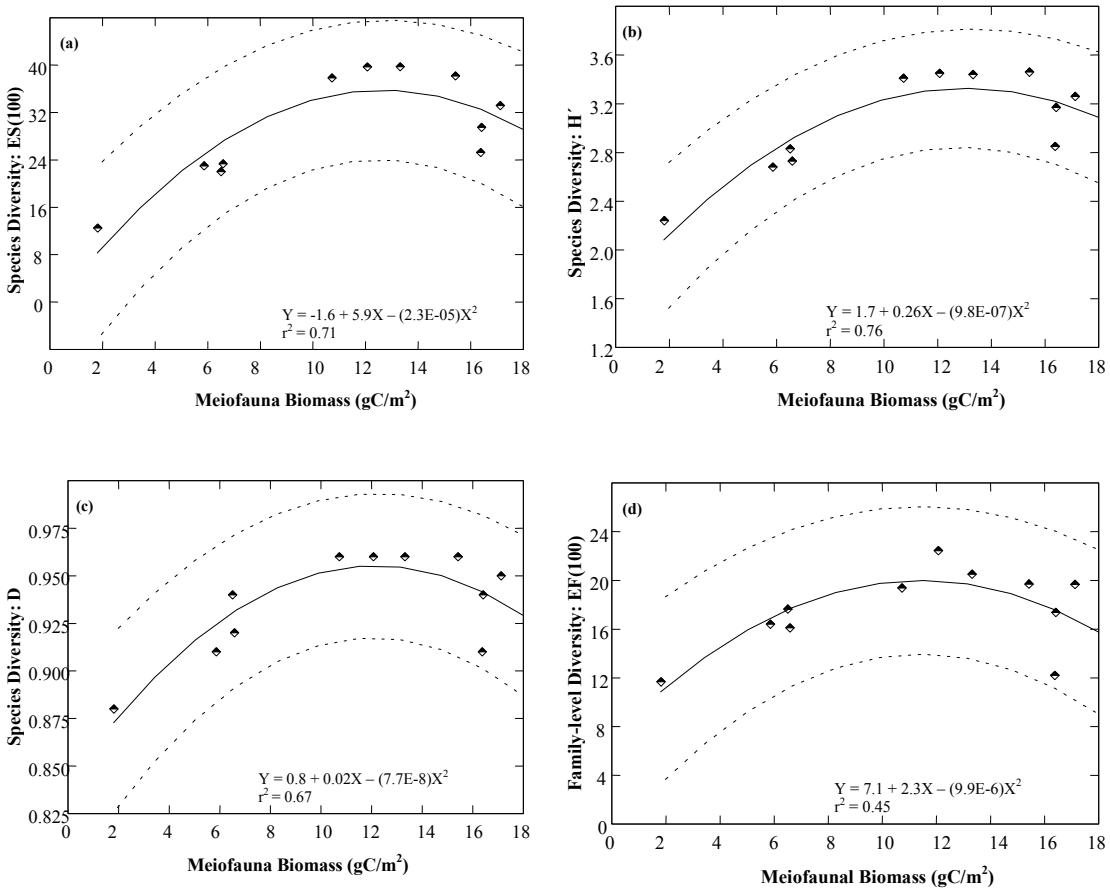


Fig 16. Statistical relationship of polychaete diversity to meiofauna biomass (gC/m^2) which was used as a proxy to potential food source for polychaetes before depth effects were removed, (a) ES(100), (b) H´, (c) D, (d) EF(100). They were best fit by the QUADRATIC model ($p < 0.05$). They all exhibited a unimodal pattern with meiofauna biomass (gC/m^2). Regression of Evenness (J´) on meiofauna biomass was not significant ($p > 0.05$).

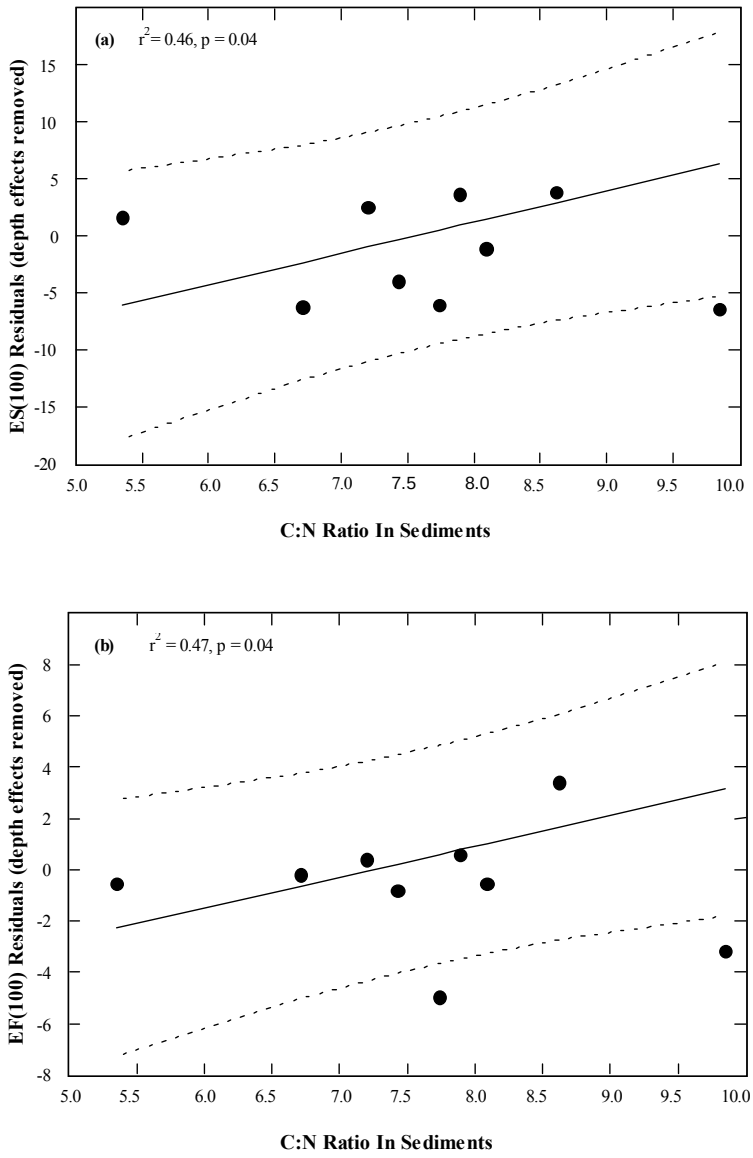


Fig. 17. Relationships of the C:N ratio to polychaete diversity measures residuals (a) ES(100) and (b) EF(100) after depth effects were removed from diversity data as a QUADRATIC model ($p < 0.05$).

4.3.6.1. Variation in Polychaete Diversity with Temperature, Dissolved Oxygen and Sediment Texture

Polychaete diversity indices were not significantly correlated with temperature of bottom water ($p > 0.05$) except for Evenness (J′) ($r^2 = 0.79$, d.f. = 9, $F = 14.84$, $p = 0.00$). Similarly, only Evenness (J′) was linearly correlated with DO concentration in bottom water ($r^2 = 0.45$, d.f. = 9, $F = 8.46$, $p = 0.01$). Salinity and σ_t had no effects on polychaete diversity ($p > 0.05$). Among sediment texture properties, percent sand and percent clay had no correlation with diversity. Regression of ES(100) on percent silt was significant, which could be described as $Y = 7.3 + 0.65X$ ($r^2 = 0.37$, d.f. = 9, $F = 6.78$, $p = 0.02$) (Fig. 18). Other diversity and evenness indices had no relationship with percent silt ($p > 0.05$). Herein, Y was polychaete diversity; X was temperature, DO concentration and percent silt respectively.

After removal of depth effects, regressions of diversity residuals on temperature, DO residuals were no longer significant ($p > 0.05$). Only ES(100) residuals had a significant linear correlation with percent silt ($r^2 = 0.38$, d.f. = 9, $F = 5.49$, $p = 0.04$). Thus, hydrographic features had no significant effects on polychaete diversity. Percent silt was the only significant factor related to diversity ES(100) among sediment texture properties.

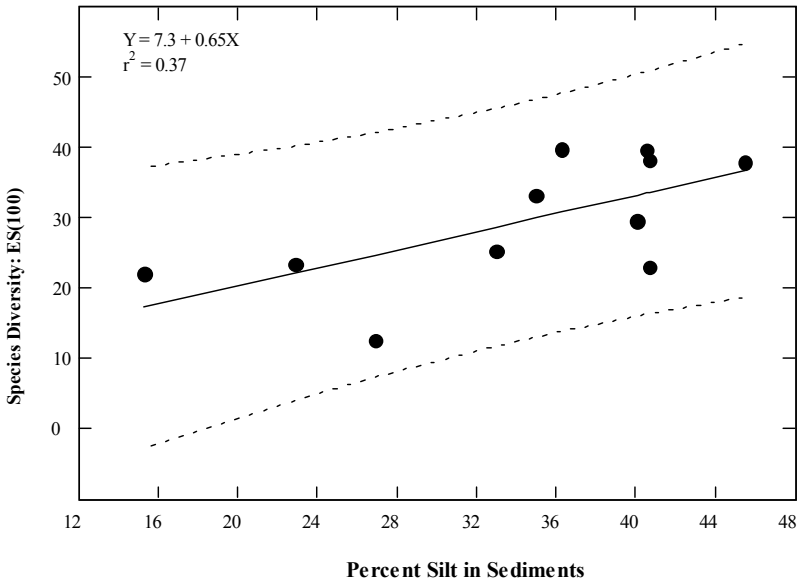


Fig. 18. Relationship of polychaete diversity ES(100) to percent silt in sediments. Circles represent observed diversity data. Solid lines represent predicated values.

4.3.7. Variation in Polychaete Diversity with Sediment Contamination

Trace metals, such as Al, Co, Cu, Hg, Mg, and Sb, and PAHs (TRAHWP and PHENAN), were not significantly correlated with any of the diversity indices ($p > 0.05$). Different trace metals and PAHs had different correlations with the polychaete diversity (Table 13). After removal of depth effects, only regression of ES(100) on Log S, regressions of EF(100) on Log As and Log Sr were significant ($p < 0.05$) (Fig. 19). Depth effects were removed from trace metal data as a negative linear function. The results indicated effects of most trace metals and PAHs depended on depth effects.

Table. 13. Regressions of polychaete diversity on trace metals and PAHs in sediments. Only significant regressions are shown ($p < 0.05$). Linear refers to linear regression. (+/-) refers to positive/negative regression. QUA refers QUADRATIC model.

		Ag	As	Cd	Mn	P	Pb	S	Sr	TI	Zn	NAPH	DIBEN	FLUORAN
ES(100)	Model	-	-	Linear (+)	-	Linear (+)	QUA	Linear (+)	-	Linear (+)	-	Linear (+)		-
	r^2	-	-	0.63	-	0.36	0.53	0.44	-	0.62	-	0.33		-
	d.f.	-	-	9	-	9	8	9	-	9	-	9		-
	F	-	-	18.13	-	6.70	6.64	8.83	-	16.79	-	5.85		-
	p	-	-	0.00	-	0.02	0.02	0.01	-	0.00	-	0.03		-
H′	Model	-	-	Linear (+)	-	Linear (+)	QUA		-	Linear (+)	-	Linear (+)		-
	r^2	-	-	0.63	-	0.36	0.43	0.43	-	0.47	-	0.36		-
	d.f.	-	-	9	-	9	8	9	-	9	-	9		-
	F	-	-	18.57	-	6.51	4.79	8.41	-	9.99	-	0.58		-
	p	-	-	0.00	-	0.03	0.04	0.01	-	0.01	-	0.03		-
D	Model	Linear (+)	-	Linear (+)	-	-	-	-	-	-	-	-	QUA	-
	r^2	0.32	-	0.64	-	-	-	-	-	-	-	-	0.49	-
	d.f.	9	-	9	-	-	-	-	-	-	-	-	8	-
	F	5.64	-	19.44	-	-	-	-	-	-	-	-	5.73	-
	p	0.04	-	0.00	-	-	-	-	-	-	-	-	0.02	-
J′	Model	Linear (+)	QUA	-	Linear (-)	-	Linear (-)	-	QUA	-	QUA	-	-	-
	r^2	0.33	0.72	-	0.387	-	0.36	-	0.77	-	0.52	-	-	-
	d.f.	9	8	-	9	-	9	-	8	-	8	-	-	-
	F	5.94	14.13	-	7.324	-	6.57	-	18.03	-	6.38	-	-	-
	p	0.03	0.00	-	0.024	-	0.03	-	0.00	-	0.02	-	-	-
EF(100)	Model	-	-	Linear (+)	-	-	-	-	-	Linear (+)	-	-	QUA	QUA
	r^2	-	-	0.71	-	-	-	-	-	0.33	-	-	0.59	0.56
	d.f.	-	-	9	-	-	-	-	-	9	-	-	8	8
	F	-	-	24.91	-	-	-	-	-	5.84	-	-	9.28	7.39
	p	-	-	0.00	-	-	-	-	-	0.03	-	-	0.01	0.01

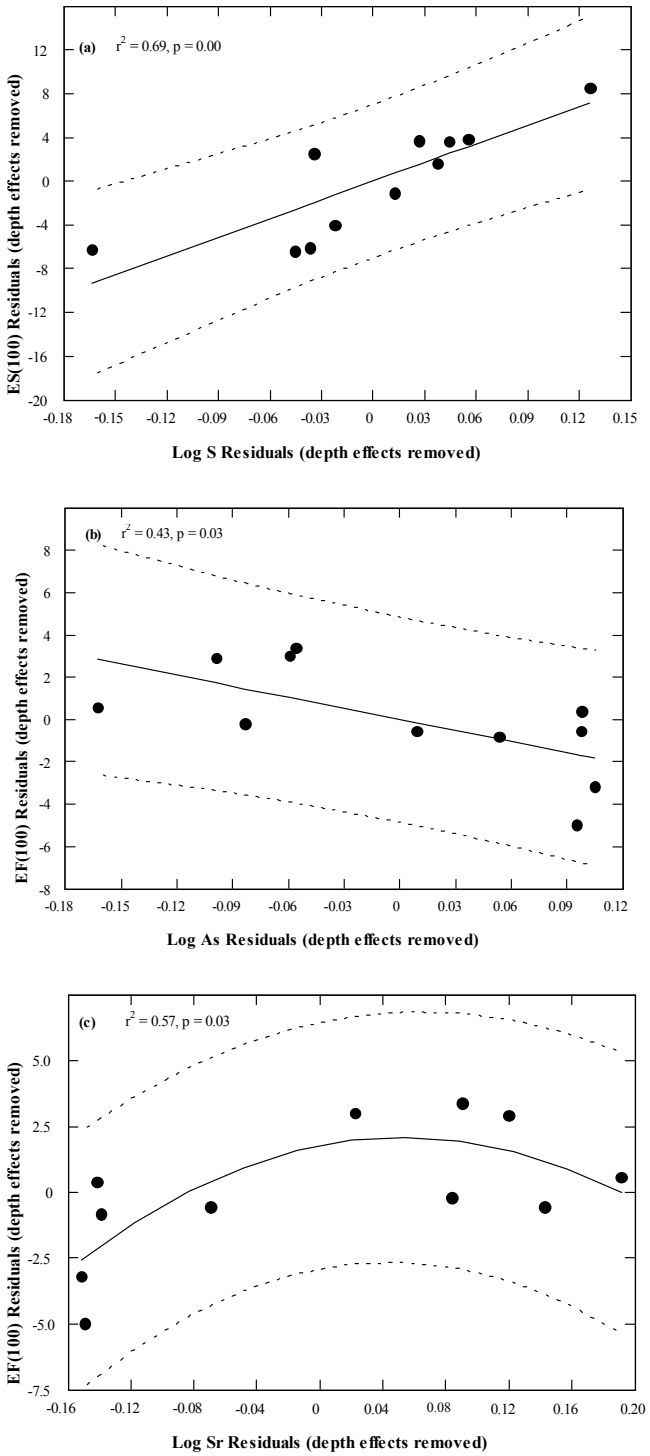


Fig. 19. Relationships of polychaete diversity measure residuals to trace metal residuals after depth effects were removed. Only significant regressions are shown ($p < 0.05$). (a) ES(100) vs. Log S, (b) EF(100) vs. Log As, and (c) EF(100) vs. Log Sr.

4.3.8. Multivariate Analysis of Effects of Environmental Factors on Diversity

BIO-ENV/BVSTEP procedures were conducted to determine the best subsets of environmental variables whose pattern could "best" match that of the polychaete diversity data, i.e., explain the most variations in similarity or dissimilarity between stations with respect to polychaete diversity.

The results indicated that depth, transect, percent silt, meiofaunal biomass (g C) and CHL concentration were the best subset of the environmental variables that could explain most variation in the polychaete diversity pattern (all the diversity indices considered) in the study area, and Spearman rank correlation coefficient ρ equals 0.64 ($p < 0.05$).

If only ES(100) is considered, then depth, transect, and meiofaunal biomass (gC/m^2) were the best subset of variables ($\rho = 0.53$, $p < 0.001$). If only H′ is considered, then depth, transect and meiofauna biomass (gC/m^2) can explain 56% of the variation ($\rho = 0.56$, $p < 0.001$). For Simpson index D, depth, transect, meiofaunal biomass (gC/m^2) and CHL concentration could explain 45% of the variation ($\rho = 0.45$, $p < 0.001$). For Evenness J′, depth and CHL concentration are the best ($\rho = 0.59$, $p < 0.001$). For EF(100), depth, transect and CHL concentration are the best ($\rho = 0.39$, $p < 0.001$).

As a result, different indices exhibited similar relationships to environmental factors. Results indicate that depth, transect, meiofaunal biomass (gC/m^2) and CHL concentration in near surface water can explain most variations in polychaete diversity between sampling stations. MDS plots were made for the 11 sampling sites in the Mississippi Canyon and the Central Transect, except for S5 (Fig. 20). Site S5 was not

included due to too many missing measurements. The MDS plots were based on the all the polychaete diversity indices combined. Stress was less than 0.01, which means the two-dimensional MDS plot gives excellent representation of the high-dimensional relationship between stations with no real prospect of misinterpretation (Clarke and Gorley, 2002). As shown in Fig. 20, the polychaete diversity was pretty close between sampling stations MT4 and C4, C12 and C14. Stations MT3, MT4, C4 and C7 (at intermediate depth) had higher diversity than other stations.

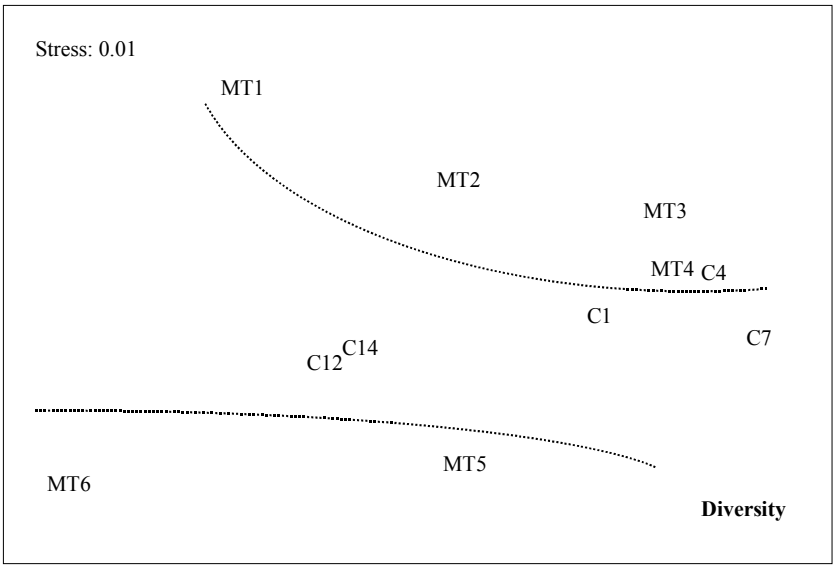


Fig. 20. MDS plots of the 11 sampling station in the Mississippi Canyon and the Central Transect, which are based on polychaete diversity (all the diversity indices considered).

4.4. Polychaete Feeding Guilds

4.4.1. General Information about Polychaete Feeding Guilds

Six feeding guilds were found in the study area, and they were carnivores (C) (12 families), omnivores (O) (6 families), scavengers (S) (1 family), selective deposit feeders (SDF) (14 families), non-selective deposit feeders (NSDF) (9 families) and suspension filter feeders (SF) (4 families) (Table 14).

Several families had the same feeding guilds. Percentage distributions of the six feeding guilds in the study area are shown in Fig. 21. Herbivorous feeders were not distinguished. Scavengers were rare on the both transects. They all belonged to Family Onuphidae (Table 14), which primarily feed on detritus. In the Mississippi Canyon, only 32 individuals were scavenging feeders, contributing less than 0.3% of the population. Similarly, in the Central Transect, scavengers were no more than 1% of the population. Suspension filter feeders (SF) were very rare too. Most of them belonged to families Oweniidae and Sabellidae.

The most abundant feeding guild was non-selective deposit feeding (NSDF), which contributed 42% and 44% of the population on the Mississippi Canyon and the Central Transect respectively (Fig. 21). NSDF feeders are mostly burrowers and tube dwellers (Ruppert and Barnes, 1994). They can consume sand or mud directly and digest the adsorbed organic material. In the study area, most NSDF feeders belonged to families Paraonidae, Maldanidae, Capitellidae and Opheliidae (Table 14).

Table 14. Comparison of faunal composition and feeding guilds in the benthic polychaete assemblages between the Mississippi Canyon and the Central Transect.

Family	Abundance		Feeding Guild
	Mississippi Canyon	Central Transect	
Aberrantidae	2	2	SDF
Acrocirridae	26	22	Selective Deposit Feeding (SDF)
Ampharetidae	258	30	SDF
Amphinomidae	43	54	Carnivorous (C)/SDF
Aphroditidae	0	1	C
Arabellidae	1	0	C
Capitellidae	230	97	Non-Selective Deposit Feeding (NSDF)
Chaetopteridae	1	7	SDF
Chrysopetalidae	2	14	C
Cirratulidae	251	114	SDF
Cossuridae	247	24	NSDF
Dorvilleidae	99	28	C
Eunicidae	11	22	Omnivorous (O)
Family B	1	0	Not available in literature
Fauveliopsidae	52	59	NSDF
Flabelligeridae	27	37	NSDF
Glyceridae	123	79	C
Goniadidae	10	14	C
Hesionidae	15	33	C
Iospilidae	0	2	C
Longosomatidae	82	6	SDF
Lumbrineridae	161	52	C
Magelonidae	0	5	SDF
Maldanidae	514	331	NSDF
Nephtyidae	451	59	O
Nereididae	35	29	O
Onuphidae	32	42	Scavenging (S)
Opheliidae	203	143	NSDF
Orbiniidae	46	50	NSDF
Oweniidae	38	27	Suspension Filter Feeding (SF)
Paralacydoniidae	57	14	O
Paraonidae	2112	709	NSDF
Pectinariidae	3	3	SDF
Phyllodocidae	37	31	C
Pilargidae	107	96	O
Poecilochaetidae	1	6	SDF
Polynoidae	2	3	C
Sabellariidae	3	1	SF
Sabellidae	27	32	SF
Scalibregmatidae	7	3	SDF
Sigalionidae	78	40	C
Sphaerodoridae	12	19	NSDF
Spionidae	2426	586	SDF
Spirorbidae	4	0	SF
Syllidae	330	394	O
Terebellidae	37	29	SDF
Trichobranchidae	132	29	SDF
Trochochaetidae	1	0	SDF
Typhloscolecidae*	3	0	C

Note: References for feeding guilds: Fauchald, 1979; Ruppert and Barnes, 1994. Hubbard, 2002. Rouse and Pleijel, 2001. Typhloscolecidae* is considered as a planktonic species.

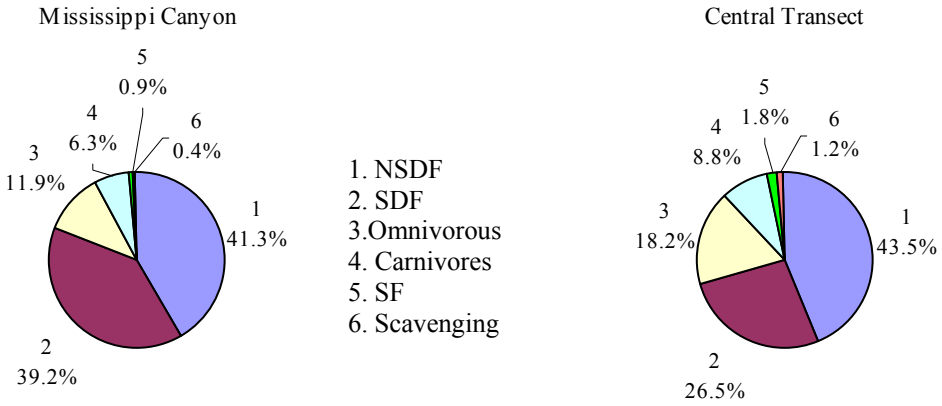


Fig. 21. Percentage distribution of polychaete feeding guilds in the Mississippi Canyon and the Central Transect. The two most abundant feeding guilds on both transects are non-selective deposit feeding (NSDF) and selective deposit feeding (SDF), followed by Omnivores (O), Carnivores (C), Suspension filter feeding (SF) and Scavenging (S) on order of relative abundance.

The Paraonidae are surface-deposit feeding, motile and non-jawed worms (Fauchald and Jumars, 1979). The Maldanidae are tube dwellers. The Capitellidae and the Opheliidae are less stationary, ingesting sediments through which they burrow. Although they are all NSDF feeders, the feeding guilds are still different. Probably that is why they could co-exist in the same community under potential competition pressure.

Selective deposit feeding (SDF) was the next most abundant feeding guild in the study area, representing 39% and 26% population on each transect respectively. They only take the organic material from the surface of sediment particles without ingesting sand or mud (Fauchald and Jumars, 1979). Most SDF feeders in the study area belonged to families Spiondae, Cirratulidae, Trichochaetidae, and Ampharetidae.

We can see that the numbers of the Paraonidae (NSDF) and the Spionidae (SDF) were very close (Table 14). Both of them were very abundant. The reason could be that the Paraonidae are NSDF feeders, while the Spionidae are SDF feeders. Therefore, the two families could share the same habitats without strong interspecies competition, i.e., participate different resources in the same environment.

4.4.2. Variation in Feeding Guilds with Sampling Year and Transect

ANOSIM analysis (in PRIMER) was conducted to test the null hypotheses that polychaete feeding guilds did not vary with transect or sampling year. The results indicated that feeding guilds were not significantly different between the Mississippi Canyon and the Central Transect, or between year 2000 and year 2001 (Table 15), since all the R values in Table 15 were close to zero, and all the p values were greater than 0.05 except for variation of selective-deposit feeders with transect ($p = 0.03$). The R value gives an absolute measure of how separated the two years or two transects were on a scale of 0 (indistinguishable) to 1 (maximal separation), and the R value is more important than the p value in the ANOSOIM analysis (Clarke and Gorley, 2001).

Table 15. Variation in most abundant feeding guilds with sampling year and transect.

	Sampling Year		Transect	
	R	Sig.	R	Sig.
Non-selective deposit feeders	0.06	0.19	0.03	0.21
Selective-deposit feeders	0.01	0.38	0.08	0.03
Omnivores	0.05	0.19	0.04	0.12
Carnivores	0.07	0.23	0.00	0.45

Note: Suspension filter feeders and scavengers were not analyzed because they were rare.

4.4.3. Variation in Polychaete Feeding Guilds with Depth

The variation of feeding guilds with depth along two transects was plotted in Fig. 22. In the Mississippi Canyon at about 482 m (MT1) the dominant feeding type was selective deposit feeding (SDF), contributing 43% of the polychaete population. As depth increased, the dominant feeding type changed to non-selective deposit feeding (NSDF), which contributed 53% at MT2 (about 677 m), 53% at MT3 (about 983 m), 48% at MT4 (1401 m) and 53% at MT6 (2746 m) except for MT5 (about 2277 m) where the dominant feeding type was Omnivore (41%). Scavenging (S) and suspension filter feeding (SF) were the least abundant feeding types in the Mississippi Canyon. No scavengers were found in the head of the Canyon stations MT1, MT2 and MT3. No suspension Filter feeding was found in MT3. The percentage of polychaete carnivores increased slightly with depth, and thus MT6 (about 2746 m) showed the highest percentage of carnivores (12%).

In the Central Transect, the dominant feeding type was non-selective deposit feeding (NSDF) at all depths. The percentage of NSDF was higher at deeper depth than shallower depth. For example, the percentage of NSDF was 47% at C1 (about 335 m), 40% at C7 (about 1072 m), 57% at C12 (2922 m) and 55% at S5 (3314 m). Similarly to the Mississippi Canyon, scavenger and suspension filter feeding were the least abundant feeding types in the Central Transect. No scavenger feeding was found at C14 (about 2490 m) and S5 (3314 m). Suspension filter feeding was only found at C7 and C4 at the very low percentages of 2% and 3%, respectively. Carnivores varied slightly with depth, the lowest percentage of carnivores was at C1 (9%), and the highest values were at C7

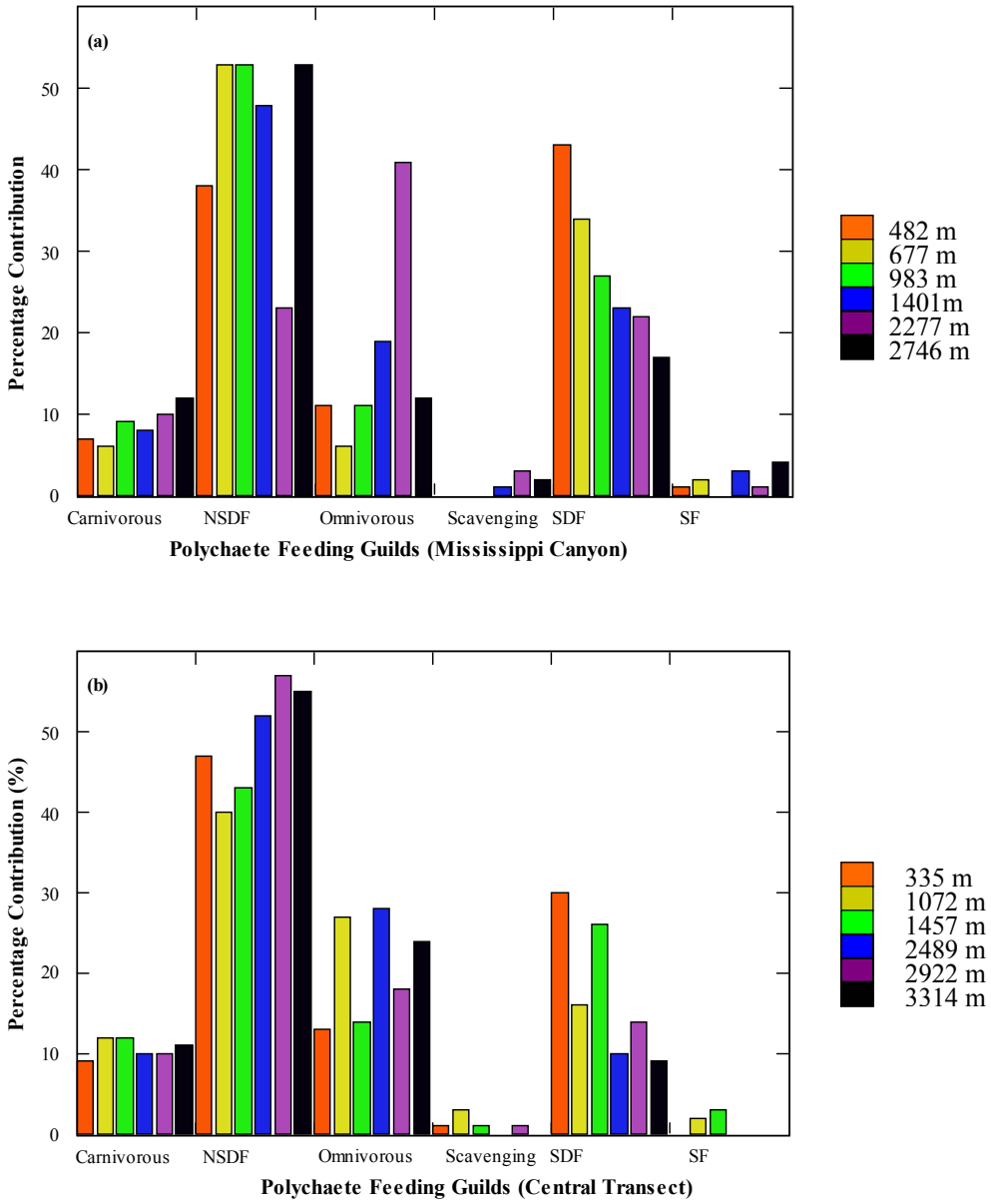


Fig. 22. Percentage distribution of six polychaete feeding guilds along two transects (a) the Mississippi Canyon and (b) the Central Transect. The orange color represents the shallowest depth on each transect. The black color represents the deepest depth on each transect.

(12%) and C4 (12%).

Further analysis using ANOSIM indicated that although distribution of the most abundant polychaete feeding guilds might not be significantly different between adjacent depths ($p > 0.05$), differences did exist among three groups of stations based on depth ($p < 0.05$) (Table 16): shallow (300 – 800 m), intermediate (800 – 1500 m) and deep (> 1500 m). For example, distribution of non-selective deposit feeders was significantly different between DEEP and SHALLOW ($R = 0.80$, $p = 0.00$), between SHALLOW and INTERMEDIATE ($R = 0.40$, $p = 0.00$), and between DEEP and INTERMEDIATE ($R = 0.39$, $p = 0.00$).

Table 16. Variation in abundant polychaete feeding guilds with three depth ranges, shallow (300 – 800 m), intermediate (800 – 1500 m) and deep (> 1500 m).

	Non-selective deposit feeders		Selective-deposit feeders		Omnivores		Carnivores	
Groups	R	Sig	R	Sig.	R	Sig.	R	Sig.
Deep-Shallow	0.79	0.00	0.51	0.00	0.34	0.00	0.28	0.00
Deep-Intermediate	0.39	0.00	0.40	0.00	0.20	0.00	0.19	0.00
Shallow-Intermediate	0.40	0.00	0.50	0.00	0.85	0.00	0.21	0.00

4.4.3. Variation in Polychaete Feeding Guilds with Sediment Grain Size

Relationships of polychaete feeding guilds to sediment grain size (percentages of sand, silt and clay), and other environmental variables were investigated through

BIOENV/BVSTEP procedures. The results indicated that percent silt and percent clay in sediments had the highest correlation with the pattern in the polychaete feeding guilds ($\rho = 0.23$, $p < 0.001$), if all feeding guilds were considered. Particulate Organic Carbon (POC) could explain 18% of the variation ($\rho = 0.18$, $p < 0.001$). Trace metals Co, Mg, and S (combined) could explain 19% of the variations in the feeding guilds pattern ($\rho = 0.19$, $p < 0.001$). Depth, temperature, DO in bottom water, chlorophyll concentration in near surface water, most trace metals and PAHs had no significant correlations with the pattern within polychaete feeding guilds in the study area ($\rho = 0.00$).

Specifically, percentage distributions of non-selective deposit feeders (NSDF), selective deposit feeders (SDF) and suspension filter feeders (SF) were more likely controlled by sediment grain size. Percent sand and percent silt could explain 40.5% of the variation in their distribution ($\rho = 0.41$, $p < 0.001$), and percent silt and percent clay could explain 40% of the variation in their distribution ($\rho = 0.40$, $p < 0.001$). The distributions of omnivores (O), carnivores (C) and scavengers (S) were more affected by POC content in sediments ($\rho = 0.22$, $p < 0.001$) compared with that of non-selective deposit feeders, selective deposit feeders (SDF) and suspension filter feeders (SF) (ρ with PON = 0.11, ρ with POC = 0.09, $p < 0.001$). No correlation was found between sediment grain size and the percentage distributions of omnivores (O), carnivores (C) and scavengers (S) ($\rho = 0.00$).

The most dominant feeding types and the least abundant feeding types at some stations are illustrated along with their sediment grain size properties, in Fig. 23. Non-selective (NSDF) and selective deposit feeders (SDF) were abundant where grain sizes

were fine, i.e., total percentage of silt and clay was very high (Fig. 23 (a)). In contrast, suspension filter feeding did not occur in sediments with very high percentage of silt and clay. In the study area, total percentage of silt and clay was higher than 90% at most sampling stations, except for MT5 (35.7%) and MT6 (70.35%), thus, non-selective (NSDF) and selective deposit feeders (SDF) were dominant at all depths, while suspension filter feeders were rare. Availability of POC in sediments was important, but not as important as the sediment grain size in terms of determining the distribution of these three feeding guilds. For example, total percentage of percent silt and percent clay at C1 (335 m) was about 95.7 % and no suspension filter feeders were found at C1 (Fig. 23 (b)) although it was in shallow water, availability of POC in sediments was expected to be higher than deeper stations. Actually POC in sediments was about 48.93 μgC/L at C1, which was the highest POC concentration in the study area. Similarly, only 1% of polychaetes were suspension filter feeders at MT1 (482) and MT2 (667 m) where total percentage of percent silt and percent clay was 98.0% and 97.2% respectively, and the concentration of POC in sediments was 19.31 μgC/L and 28.45 μgC/L respectively. Omnivores were dominant at MT5 (2277 m) ((Fig. 23 (c)), where percent sand was the highest (65%) in the study area.

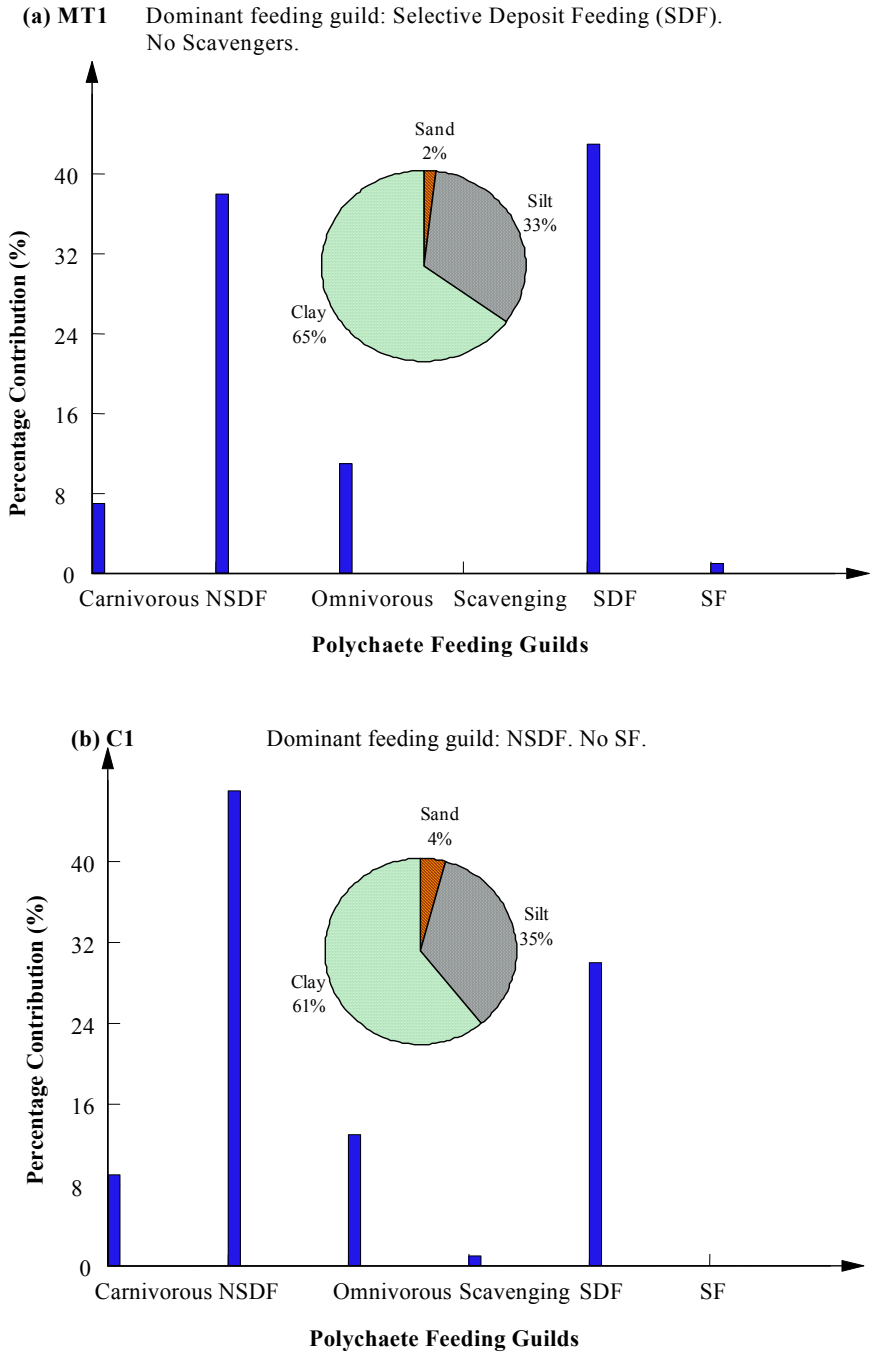


Fig. 23. The dominant feeding guilds and the least abundant feeding guilds at selected stations along with sediment texture properties. Non-selective and selective deposit feeders were abundant where the total percentage of silt and clay were very high. Suspension filter feeding did not occur in sediments with very high percentage of silt and clay (combined). Omnivores were dominant at MT5 where percent sand was the highest (65%) in the study area.

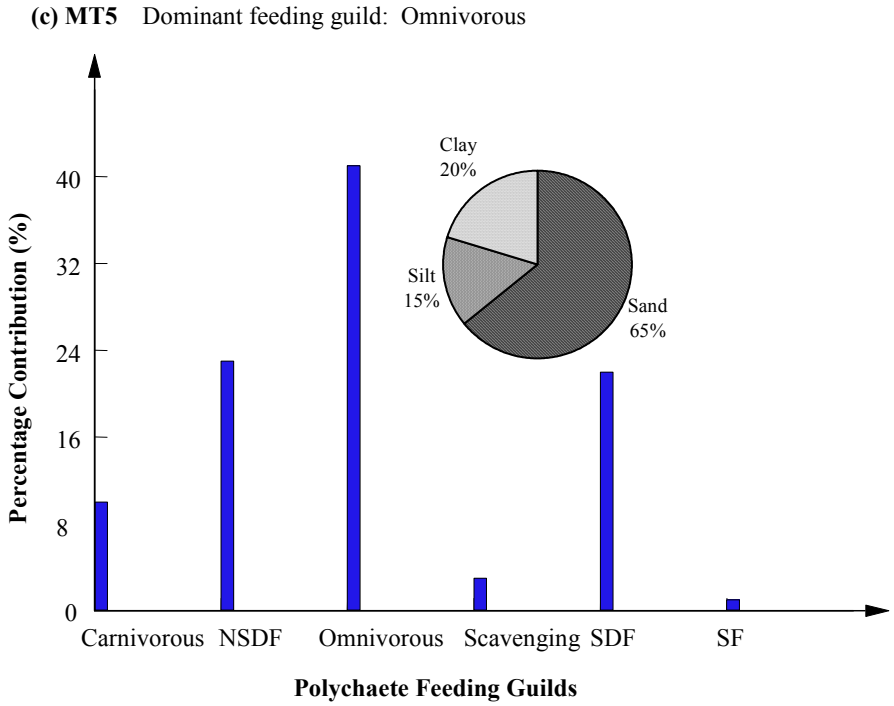


Fig. 23. – Continuted.

4.5. Polychaete Faunal Composition

4.5.1. General Information about Polychaete Faunal Composition

In this study, 11,720 polychaete specimens were identified and belonged to 51 families, 199 genera and 371 species. 301 species were found in the Mississippi Canyon and 223 species were found in the Central Transect. Among these species, 66 species were only found in the Central Transect, and 141 species were only found in the

Mississippi Canyon. Thus, the Mississippi Canyon had higher species richness than the Central Transect.

Family Level

Approximately 50% of individuals identified belonged to families Spionidae and Paraonidae, the two most abundant families in the study area (Fig. 24). Six families Spionidae, Paraonidae, Maldanidae, Syllidae, Nephtyidae and Cirratulidae contributed about 70% of the population. The other 45 families contributed a much smaller proportion (only 30%) of the fauna. Many specimens collected were in poor physical condition, and thus not identifiable.

The Spionidae, Paraonidae, Maldanidae, and Syllidae were among the five most abundant families on both transects (Fig. 24, Table 17). In the Mississippi Canyon, the most abundant family was the Spionidae. In the Central Transect, the most abundant family was the Paraonidae. The Arabellidae, the Family B, the Spirorbidae and the Trochochaetidae had very low occurrences, and were only found in the Mississippi Canyon. The Aphroditidae, the Iospilidae, and the Magelonidae were only found in the Central Transect. On the other hand, some families the Ampharetidae, the Capitellidae, the Cossuridae, and the Nephtyidae were abundant on one transect, but relatively rare on the other transect.

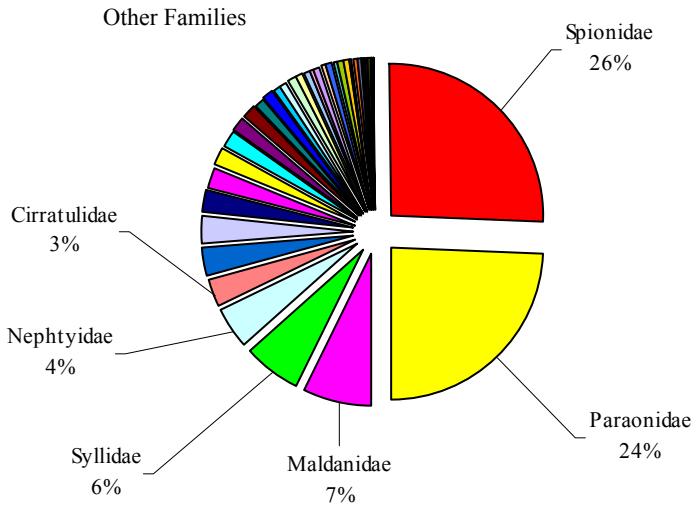


Fig. 24. Percentage distribution of most abundant polychaete families in the Mississippi Canyon and the Central Transect. Spionidae and Paraonidae were the two most abundant families, and they contributed 50% of those that could be identified.

Species Level

The five most abundant species in the Mississippi Canyon had higher numbers of individuals than in the Central Transect (Table 17). About 50.7% of the population was contributed by 17 species belonging to 10 families (Table 18). Twenty-six species contributed more than 1% of the total repetitively. The most abundant species was *Prionospio cirrifera* (Spionidae), which contributed 7% alone (Table 18). On the other hand, 251 species with less than 10 individuals, respectively, contributed only 8% of the total polychaete population.

Table 17. Comparison of the five most abundant polychaete species between the Mississippi Canyon and the Central Transect.

Sampling Transect	Family	Genus & Species	No. of Ind.
Mississippi Canyon	Spionidae	Prionospio cirrifera	515
	Spionidae	*Prionospio ehlersi*	382
	Paraonidae	*Aricidea suecica*	331
	Paraonidae	*Aricidea mirifica*	289
	Nephtyidae	*Aglaophamus verrilli*	282
Central Transect	Paraonidae	*Paraonella monilaris*	185
	Spionidae	*Prionospio cirrifera*	107
	Opheliidae	*Tachytrypane sp.A*	89
	Syllidae	*Exogone sp.A*	82
	Glyceridae	*Glycera sp.*	79

4.5.2. Variation in Faunal Composition with Sampling Year

ANOSIM procedure was conducted to test the null hypothesis that there was no difference in polychaete faunal composition between year 2000 and year 2001. The polychaete data from C7, MT1, MT3, and MT6 were used for the test, since only those stations were sampled in both year 2000 and year 2001. The results indicated that the faunal composition was not significantly different between the two years ($R = 0.05$, $p = 0.18$) based on presence/absence data. Similarly, if abundance was taken into account, the faunal composition was still not significantly different ($R = 0.07$, $p = 0.13$). Hence, the faunal composition was similar between year 2000 and 2001. Station MT1 was sampled in three years: 2000, 2001, and 2002. The results of ANOSIM indicated that there was no significant difference in faunal composition among different years for presence/absence data ($R = 0.17$, $P = 0.13$), and no difference for abundance data ($R = 0.22$, $p = 0.11$).

Table 18. The 26 most abundant polychaete species in the Mississippi Canyon and the Central Transect**.**

ID	Family	Genus & Species	Cumulative Percentage	No. of Ind.
P306	Spionidae	Prionospio cirrifera	7.0%	622
P220	Paraonidae	*Aricidea suecica*	11.6%	405
P310	Spionidae	*Prionospio ehlersi*	16.0%	390
P324	Spionidae	*Spiophanes berkeleyorum*	19.5%	308
P211	Paraonidae	*Aricidea minuta*	22.9%	306
P157	Nephtyidae	*Aglaophamus verrilli*	26.1%	288
P207	Paraonidae	*Aedicira sp.*	29.2%	275
P219	Paraonidae	*Aricidea simplex*	32.2%	271
P236	Paraonidae	*Paraonella monilaris*	35.2%	268
P186	Opheliidae	*Tachytrypane sp.A*	37.9%	242
P072	Cossuridae	*Cossura delta*	40.2%	206
P069	Cirratulidae	*Tharyx marioni*	42.4%	199
P114	Glyceridae	*Glycera sp.*	44.5%	188
P339	Syllidae	*Exogone sp.A*	46.2%	148
P235	Paraonidae	*Levensenia uncinata*	47.8%	144
P153	Maldanidae	*Micromaldane sp.*	49.2%	126
P366	Trichobranchidae	*Terebellides distincta*	50.6%	125
P233	Paraonidae	Levinsenia oligobraniata	51.9%	115
P307	Spionidae	Prionospio cirrobranchiata	53.1%	106
P009	Ampharetidae	Isolda pulchella	54.3%	103
P231	Paraonidae	Levinsenia gracilis	55.5%	103
P104	Fauveliopsidae	Fauveliopsis sp. A	56.6%	96
P068	Cirratulidae	Tharyx annulosus	57.6%	92
P142	Lumbrineridae	Lumbrineris verrilli	58.6%	92
P212	Paraonidae	Aricidea catherinae	59.6%	91
P206	Paraonidae	Aedicira beglicae	60.6%	90

4.5.3. Variation in Faunal Composition with Transect

ANOSIM procedure was conducted to test the null hypothesis that there was no difference in polychaete faunal composition between the Mississippi Canyon and the Central Transect. The results indicated that the faunal composition (presence/absence) was significantly different ($R = 0.33$, $p = 0.00$), and the faunal composition (based on abundance) was significantly different as well ($R = 0.41$, $p = 0.00$). Hence, the faunal composition was statistically different between the Mississippi Canyon and the Central Transect according to statistical analysis.

4.5.4. Variation in Faunal Composition with Depth (Species Zonation)

A zoned distribution of organisms with environmental gradients is commonly observed. The relationship of polychaete species distribution to depth was investigated to see if a certain species occurred only in one band and then was replaced by another species along the depth gradient. Cluster Analysis was employed to see if polychaete species could be grouped by depth. ANOSIM procedure was used to test the null hypothesis: there was no significant difference in polychaete faunal composition among different depths. SIMPER (similarity percentage) procedures (available in PRIMER) were conducted to evaluate the role of individual species in contributing to the average similarity or dissimilarity among depths.

Zoned Distribution of the Most Dominant Species along Depth Gradient

The most dominant species varied along the depth gradient on both transects (Table 19). In the Mississippi Canyon, *Prionospio ehlersi*, *Aglaophamus verrilli*, *Cossura delta* and *Aedicira sp.* were only dominant at shallow depth (300 – 800 m). *Aricidea simplex*, *Tachytrypane sp. A*, *Micromaldane sp.* and *Tharyx marioni* were only dominant at intermediate depth (800 – 1500 m). *Exogone sp. B*, *Exogone atlantica* and *Glycera sp.* were only dominant at the deepest depth (> 1500 m). *Prionospio cirrifera* was dominant at both shallow and intermediate depth. *Paraonella monilaris* was dominant at both intermediate depth and deep depth. In the Central Canyon, *Prionospio cirrifera*, *Tachytrypane sp. A* and *Aricidea simplex* dominated at shallow depth. *Exogone sp. A*, *Aricidea suecica*, *Cirrophorus brebibranchiatus*, *Glycera sp.* and *Aedicira sp.* dominated at intermediate depth. *Sabidius cornatus*, *Synelmis klatti*, *Fauveliopsis sp. A* and *Exogone dispar* dominated deep. *Paraonella monilaris* dominated at both intermediate depth and deep depth. Therefore, the dominant polychaete species showed a zoned distribution between different depths on both transects.

There was little variation in the family-level composition along the depth gradient. The Spionidae and Paraonidae were the most abundant families that dominated at all depths on both transects. The Syllidae and the Maldanidae were less abundant than the Spionidae and the Paraonidae, but they also could dominate at all depths. Thus, there was no obvious family-level zoned distribution in polychaetes in the study area.

Table 19. The 3 most dominant species along depth gradient in the Mississippi Canyon and the Central Transect.

	Depth (m)	First dominant species	Second dominant species	Third dominant species
Central Transect	335	*Prionospio cirrifera*	*Tachytrypane sp. A*	*Aricidea simplex*
	1072	*Exogone sp. A*	*Aricidea suecica*	*Cirrophorus brebibranchiatus*
	1457	*Paraonella monilaris*	*Glycera sp.*	*Aedicira sp.*
	2489	*Paraonella monilaris*	*Sabidius cornatus*	*Synelmis klatti*
	2922	*Paraonella monilaris*	*Fauveliopsis sp. A*	*Exogone dispar*
	3314	*Paraonella monilaris*	*Sabidius cornatus*	*Synelmis klatti*
Mississippi Canyon	482	*Prionospio ehlersi*	*Prionospio cirrifera*	*Aglaophamus verrilli*
	677	*Cossura delta*	*Prionospio cirrifera*	*Aedicira sp.*
	983	*Aricidea simplex*	*Tachytrypane sp. A*	*Prionospio cirrifera*
	1401	*Micromaldane sp.*	*Paraonella monilaris*	*Tharyx marioni*
	2277	*Exogone sp. B*	*Exogone atlantica*	*Glycera sp.*
	2746	*Paraonella monilaris*	*Lumriclymeninae sp.*	*Glycera sp.*

Zoned Distribution of 26 Most Abundant Polychaete Species along Depth Gradient

There were 26 polychaete species that each contributed more than 1% of the total population in the study area (Table 18), and thus, they were considered abundant species. Cluster analysis was employed on those abundant species based on Bray-Curtis similarities to see if those species could be grouped by depth. Most abundant species were found mainly at shallow or intermediate depth (300 – 1500 m) (Fig. 25). Only one species, *Paraonella monilaris* (Paraonidae), was abundant at both intermediate and deep depths (1457 – 2922 m). The dendrogram can be divided into two clusters of species defined at an arbitrary similarity level of 28%. The first group mainly included species that were abundant both at shallow and intermediate depth (300 – 1500 m), such as

Glycera sp. (Glyceridae), and species that were only abundant in the intermediate range (800 – 1500 m), such as *Exogone sp. A* (Syllidae) and *Tharyx annulosus* (Cirratulidae). The second group mainly included species that were only abundant in the shallow interval (300 - 800 m), such as *Prionospio ehlersi* (Spionidae) and *Aglaophamus verrilli* (Nephtytidae). Both were only abundant at station MT1 (482 m). The exceptions were *Aricidea suecica* (Paraonidae) and *Spiophanes berkeleyorum* (Spionidae), which were abundant at both the shallow and intermediate zones.

The dendrogram indicated that most abundant species occurred at shallow and intermediate depth (300 – 1500 m), which could be due to more POC flux to the ocean floor. These abundant species had their own optimum depth. Some of them preferred to exist only at shallow depth, some of them preferred to live at intermediate depth, and some of them could be abundant at both shallow and intermediate depth.

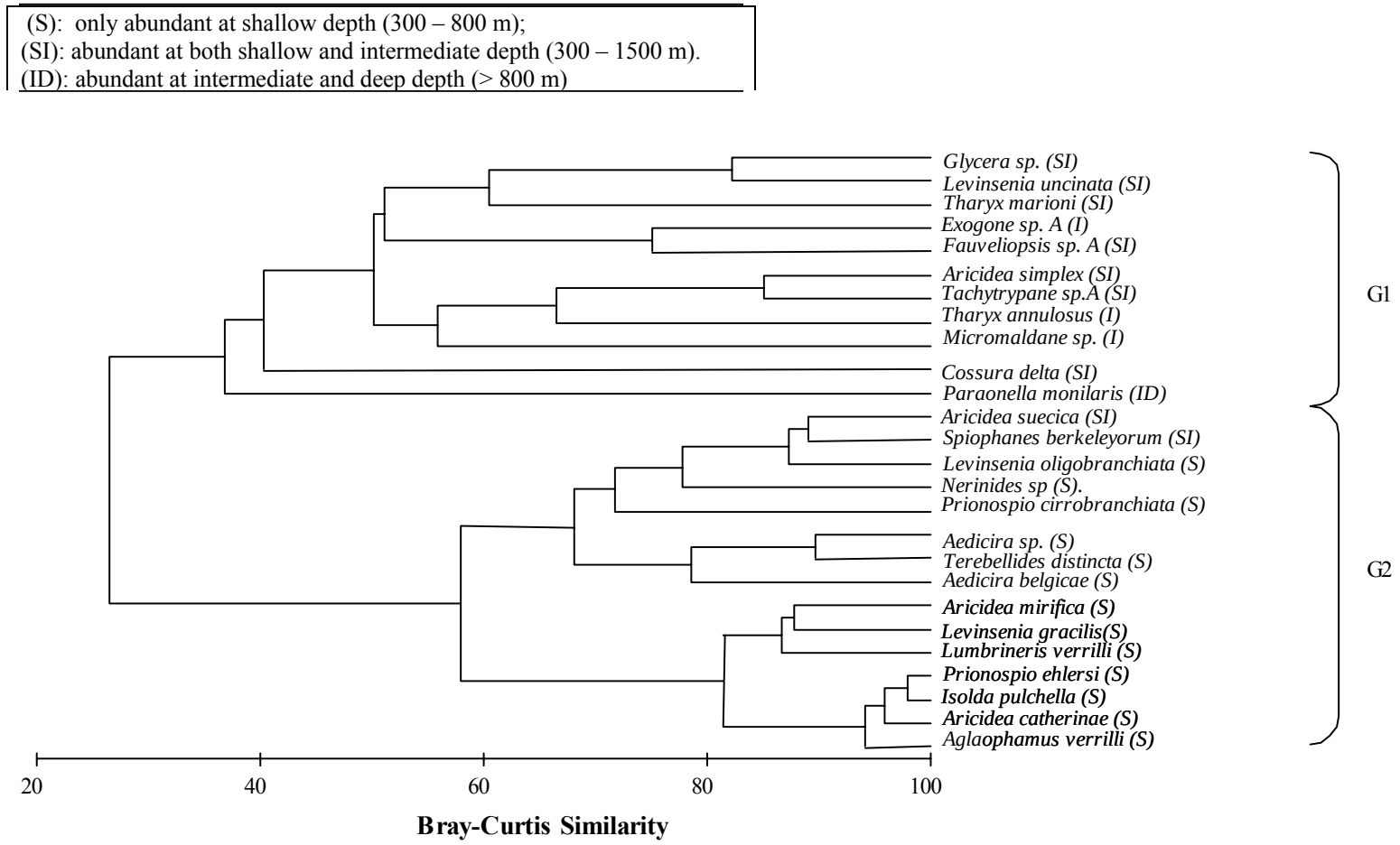


Fig. 25. Bray-Curtis similarities among the most abundant polychaete species based on their occurrence and abundance. Most of these species were abundant at shallow or intermediate depth (300 – 1500 m). Two main groups were defined at an arbitrary similarity level of 28%. The first group mainly included species that were abundant both at shallow and intermediate depth (300 – 1500 m). The second group mainly included species that were only abundant at shallow depth (300 -800 m).

Zoned Faunal Assemblages along the Depth Gradient (all the species considered)

Cluster analysis was used to group the 12 stations based on faunal assemblages (Fig. 26). Each pair of stations was thought of as "similar" if their faunal composition tended to vary in parallel across all the species. Two major groups of stations were defined at arbitrary similarity level of 36% in Fig. 26 (a). The first group included S5, C14, MT6, C12 and MT5; the second group included C4, C7, MT4, MT3, C1, MT2 and MT1. Their average depths were presented in Fig. 26 (b) using the same dendrogram. The first group included all the deep stations (> 1500 m). The second group could be split into two sub-groups at arbitrary similarity level 45%: shallow stations (300 – 800 m) and intermediate stations (800 – 1500 m). The stations at intermediate depth were C4, C7, MT4 and MT3. Station C1 (335 m) was slightly different from the other two stations MT1 and MT2.

The dendrogram in Fig. 25 suggested that the polychaete faunal composition (the presence/absence of a certain species and its abundance) was closely correlated with depth. Thus, the polychaete faunal assemblage could be divided into three groups along the depth gradient: shallow (300 – 800 m), intermediate (800 - 1500 m) and deep (> 1500 m) in the study area. ANOSIM was conducted to test the null hypothesis that there was no significant difference in faunal composition among these three groups. The results indicated that significant difference existed between each pair of the groups. For example, difference between SHALLOW and INTERMEDIATE was significant ($R = 0.57$, $p = 0.00$). It is also significant between INTERMEDIATE and DEEP ($R = 0.34$, $p = 0.00$) and between SHALLOW and DEEP ($R = 0.73$, $p = 0.00$).

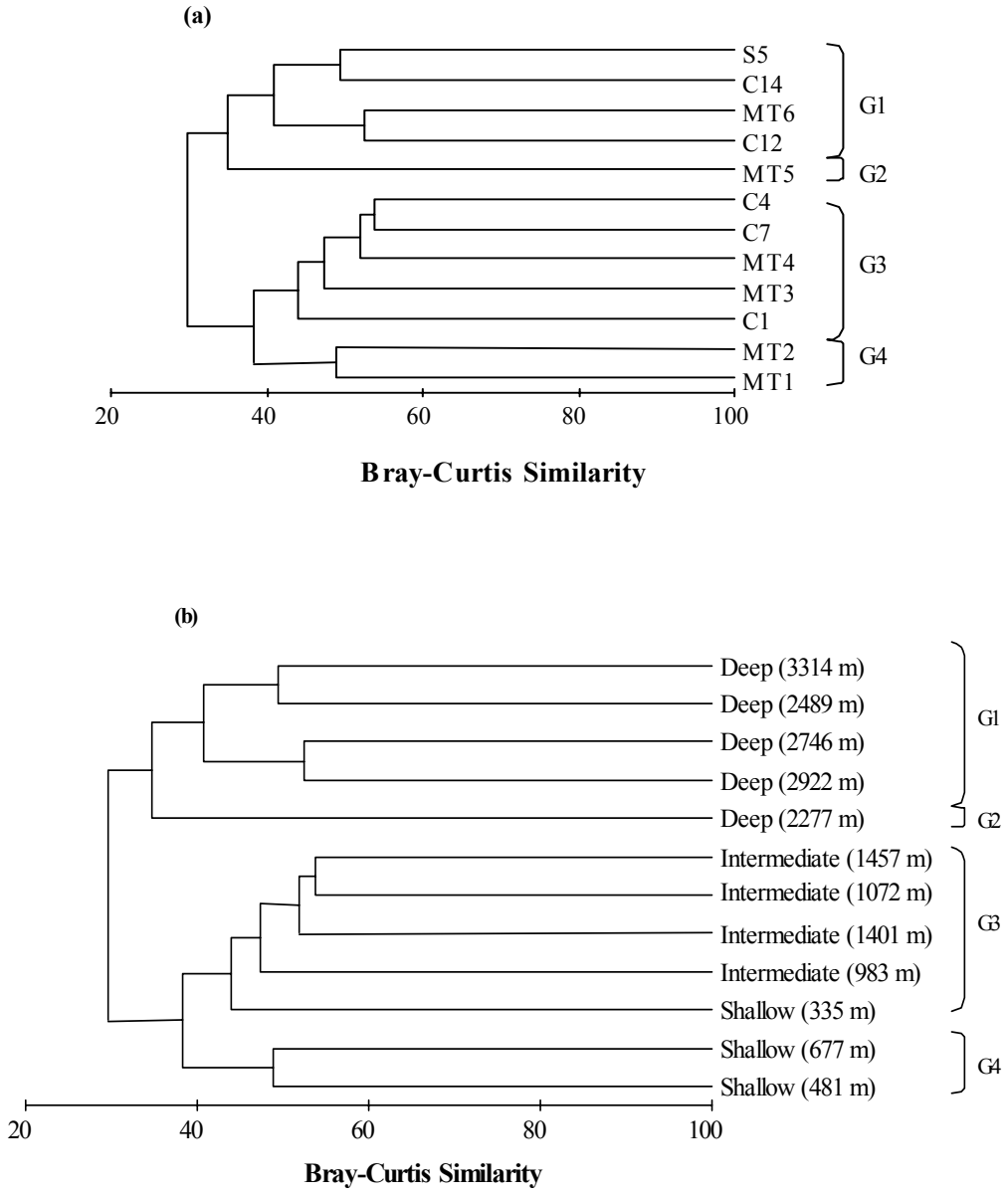


Fig. 26. Dendrogram of Bray-Curtis similarities among 12 sampling stations based on faunal composition (taxonomic composition and associated abundance). There were two main groups defined at arbitrary similarity level of 36%. The first group included all the stations at deep depth (> 1500 m). The second group could be split into two sub-groups: stations at intermediate depth (800 – 1500 m) and stations at shallow depth (300 – 800 m). Thus, the polychaete faunal assemblage could be defined as three groups, shallow, intermediate and deep, in the study area.

*Species Contribution to Dissimilarity among Three Groups of Faunal Assemblage*s

Three groups of faunal assemblages have been identified in the study area and confirmed by ANOSIM test. They are the shallow (300 – 800 m), intermediate (800-1500 m) and deep (> 1500 m).

SIMPER (similarity percentages) procedures were conducted to identify which polychaete species could primarily account for the difference among those three groups, i.e., which species contributed most to Bray-Curtis dissimilarity among three groups, SHALLOW, INTERMEDIATE and DEEP. The results indicated that abundant species contributed more to the average dissimilarity among the three groups of faunal assemblages than rare species, since the top three species that contribute the most, listed in Table 20, were all abundant species.

We can see the average dissimilarity between SHALLOW and DEEP was 84%, which was the highest dissimilarity in the study area. *Prionospio cirrifera* contributed the most dissimilarity at 2.45% (Table 20). The average dissimilarity between DEEP and INTERMEDIATE was 79%, and *Tharyx annulosus* contributed the most to this dissimilarity (1.92%). The lowest average dissimilarity was between SHALLOW and INTERMEDIATE (74%.), 1.84% of which was contributed by *Aglaophamus verrilli*.

The results of SIMPER procedures also indicated that some species were found consistently in high abundances in most samples of the same group (Table 21). For example, *Prionospio cirrifera* was a typical species at shallow depth, contributing 6% of the average within-group similarity of 36%. *Glycera sp.* was typical at intermediate depth and contributed 6% of the average within-group similarity of 33%.

Table 20. Species contribution to Bray-Curtis dissimilarity among three groups of polychaete faunal assemblages: SHALLOW, INTERMEDIATE and DEEP. Only the top three species that contributed the most are listed.

Groups	Species	Contribution (%)	Cumulative (%)
Shallow-Deep Dissimilarity = 84%	Prionospio cirrifera	2.45	2.45
	Aglaophamus verrilli	2.41	4.86
	Prionospio ehlersi	2.26	7.11
Deep-Intermediate Dissimilarity = 79%	*Tharyx annulosus*	1.92	1.92
	Micromaldane sp.	1.56	3.48
	Aricidea simplex	1.55	5.04
Shallow-Intermediate Dissimilarity = 74%	*Aglaophamus verrilli*	1.84	1.84
	Prionospio cirrifera	1.67	3.51
	Prionospio ehlersi	1.64	5.14

Table 21. Species contribution to Bray-Curtis similarity within groups of polychaete faunal assemblages: SHALLOW, INTERMEDIATE and DEEP. Only the top three species that contributed the most are listed.

Groups	Species	Contribution (%)	Cumulative (%)
Shallow Similarity = 36%	Prionospio cirrifera	6.02	6.02
	Spiophanes berkeleyorum	5.69	11.71
	Aglaophamus verrilli	5.11	16.81
Intermediate Similarity = 33%	*Glycera sp.*	5.98	5.98
	Exogone sp. A	5.22	11.2
	Tharyx annulosus	4.97	16.17
Deep Similarity = 24%	*Paraonella monilaris*	21.69	21.69
	Glycera sp.	9.47	31.17
	Fauveliopsis sp. A	7.81	38.98

Paraonella monilaris was typical of the deep group and contributed 22 % of the average within-group similarity, 24%. Since those species were only typical in one group, they are good discriminators between groups. Abundant species not only contributed a lot to dissimilarity among groups (Table 20), but also contributed a lot to similarity within groups (Table 21). This phenomenon indicated that abundant species played an important role in the assemblages. They may have a zoned distribution along the depth gradient.

Comparison of Species Turnover Rates (Replacement) Between the Mississippi Canyon and the Central Transect

Species turnover (replacement) rates were different between the Mississippi Canyon and the Central Transect (Table 22). In the Mississippi Canyon, species turnover (replacement) rates at shallow and intermediate depth were relatively faster than that at deep depth. For example, the faunal composition was significantly different between 482 m and 677 m (both in shallow water) ($R = 0.47$, $p < 0.05$), between 677 m and 983 m ($R = 0.87$, $p < 0.05$), and between 983 m and 1401 m (both in intermediate water) ($R = 0.80$, $p < 0.05$). On the other hand, the faunal composition was similar among those stations at deep depth ($p > 0.05$). In the Central Transect, no significant difference was found among intermediate-depth stations ($p > 0.05$), or among deep-depth stations ($p > 0.05$).

Table 22. ANOSIM table (based on Bray-Curtis similarity) to test if there was no variation in the polychaete faunal composition at different depths in the Mississippi Canyon and the Central Transect.

Mississippi Canyon			Central Transect		
Groups	R value	Sig.	Groups	R value	Sig.
482, 677	0.47	0.01	2922, 2489	0.148	0.4
482, 983	0.94	0.00	2922, 335	0.889	0.1
482, 1401	0.92	0.00	2922, 1459	0.370	0.2
482, 2277	1.00	0.00	2922, 1072	0.528	0.01
482, 2746	0.79	0.00	2922, 3314	0.667	0.1
677, 983	0.87	0.01	2489, 335	0.778	0.1
677, 1401	0.52	0.1	2489, 1459	0.963	0.1
677, 2277	0.82	0.1	2489, 1072	0.753	0.01
677, 2746	0.36	0.08	2489, 3314	0.000	0.9
983, 1401	0.80	0.01	335, 1459	0.704	0.1
983, 2277	0.88	0.01	335, 1072	0.605	0.02
983, 2746	0.57	0.00	335, 3314	0.917	0.1
1401, 2277	0.00	0.7	1459, 1072	0.265	0.14
1401, 2746	0.17	0.23	1459, 3314	1.000	0.1
2277, 2746	0.09	0.28	1072, 3314	0.865	0.03

4.5.5. Multivariate Analysis of Relationship of Faunal Composition to Environmental Variables

The results of BIO-ENV/BVSTEP analyses suggested depth and transect were the best subset of environmental variables that could explain most variations in faunal composition among stations, and the Spearman correlation coefficient ρ was 0.61 ($p < 0.001$). Sediment texture, including percent sand, percent silt and percent clay, could explain 33 % of the variation in faunal composition ($p < 0.001$). Other variables were not correlated with the faunal composition pattern, and the correlation coefficient ρ was low.

4.6. Ecological Niche Analysis of 26 Most Abundant Species

Ecological niche breadth and overlap for habitat utilization were measured using Ecosim 7 software and listed in Fig. 27 and Table 23 respectively. Niche breadth for each of the most abundant polychaete species was calculated using Levin's measure (B) and Smith's measure (FT) based on their distributions among 12 sampling stations. Both indices varied between 0 (minimal niche breadth) and 1 (maximal niche breadth). The two measures showed similar tendency in niche breadth data. Among the abundant species, *Prionospio ehlersi* (B = 0.01, FT = 0.50) and *Aglaophamus verrilliwas* (B = 0.23, FT = 0.53) had the smallest niche breadth, while *Paraonella monilaris* (B = 0.64, FT = 0.92), *Lenvinsenia uncinata* (B = 0.62, FT = 0.92) and *Glycera sp.* (B = 0.64, FT = 0.93) had the broadest niche breadth. *Isolda pulchella* and *Lumbrineris verrilli* had the same ecological niche breadth in terms of habitat utilization for both Levins' measure and Smith's measure (B = 0.02, FT = 0.59).

Niche overlap for each pair of the 26 most abundant species was measured using Pianka's niche overlap index (1973), which measured the relative amount of habitat overlap between each pair of polychaete species and ranges from 0 (minimum overlap, no shared habitat) to 1 (maximum overlap, identical habitat use). These species are represented by designated ID numbers (Table 18), and their observed pairwise niche overlaps were presented in Table 24. One group of species with identical habitat use (overlap close to 1), included species P009 (*Isolda pulchella*), P142 (*Lumbrineris verrilli*), P157 (*Aglaophamus verrilli*), P217 (*Aricidea mirifica*), P231 (*Levinsenia gracilis*), P212 (*Aricidea catherinae*) and P310 (*Prionospio ehlersi*) (Group I). Although

they had the same habitat utilization, they still could co-exist with relatively high abundance because other differences between species were sufficient to allow for species co-existence, such as feeding guilds.

On the other hand, species P068 (*Tharyx annulosus*), P104 (*Fauveliopsis sp. A*), P339 (*Exogone sp. A*), P186 (*Tachytrypane sp. A*) (Group II) were extremely different from species in Group I (overlap close to 0) in terms of habitat utilization, and the observed overlap between each pair ranged from 0.73 to 0.91, and thus, these species in Group II had relatively similar habitat utilization.

Ecosim 7 also provided a way to compare observed niche overlap to expected overlap. The observed mean niche overlap was 0.54 ± 0.32 which was calculated from all the observed niche overlaps. The expected overlap was 0.26 ± 0.24 which was calculated from 1000 simulations of niche overlap. The results of 1000 simulations indicated that the observed niche overlap was higher than expected ($p = 0.00$, $p < 0.05$).

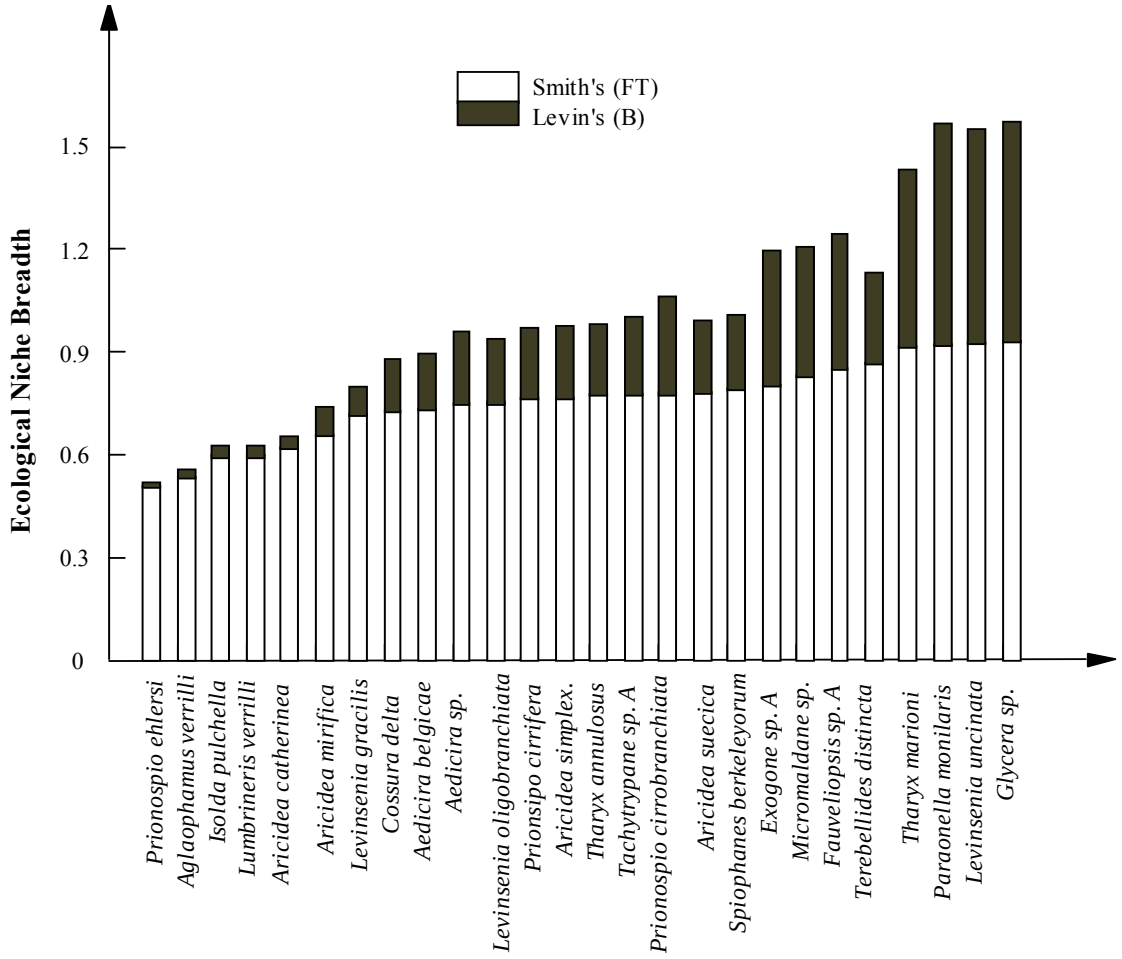


Fig. 27. Ecological niche breadth analysis for 26 most abundant polychaete species in the study area. Dark area represents Levin's measure (B) for niche breadth, and white area represents Smith's measure (FT) (mean value). Both indices varied between 0 (minimal niche breadth) and 1 (maximal niche breadth).

Table. 23. Ecological niche overlap analysis for 26 most abundant polychaete species using Pianka's (1973) niche overlap index. The index ranges from 0 (no shared habitat) to 1 (identical habitat use).

	P206	P212	P068	P142	P104	P009	P231	P307	P233	P366	P153	P235	P339	P114	P69	P72	P186	P236	P219	P207	P157	P217	P324	P310	P220	P306
P206		0.88	0.03	0.90	0.06	0.89	0.91	0.82	0.90	0.95	0.27	0.54	0.04	0.71	0.49	0.52	0.12	0.32	0.28	0.95	0.91	0.95	0.93	0.89	0.94	0.96
P212			0.02	0.99	0.03	1.00	0.99	0.73	0.91	0.70	0.10	0.53	0.03	0.59	0.15	0.12	0.03	0.26	0.20	0.71	1.00	0.98	0.91	1.00	0.94	0.91
P068				0.12	0.73	0.00	0.04	0.22	0.10	0.16	0.83	0.66	0.78	0.49	0.48	0.35	0.88	0.23	0.88	0.06	0.00	0.09	0.33	0.00	0.22	0.22
P142					0.12	0.99	0.99	0.76	0.92	0.74	0.18	0.60	0.12	0.66	0.22	0.20	0.13	0.28	0.30	0.73	0.99	0.99	0.95	0.99	0.96	0.93
P104						0.00	0.05	0.13	0.10	0.17	0.54	0.74	0.91	0.60	0.42	0.36	0.80	0.45	0.74	0.11	0.00	0.09	0.32	0.00	0.25	0.20
P009							0.99	0.74	0.91	0.71	0.10	0.51	0.00	0.58	0.16	0.13	0.00	0.26	0.18	0.72	1.00	0.98	0.91	1.00	0.94	0.91
P231								0.80	0.95	0.75	0.14	0.57	0.05	0.64	0.24	0.20	0.08	0.28	0.24	0.76	1.00	0.99	0.94	1.00	0.96	0.94
P307									0.09	0.80	0.35	0.62	0.14	0.71	0.68	0.49	0.37	0.25	0.47	0.81	0.76	0.82	0.84	0.74	0.83	0.91
P233										0.79	0.21	0.63	0.11	0.72	0.46	0.32	0.22	0.27	0.35	0.81	0.93	0.95	0.92	0.92	0.94	0.96
P366											0.45	0.56	0.15	0.75	0.71	0.75	0.27	0.36	0.41	0.99	0.73	0.82	0.86	0.71	0.86	0.90
P153												0.66	0.68	0.63	0.72	0.56	0.65	0.41	0.67	0.39	0.10	0.21	0.40	0.10	0.36	0.35
P235													0.82	0.94	0.60	0.36	0.68	0.59	0.70	0.52	0.52	0.58	0.73	0.52	0.73	0.68
P339														0.67	0.45	0.27	0.74	0.47	0.67	0.09	0.00	0.08	0.29	0.00	0.27	0.19
P114															0.71	0.50	0.55	0.60	0.60	0.72	0.59	0.67	0.79	0.59	0.81	0.78
P069																0.84	0.63	0.38	0.63	0.69	0.19	0.32	0.48	0.16	0.45	0.54
P072																	0.54	0.16	0.59	0.72	0.17	0.31	0.46	0.13	0.40	0.49
P186																		0.16	0.97	0.18	0.02	0.13	0.38	0.00	0.27	0.31
P236																			0.15	0.35	0.26	0.28	0.34	0.26	0.36	0.32
P219																				0.31	0.19	0.30	0.53	0.18	0.41	0.46
P207																					0.75	0.82	0.83	0.72	0.85	0.89
P157																						0.99	0.92	1.00	0.94	0.92
P217																							0.96	0.98	0.97	0.97
P324																								0.91	0.98	0.98
P310																									0.94	0.91
P220																										0.98
P306																										

4.7. Geographic Information System (GIS) Analysis

Spatial Analyst in ESRI ArcMap (available in ArcGIS) was conducted to establish correlation between the slope of bathymetry and biological data, especially polychaete density and diversity. Results of slope analysis indicated that the slope of bathymetry in the Northern Gulf of Mexico could have some effects on polychaete diversity, but no direct correlations with polychaete density ($p > 0.05$). The percentage distribution of slopes at each station was listed in Table 24. Buffers were made around the sampling sites at 1000 m scale. Relationships between the bathymetric slope and polychaete density/diversity were shown in Fig. 28 – 29.

Slopes were divided into 12 categories that ranged from 0 (flat) to 11 (steep). The highest slope value was 73 degrees, and the lowest value was 0 degrees. As shown in Table 24, most sampling stations in the Mississippi Canyon were located in flat areas (0 – 12 degree), especially MT6, where 100% of the slopes were 0 - 6 degree. Slopes in the Central Transect were slightly steeper than that in the Mississippi Canyon (mainly from 6 – 18 degree). Slopes at S5 were the same as that at MT6, which indicated that deep-sea ocean floors in the study area were very flat. Site C7 was quite different from other stations, where slopes ranged from 0 to 73 degrees. Slopes at C4 ranged from 0 to 24 degrees. Therefore, slopes around site C7 varied significantly, followed by site C4. Slopes around S5 and MT6 had no variation (Table 25). Considering that higher species diversity was found in the Central Transect, especially at sites C7 and C4, there is a possibility that polychaete diversity may be positively correlated with slope variation in the study area. Another reason

for higher diversity at station C7 is probably due to more organic matter input since C7 is considered to be a cold seep site.

Table 24. The percentage distribution of slopes at 12 sampling stations in the Mississippi Canyon and the Central Transect.

Slope (degree)	C1	C7	C4	C14	C12	S5	MT1	MT2	MT3	MT4	MT5	MT6
0 - 6			17.5	46.3	83.7	100	17.1	20.6	44.6	31.4	36.5	100.
6 - 12	29.5	2.3	43.9	53.7	16.3		68.3	76.5	49.2	57.1	61.5	
12 - 18	68.2	11.4	31.6				14.6	2.9	6.2	11.4	1.9	
18 - 24	2.3	25.0	7.0									
24 - 30		13.6										
30 - 36		2.3										
36 - 42		9.1										
42 - 48		4.5										
48 - 54		9.1										
54 - 60		9.1										
60 - 66		6.8										
66 - 73		6.8										

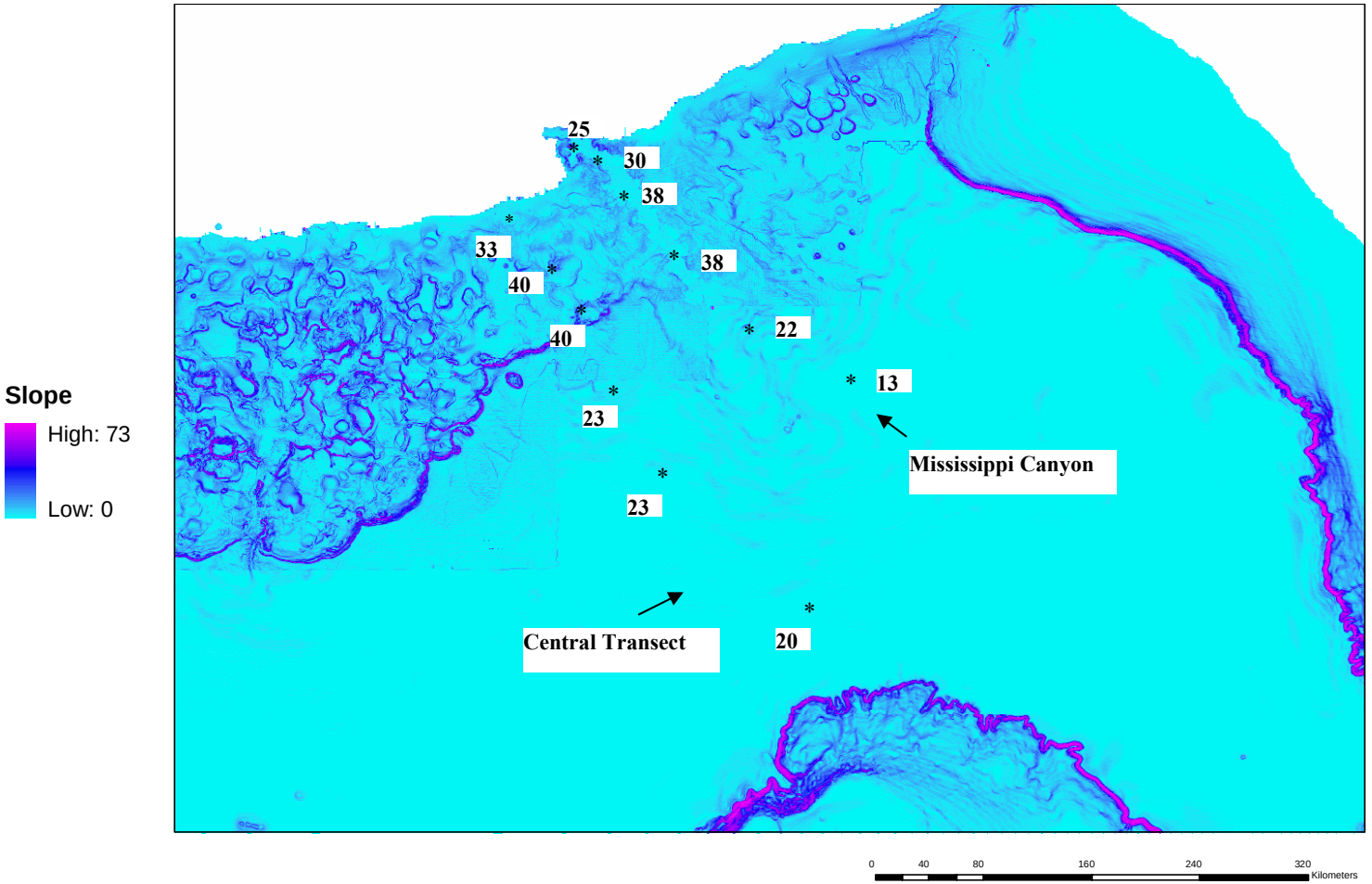


Fig. 28. 12 Sampling stations (black asteria) with the mean polychaete diversity ES(100) plotted on a slope map (in degrees) as a result of GIS slope analysis.

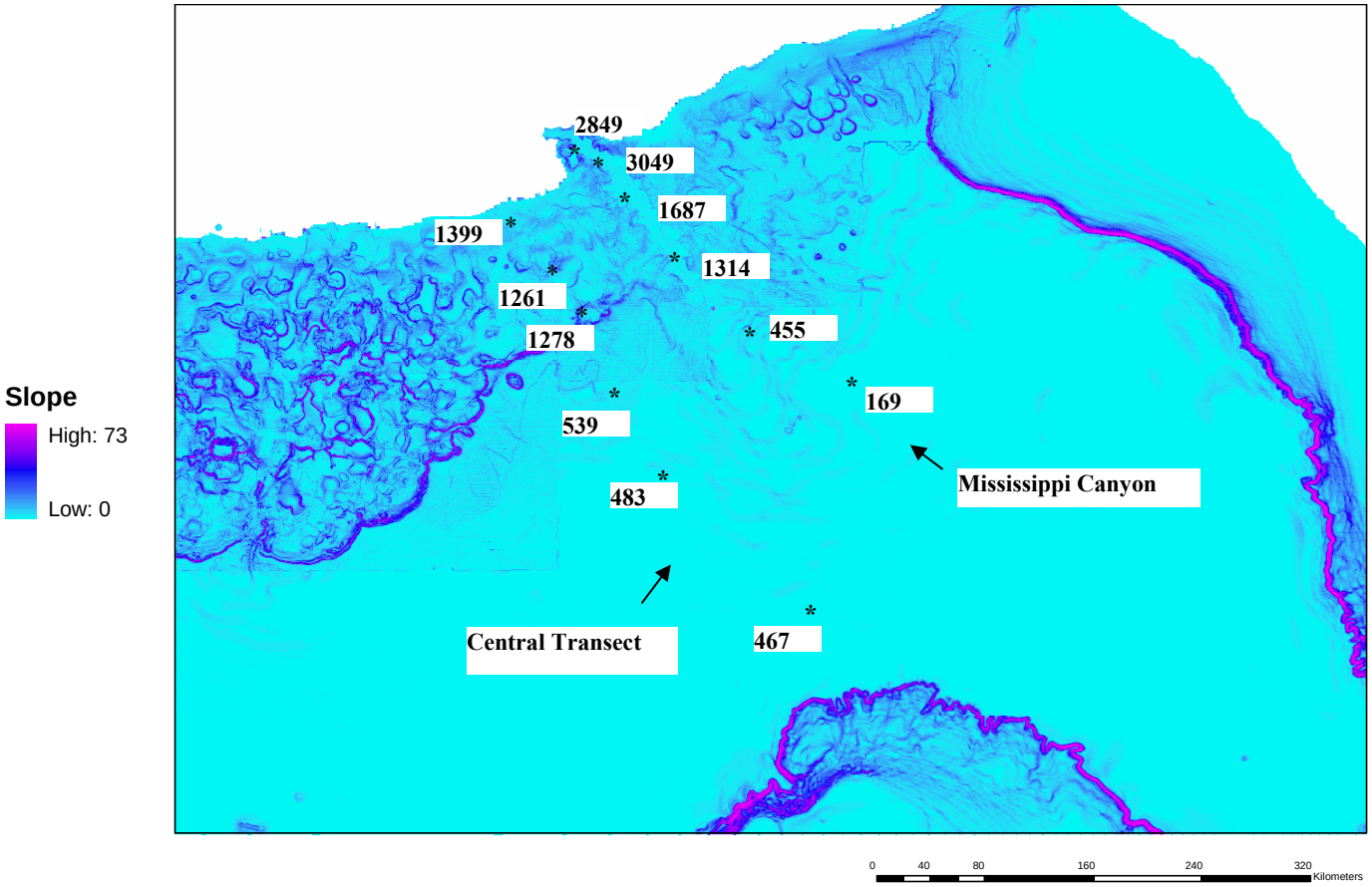


Fig. 29. 12 sampling stations (black asreria) with the mean polychaete density (N/m^2) plotted on a slope map (in degrees) as a result of GIS slope analysis.

5. DISCUSSION

5.1 Effects of Transect on Polychaete Assemblage

The polychaete density decreased with increasing depth exponentially on both transects according to the equation $Y = ae^{bx}$, where Y refers to density, x refers to depth, and *a* and *b* are two coefficients. Rowe (1971, 1974) also observed the exponential relationship between depth and macrofauna density previously in the northwest Atlantic, the Gulf of Mexico and off South America. The mean density in the Mississippi Canyon was significantly higher than the Central Transect. The density decreased more sharply in the Mississippi Canyon. The coefficient *a* in the equation for the Mississippi Canyon was thus higher than that for the Central Transect, i.e., 5586.9 > 1855.5. Explanation for this difference could be that large amounts of organic input from the Mississippi river outflow are entrapped in the upper Canyon, especially at the head of the Canyon, MT1, and thus lead to high polychaete density. The coefficient *a* might be related to euphotic zone primary production (Rowe, 1971, 1974), and could be an indicator of food availability to benthic consumers. Higher food availability in the upper Canyon was confirmed by the observations of the highest CHL concentration in near surface water and the highest particulate organic matter content in sediments at MT1. In the lower Canyon, POC input decreased greatly with increasing depth and distance from the coast. Therefore, the polychaete density would continue to decrease with depth.

The Mississippi Canyon had higher species richness (301 species) than the Central Transect (223 species), which could be attributed to physical complexity in the

Canyon. Complex topography in the Canyon may create more microhabitats for specialized polychaete species, and thus increase species richness. As to diversity, Expected Number of Species (ES(100)) and Expected Number of Families (EF(100)) were significantly higher in the Central Transect than in the Canyon according to ANOVA tests. Other indices could not detect differences between the two transects. Thus, the rarefaction is more informative than other diversity indices. The depressed biodiversity in the Mississippi Canyon could be due to higher POC input by the Mississippi River, which potentially accelerated competitive exclusion (Rex, 1976). On the other hand, several sampling stations in the Central Transect had steeper slopes than the Canyon according to GIS analysis. Usually a canyon would be expected to have steeper slopes as a whole than in non-canyon areas. But, according to GIS slope analysis, sites in the Mississippi Canyon were all located on relatively flat canyon floor, not on the walls, and thus they had lower slopes than might have been expected. Intensified bottom currents in the Canyon (> 20 or 25 cm/sec, based on Burden (1999)'s results) may potentially reduce habitat heterogeneity, and then lead to lower biodiversity. Site C7 was suspected to be a cold seep site, which also contributed largely to high diversity on the Central Transect. The C:N ratio may also be related to the differences. Flemer et al. (1999) suggested that the C:N ratio can be an indicator of food quality for benthic communities. Higher C:N ratio in the Central Transect indicated lower food quality, which could lower competitive exclusion, and thus promote higher biodiversity in the Central Transect, and partially explained lower density in the Central Transect.

No significant differences were found in the percentage distribution of feeding guilds between the two transects. Among six feeding guilds found in the study area, non-selective deposit feeding (NSDF) and selective deposit feeding (SDF) were the most abundant on both transects. No herbivores were encountered, because they primarily feed on algae. The polychaete communities studied were all far way from the coastal areas and at depth greater than 200 m, which made the availability of algae very low. Surface filter feeders were rare on both transects. They are sessile, and use their special feeding processes to collect detritus and plankton from the surrounding water (Ruppert and Barnes, 1994). Therefore, they would not be abundant in an environment with relatively weak bottom current and fine-grained sediments.

The faunal compositions of the Mississippi Canyon and the Central Transect were significantly different. There were 141 species found only in the Canyon, and 66 species found only in the Central Transect. The Mississippi Canyon and the Central Transect were very close geographically, but the differences in fauna support Burden's (1999) conclusion that the Mississippi Canyon is a unique environment with a large amount of terrigenous particulate organic matter and sediment input, along with bottom currents of high variability. In conclusion, polychaete assemblages are significantly different between the Canyon and non-canyon area (the Central Transect). The impacts of TRANSECT could be attributed to higher physical complexity in the Canyon, higher food quality and terrigenous organic matter input to the Canyon by the Mississippi River outflow.

5.2. Effects of Food Availability on Polychaete Assemblage

The polychaete density increased with surrogates for surface water productivity, but diversity was not correlated with similar measures. In contrast, polychaete diversity exhibited a unimodal pattern with polychaete density and meiofaunal biomass (gC/m^2) before depth effects were removed. The polychaete diversity increased with polychaete density to its maximum and then decreased with increasing density. The decrease in diversity could be due to promoted competitive exclusion. Once depth was controlled, most proxies of food availability had no further impacts on diversity. Paterson et al. (1998) also suggested that abundance of abyssal polychaetes was related to nutrients reaching the deep-sea floor, but diversity had no direct link to fluxes or benthic productivity. Statistical analysis indicated that the species-level and the family-level diversity could be partially controlled by food quality (the C:N ratio), since regression of diversity on the C:N ratio was significant even after depth effects were removed.

5.3. Effects of Sediment Texture on Polychaete Assemblage

The relationship of polychaete density to sediment texture degenerated after removal of depth effects. Thus, sediment texture had no significant effects on density. Percent silt was the only parameter correlated with polychaete diversity among the properties of sediment texture. This agrees with Levin and Gage (1998) who also observed percent sand and percent clay were not correlated with diversity. But they could not test effects of percent silt due to lack of data. Etter and Grassle (1992) suggested the depth-related patterns in species diversity reflected the effects of silt diversity as a consequence of changes in sediment characteristics with depth.

Polychaete feeding guilds were mainly affected by sediment texture rather than depth, especially percent silt and percent clay, followed by POC content in sediments. Deposit and suspension filter feeders were mainly controlled by sediment texture, while sediment texture had no significant correlations with distributions of omnivores, carnivores and scavengers. The faunal compositions had weak correlation with sediment texture, which suggested sediment texture was not as important as depth in structuring benthic community composition.

5.4. Effects of Sediment Contamination on Polychaete Assemblage

Chemical contaminants, including trace metals and PAHs, have resulted in significant reduction of benthos abundance in previous studies (e.g., Belan, 2003). But in this research, no correlations were found between polychaete assemblages and these chemical contaminants. The reasons for absence of significant correlation may be due to the observations that their concentrations in sediments were too low to have any adverse effects on polychaete communities. Concentrations of trace metals and PAHs in the study area were much lower than in literature which had adverse effects on benthic community (e.g., Olsgard and Gray, 1995). Therefore, the study area was probably not significantly contaminated by trace metals and PAHs, although the Mississippi Canyon is an oil-rich area.

5.5. Effects of Depth on Polychaete Assemblage

Both density and body sizes decreased with depth, which could be attributed to reduced food availability along the depth gradient. Theil (1979) also observed decreased

average organism size with depth at the community level and increase in the relative abundance of meiofauna. Polychaete diversity increased with increasing depth to a maximum at about 1200 m, and then decreased, showing a unimodal pattern. This pattern is often encountered on continental margins (Rex, 1983), but its causes remain unclear (Levin et al., 2001). Maximum diversity occurred at different depths depending on indices used. Thus, depth was a very important factor correlating with polychaete diversity. Some depth-related changes may regulate polychaete species distribution and result in a unimodal pattern of diversity with depth, such as physical stability, biological disturbance and competition.

Physical Satiability

Species diversity would increase with environmental stability on geological time (Sanders, 1979). Hydrodynamic regime varies with depth, and profoundly affects many ecological processes that may be important in regulating benthic community structure (Jumars and Nowell, 1984). Thus, hydrodynamic regime could be fundamental to understanding why diversity has a unimodal pattern with depth. Extensive observational data from current meter records and mathematical models suggest that in the central Gulf of Mexico Loop Current and atmospheric storms intensify the surface current with maximum speed. The current speed decreases exponentially with increasing depth. The intermediate-depth current (800 – 1000 m) has minimum speed and variation compared with other depth ranges (Nowlin et al., 2001). Below 1000 m, strong current events have been observed and exhibited bottom intensification (reviewed by Jochens, 2003). Hence, the intermediate depth range (800 – 1000m) can be a stable environment with respect to hydrodynamic energy compared with shallow and deep depth ranges in the

Gulf of Mexico. Such a hydrodynamically stable environment may enable more species to coexist, and lead to higher biodiversity at intermediate depths. This agrees with Gage (1997) who found that high-energy environments had enhanced macrofaunal abundance and depressed biodiversity, compared with quiescent areas.

Biological Disturbance and Competition

Previous studies suggest that species diversity may reflect a dynamic balance between biological disturbance in the form of "cropping" (Dayton and Hessler, 1972) and competitive exclusion (reviewed by Huston, 1994). Biological disturbance crops down population, reduces competitive exclusion and promotes coexistence, leading to higher diversity. In this study, polychaete diversity exhibited a unimodal pattern with density (Fig. 15 a). This indicated that competitive exclusion may positively correlate with polychaete population, and when the community is near competitive equilibrium, some species are excluded, thereby depressing biodiversity. The Dynamic Equilibrium Model (Huston, 1979) could be used to explain depth-related variation in polychaete diversity. In shallow depth ranges, competitive exclusion is very high due to higher food availability, larger densities and larger sizes, while biological disturbance could be relatively low (Rex, 1983), and thus diversity is low. At intermediate depths, moderate exclusion and biological disturbance result in maximum diversity by allowing more species to coexist. At deep depths, both exclusion and biological disturbance are very low, probably due to limited food availability. Such a low disturbance may not prevent the community from approaching competitive equilibrium, and thus result in lower diversity.

Vinogradova (1962) suggested that mixture of shallow-water species and deep-water species could increase species richness at intermediate depths (about 3000 m). The boundaries may vary depending on the configuration of the ocean floor. In closed basins this boundary may shift upwards. The Gulf of Mexico is a semi-closed basin with continental shelves surrounding a deep abyss reaching to about 3800 m (reviewed by Jochens, 2003). Thus, the depth of maximum diversity may shift to shallow water (about 1200 m) instead of 2000 ~ 3000 m suggested by Rex (1983) in his study in the northwestern Atlantic.

Feeding guilds and the faunal composition could be arranged by depth into three groups: shallow (300 – 800 m), intermediate (800 – 1500 m) and deep (> 1500 m). These zones had significantly different environmental properties (ANOSIM test, Table 25). In addition to depth, variables contributing the most to dissimilarity included sediment texture and food availability (CHL concentration in surface water, meiofauna biomass, POC and PON) (SIMPER test, Table 25). Thus, zoned distribution with depth was also a function of consistent differences in environmental properties between zones. Rowe and Menzies (1969) also found that observed zonation of large epibenthic invertebrates along the depth gradient correlated with marked changes in sediment size and temperature variations. Vertical distribution of feeding types may coincide with steepest portion of the hypsographic curve of the earth's crust and its inflections (Sokolova, 1958). Measurements of organic carbon flux and sediment oxygen demand suggested that mid-slope depths at about 1000 m are a "depocenter" for fine-grained organic debris exported from the continental shelf (Walsh et al., 1981, 1985; Anderson et al., 1994; Rowe et al., 1994). This depth-related change in organic deposit on the

ocean floor could determine polychaete community structure and cause zoned distribution in the central Gulf of Mexico.

Depth has been considered as a primary habitat factor in organizing benthic communities (e.g., Hyland et al., 1991; Bergen et al., 2001). On the other hand, it has been suggested that depth probably is just a surrogate integrating a combination of various parameters over time (e.g., Burden, 2001). In my opinion, depth was a primary determinant in structuring a deep-sea environment or habitat for benthic polychaete communities in the Northern Gulf of Mexico, because it correlates with hydrodynamic energy, food availability and sediment contamination. Their effects may vary, depending on the community parameter in question. Bottom slope and sediment texture (especially percent silt) may have their own effects on density or biodiversity, and these are not necessarily correlated with depth. Correlations do not imply causality. In order to determine if a variable has impacts on polychaete assemblages, we would have to test effects through direct field or laboratory experimentation, as suggested by Etter and Grassle (1992).

Table 25. Environmental variables that contributed most to dissimilarity among three depth ranges: SHALLOW (300 – 800 m), INTERMEDIATE (800 – 1500 m) and DEEP (> 1500 m).

	ANOSM test		SIMPER test	
Groups	R	Sig.	Variables (in order of contribution, other than depth)	Total Contribution %
Shallow-Intermediate	0.85	0.03	POC, % Sand, Temperature, % Clay, CHL	90.2 %
Shallow-Deep	0.93	0.03	% Sand, POC, Meiofaunal biomass % Clay	90.4 %
Intermediate-Deep	0.59	0.03	% Sand, Meiofaunal biomass, % Clay, % Silt	91.9 %

5.6 Comparison with Historical Studies on Polychaetes

Polychaetes, as a numerically dominant group in marine benthic infaunal communities, have been studied extensively. On the northern Gulf of Mexico continental slope between 86º W and 93º W, polychaetes were the most diverse group of macrofauna sampled, with 446 species, 299 genera and 59 families (Pequegnat et al., 1987; Hubbard, 1995). My study documented 371 species, 199 genera and 51 families in the Mississippi Canyon and the Central Transect (88º - 90º West) in the central northern Gulf of Mexico. Although the study area in this project was much smaller than previous study, almost as many as families and species were found. Thus, the central region is an area with high species richness.

In the northern Gulf of Mexico, polychaete density decreased with depth from 1982 N/m^2 to 482 N/m^2, and could be arranged by depth as four groups: 298 – 492 m, 500 – 900 m, 1500 – 2000 m and 2000 – 2845 m (Pequegnat et al., 1987). Polychaete faunal composition and mean densities were significantly different in the eastern, the central and the western Gulf of Mexico (Hubbard, 1995). The eastern region had the highest mean density (1863 N/m^2). The central region had a mean density of 1401 N/m^2, which was close to the mean on both the Mississippi Canyon and the Central Transect (1387 ± 1053 N/m^2). The mean density in the western region was 1321 individuals/m^2. Hubbard (1995) argued that in the eastern region there was greater numerical abundance than in the west due to the predominant carbonate sediments in the east, in contrast to the silty-clay sediments in the west, while the central region production was enhanced by the influence of the Mississippi River outflow. In my study, higher CHL concentrations and particulate organic matter content were observed

at the head of the Mississippi Canyon, which confirmed the influence of the Mississippi River.

Hubbard (1995) found that feeding type distributions were uniform across all transects on the northern Gulf of Mexico slope with deposit feeders being the most abundant. His findings were similar to my results, except that I found distribution of feeding types could be different among depth ranges, shallow (300 – 800 m), intermediate (800 – 1500 m) and deep (> 1500 m). He suggested that macrofaunal polychaetes on the northern Gulf of Mexico continental slope were more closely related to those of the Southern U.S Atlantic slope, less to the Mid-Atlantic slope, and hardly at all to the North Atlantic Slope. Polychaete diversity had a unimodal pattern with depth on the U.S Atlantic continental slope and rise, and the maximum diversity occurred on the order of 2000 m (Grassle, 1987). Hubbard (1995) found the depth of maximum diversity at about 600 –700 m in the northern Gulf of Mexico, which was attributed to intermediate environmental disturbance. Such disturbances would reduce competition and increase biodiversity. I found the depth of diversity maximum was at about 1269 m, and the possible reason for this is the intermediate depth range was a hydrodynamically stable environment, which allowed more species to co-exist.

Polychaete assemblages have been studied in other deep oceans, including the central Pacific (Glover et al., 2002), the northeast Atlantic (Paterson and Lambshead, 1995), and the Indian Oceans (Levin and Gage, 1998). Environmental factors considered have included sediment texture, latitude, surface ocean productivity, oxygen, sediment contaminations, etc. Depth however is the most well-recognized factor correlating with polychaete community structure. Studies in the NE Atlantic (Paterson

et al., 1998), the equatorial Pacific (Glover et al., 2002), and the central Gulf of Mexico all indicate that polychaete diversity has no direct relationship to surface primary productivity or POC flux, although polychaete numerical abundance showed a first-order relationship with both. Oxygen is a significant factor when oxygen concentrations are lower than 0.45 ml/L. Thus, oxygen minimum zones (OMZs) under upwelling ecosystems and the hypoxia zone on the northern Gulf of Mexico continental shelf have adverse effects on polychaete diversity. In my study, oxygen effects were not observed, since the near-bottom oxygen concentrations were high in the Mississippi Canyon and the Central transect, ranging from 2.4 – 7.2 ml/L. Previous studies on trace metals and PAHs indicate that they have adverse ecological effects on polychaete assemblages (e.g., Grant and Briggs, 2002).

Future studies on polychaete assemblages in the Gulf of Mexico should focus on growth and reproduction, as part of Carbon cycle; specialized assemblages at seeps; specialized assemblages in strong currents; and specialized assemblages or indicator species at continental shelf sites near oil exploration and production facilities.

6. SUMMARY

Polychaete density decreased exponentially with increasing depth in the study area. Higher density was found in the Mississippi Canyon probably due to better food quality (lower C:N ratio) or more terrigenous input from the Mississippi River outflow. Higher diversity was found in the Central Transect based on statistical analysis. Depressed diversity in the Mississippi Canyon could be attributed largely to entrapped terrigenous organic matter input, which enhanced competition exclusion. Polychaete diversity exhibited a unimodal pattern with depth with its maximum value occurring in intermediate depth range (800 m – 1500 m). Maximum diversity however occurred at different depths, depending on indices used. The depth range (800 m – 1000 m) was a hydrodynamically stable environment with minimum current speed and variation, which could enable more species to co-exist, leading to higher biodiversity. Diversity indices had different abilities to discriminate between samples. Rarefaction (Expected Number of Species E(Sn)) was more informative than other indices. Family-level diversity exhibited a pattern similar to species-level diversity. Both rarefaction and Species Cumulative Curves were useful tools for comparison between large sampling areas.

Six feeding guilds were found in the study area. Non-selective deposit feeding (NSDF) and selective deposit feeding (SDF) were the most abundant on both transects, followed by omnivores and carnivores. Suspension filter feeders and scavengers were rare. Percentage distributions of feeding guilds were similar between the two transect. The faunal compositions were significantly different between the two transects, and

higher species richness was found in the Canyon (301 species). Both distribution of polychaete feeding guilds and faunal composition varied along the depth gradient. These could be divided into three groups: shallow (300 m – 800 m), intermediate (800 m – 1500 m) and deep (> 1500 m). Zoned species distribution was observed, which was probably caused by dramatic changes in environmental properties among three depth ranges.

Sampling Year had no effects on polychaete assemblages. Depth was the most important determinant in organizing polychaete assemblages. Most environmental variables were depth-related parameters. Spatial heterogeneity and sediment grain size may not necessarily correlate with depth. The Mississippi Canyon and the Central Transect were not contaminated by trace metals or PAHs in sediments at the time of this study. The environmental properties of these two transects were similar except for the C:N ratio.

Future research on deep-sea biodiversity should take into account effects of bottom currents, which were unfortunately not quantified in this research. Multivariate regression methods were very useful in evaluating impacts of most environmental factors quantitatively. Geographic Information System (GIS) was helpful in correlating biological data with geographic features. Effects of geographic features on benthic assemblages were almost neglected in previous literature for many reasons. In future studies on marine biodiversity, GIS may play an important role.

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APPENDIX

Table 26. Species found in the Mississippi Canyon and the Central Transect (2000 – 2002).

	Family	Genus	Species	C1	C7	C4	C14	C12	S5	MT1	MT2	MT3	MT4	MT5	MT6
PS001	Aberrantidae	Aberranta	sp.	0	1	1	0	0	0	0	0	2	0	0	0
PS002	Acrocirridae	Acrocirrus	frontifilis	0	0	0	0	0	0	0	0	0	0	1	1
PS003	Acrocirridae	Macrochaeta	clavicornis	1	2	5	4	4	0	0	0	0	2	4	0
PS004	Acrocirridae	Macrochaeta	sp.A	0	1	0	0	0	0	0	0	0	0	0	0
PS005	Ampharetidae	Ampharete	sp.A	1	0	1	0	0	0	0	5	1	1	3	0
PS006	Ampharetidae	Amphicteis	gunneri	0	0	4	0	0	0	10	0	1	0	0	0
PS007	Ampharetidae	Genus_A	\	0	2	0	0	0	0	0	0	0	0	0	0
PS008	Ampharetidae	Hobsonia	sp.	0	0	0	0	0	0	1	0	0	0	0	0
PS009	Ampharetidae	Isolda	pulchella	0	0	0	0	0	0	100	2	0	1	0	0
PS010	Ampharetidae	Melinna	cristata	0	0	0	0	0	0	7	0	0	0	0	0
PS011	Ampharetidae	Melinna	maculata	0	0	0	0	0	0	69	0	0	0	0	0
PS012	Amphinomidae	Chloeia	viridis	0	0	0	0	0	0	2	0	0	0	0	0
PS013	Amphinomidae	Eurythoe	sp.A	0	1	0	0	2	0	0	1	1	0	0	0
PS014	Amphinomidae	Eurythoe	sp.B	0	1	3	0	2	0	1	0	0	1	1	1
PS015	Amphinomidae	Paramphinome	jeffreysii	5	20	0	2	0	0	0	0	10	0	0	0
PS016	Amphinomidae	Paramphinome	sp.A	0	8	2	0	2	0	0	0	9	8	3	2
PS017	Amphinomidae	Paramphinome	sp.B	0	0	1	0	0	0	0	0	0	0	0	0
PS018	Aphroditidae	\	sp.	0	0	1	0	0	0	0	0	0	0	0	0
PS019	Arabellidae	Oenonidae	sp.	0	0	0	0	0	0	0	0	1	0	0	0
PS020	Capitellidae	Barantolla	sp.A	5	0	0	0	0	0	0	0	1	6	0	0

Table 26. – Continued

	Family	Genus	Species	C1	C7	C4	C14	C12	S5	MT1	MT2	MT3	MT4	MT5	MT6
PS021	Capitellidae	Capitella	capitata	0	0	0	0	0	0	0	0	2	1	0	0
PS022	Capitellidae	Dasybranchus	lunulatus	0	0	0	0	0	0	1	0	0	0	0	0
PS023	Capitellidae	Decamastus	gracilis	0	0	0	0	0	0	0	1	1	0	0	0
PS024	Capitellidae	Decamastus	sp. A	0	0	0	0	0	0	4	2	5	2	0	0
PS025	Capitellidae	Genus A	\	7	3	0	0	0	1	0	1	4	2	0	1
PS026	Capitellidae	Genus AA	\	2	0	0	0	0	0	33	1	0	0	0	1
PS027	Capitellidae	Genus AC	\	0	0	0	0	0	0	0	0	0	2	0	0
PS028	Capitellidae	Genus AE	\	1	0	0	0	0	0	0	0	2	1	0	0
PS029	Capitellidae	Genus AF	\	0	2	0	0	0	0	0	0	2	6	0	0
PS030	Capitellidae	Genus AG	\	0	0	3	0	0	0	1	0	0	0	0	0
PS031	Capitellidae	Genus AK	\	0	0	1	0	0	0	0	0	0	1	0	0
PS032	Capitellidae	Genus AM	\	0	0	0	0	0	0	1	0	0	0	0	0
PS033	Capitellidae	Genus AN	\	0	0	1	0	0	0	0	0	0	0	0	0
PS034	Capitellidae	Genus AQ	\	0	0	0	0	0	0	2	0	0	1	0	0
PS035	Capitellidae	Genus C	\	0	2	0	0	0	0	2	8	1	0	0	0
PS036	Capitellidae	Genus G	\	1	2	0	0	0	0	0	0	1	0	0	0
PS037	Capitellidae	Genus H	\	2	0	0	0	0	0	0	0	1	0	0	0
PS038	Capitellidae	Genus K	\	0	0	0	0	0	0	0	0	1	0	0	0
PS039	Capitellidae	Genus N	\	0	0	1	0	0	0	0	0	0	0	0	0
PS040	Capitellidae	Genus O	\	0	1	0	0	0	0	6	0	2	0	0	1
PS041	Capitellidae	Genus P	\	0	0	0	1	0	0	0	1	0	0	0	0
PS042	Capitellidae	Genus R	\	0	0	0	0	0	0	1	1	1	0	0	0
PS043	Capitellidae	Genus S	\	0	0	0	0	0	0	0	0	7	1	0	0
PS044	Capitellidae	Genus T	\	0	0	0	0	0	0	0	0	1	0	0	0
PS045	Capitellidae	Genus X	\	0	0	0	0	0	0	5	0	0	0	0	0
PS046	Capitellidae	Genus Y	\	0	0	0	0	0	0	1	1	1	0	1	0

Table 26. - Continued.

	Family	Genus	Species	C1	C7	C4	C14	C12	S5	MT1	MT2	MT3	MT4	MT5	MT6
PS047	Capitellidae	Heteromastides	sp. A	0	0	0	0	0	0	0	0	1	0	0	0
PS048	Capitellidae	Heteromastus	sp. A	1	0	0	0	0	0	0	0	0	0	0	0
PS049	Capitellidae	Mediomastus	californiensis	7	0	0	0	0	0	0	0	1	3	0	0
PS050	Capitellidae	Neoheteromastus	sp. B	0	1	0	0	0	0	0	0	1	0	0	0
PS051	Capitellidae	Neomediomastus	sp. A	0	0	0	0	0	0	0	0	1	2	0	0
PS052	Capitellidae	Neomediomastus	sp. B	3	0	0	0	0	0	0	0	0	0	0	0
PS053	Capitellidae	Notomastus	americanus	0	3	0	0	0	0	9	7	4	1	0	0
PS054	Capitellidae	Notomastus	hemipodus	0	2	0	0	0	0	4	2	5	1	0	0
PS055	Capitellidae	Notomastus	latericeus	0	0	0	0	0	0	4	0	1	0	0	1
PS056	Capitellidae	Notomastus	letericeus	0	0	1	0	0	0	0	0	0	0	0	0
PS057	Capitellidae	Notomastus	sp. A	0	0	0	0	0	0	0	1	0	0	0	0
PS058	Capitellidae	Paraleiocapitella	sp.	0	0	0	0	0	0	0	0	1	0	0	0
PS059	Chaetopteridae	Spiochaetopterus	costarum	0	1	5	0	0	0	0	0	1	0	0	0
PS060	Chrysopetalidae	Dysponetus	sp. A	2	0	0	0	0	0	0	0	0	0	0	0
PS061	Chrysopetalidae	Dysponetus	sp. B	0	5	1	0	1	2	0	0	0	1	0	0
PS062	Chrysopetalidae	Paleanotus	sp. A	3	0	0	0	0	0	0	0	0	0	0	0
PS063	Cirratulidae	Caulleriella	sp. A	0	0	0	0	0	0	0	0	0	1	0	0
PS064	Cirratulidae	Chaetozone	sp. A	1	1	0	0	0	0	0	0	7	0	0	0
PS065	Cirratulidae	Cirriformia	sp. A	0	0	0	0	0	0	0	0	2	0	1	0
PS066	Cirratulidae	Cirriformia	sp. B	0	0	0	0	0	0	0	0	2	2	0	0
PS067	Cirratulidae	Cirriformia	sp. C	0	0	0	0	0	0	0	0	1	0	0	0
PS068	Cirratulidae	Tharyx	annulosus	5	8	7	0	0	0	0	0	51	20	0	1
PS069	Cirratulidae	Tharyx	marioni	34	12	14	5	3	6	11	58	26	22	5	3
PS070	Cossuridae	Cossura	alba	1	0	0	0	0	0	0	0	0	0	0	0
PS071	Cossuridae	Cossura	alta	0	0	0	0	0	0	1	0	0	0	0	0
PS072	Cossuridae	Cossura	delta	5	0	0	7	0	7	15	120	49	3	0	0
PS073	Cossuridae	Cossura	laeviseta	0	0	0	0	0	0	0	2	0	0	0	0

Table 26. - Continued

	Family	Genus	Species	C1	C7	C4	C14	C12	S5	MT1	MT2	MT3	MT4	MT5	MT6
PS074	Cossuridae	Cossura	soyeri	1	0	0	0	0	0	6	39	8	0	0	0
PS075	Cossuridae	Cossura	sp. A	2	0	0	1	0	0	0	0	4	0	0	0
PS076	Dorvilleidae	Dorvillea	sp. A	0	0	0	0	0	0	0	1	0	0	0	0
PS077	Dorvilleidae	Dorvillea	sp. C	0	0	0	0	0	0	6	0	0	0	0	0
PS078	Dorvilleidae	Genus A	\	3	0	0	0	0	0	11	0	1	0	0	0
PS079	Dorvilleidae	Genus C	\	0	0	0	0	0	0	4	0	2	0	0	0
PS080	Dorvilleidae	Meiodorvillea	sp. A	0	1	2	2	0	2	0	3	0	0	0	0
PS081	Dorvilleidae	Meiodorvillea	sp. B	0	0	0	0	0	4	0	0	1	3	0	0
PS082	Dorvilleidae	Meiodorvillea	sp. C	5	0	0	0	0	0	0	0	0	0	0	0
PS083	Dorvilleidae	Ophryotrocha	sp. A	0	0	0	0	0	0	0	0	3	0	0	0
PS084	Dorvilleidae	Pettiboneia	sp. A	0	0	0	0	0	0	8	6	0	0	0	0
PS085	Dorvilleidae	Pettiboneia	sp. B	0	0	0	0	0	0	0	2	0	0	0	0
PS086	Dorvilleidae	Schistomeringos	pectinata	0	0	0	1	0	0	0	0	0	0	0	0
PS087	Dorvilleidae	Schistomeringos	rudolphi	0	0	0	0	0	0	9	13	0	0	0	0
PS088	Dorvilleidae	Schistomeringos	sp. B	0	2	0	0	0	0	19	0	0	0	0	0
PS089	Eunicea	\	sp.	1	0	0	0	0	0	0	0	0	0	0	0
PS090	Eunicidae	Eunice	antennata	0	0	0	0	0	0	0	0	1	0	0	0
PS091	Eunicidae	Eunice	filamentosa	0	0	0	0	0	0	0	0	0	1	0	0
PS092	Eunicidae	Eunice	tenuis	0	1	4	0	0	0	0	0	0	2	0	0
PS093	Eunicidae	Euniphysa	aculeata	0	0	0	0	0	0	0	3	0	0	0	0
PS094	Eunicidae	Lysidice	ninetta	2	0	0	0	0	0	0	0	0	0	0	0
PS095	Eunicidae	Marphysa	belli	0	0	0	0	0	0	0	1	0	0	0	0
PS096	Eunicidae	Marphysa	conferta	0	1	4	0	0	0	0	0	0	0	0	0
PS097	Eunicidae	Marphysa	mortenseni	0	2	0	0	0	0	0	0	0	0	0	0
PS098	Eunicidae	Marphysa	sp. A	0	0	0	0	0	0	0	1	0	0	0	0
PS099	Eunicidae	Marphysa	sp. F	0	0	0	0	0	0	0	1	0	0	0	0
PS100	Eunicidae	Nematonereis	hebes	0	0	0	0	0	0	0	0	0	0	1	0

Table 26. - Continued

	Family	Genus	Species	C1	C7	C4	C14	C12	S5	MT1	MT2	MT3	MT4	MT5	MT6
PS101	Eunicidae	Palola	siciliensis	0	1	0	0	0	0	0	0	0	0	0	0
PS102	Eunicidae	Paramarphysa	sp.	2	0	0	0	0	0	0	0	0	0	0	0
PS103	Family B	\	sp.	0	0	0	0	0	0	0	0	1	0	0	0
PS104	Fauveliopsidae	Fauveliopsis	sp. A	0	24	0	6	17	5	0	4	32	0	4	4
PS105	Fauveliopsidae	Fauveliopsis	sp. B	0	3	1	0	2	0	0	2	0	2	1	1
PS106	Fauveliopsidae	Fauveliopsis	sp. C	0	1	0	0	0	0	0	0	0	0	0	0
PS107	Flabelligeridae	Brada	villosa	0	1	0	0	0	0	0	0	1	0	0	0
PS108	Flabelligeridae	Diplocirrus	capensis	2	8	6	0	2	0	0	1	6	1	0	0
PS109	Flabelligeridae	Diplocirrus	sp. A	3	4	0	0	0	0	0	0	0	3	0	0
PS110	Flabelligeridae	Diplocirrus	sp. B	3	2	0	0	0	0	0	0	0	0	0	0
PS111	Flabelligeridae	Flabelligera	sp.	0	1	0	0	0	0	0	0	0	0	0	0
PS112	Flabelligeridae	Pherusa	inflata	0	0	0	0	0	0	0	2	0	0	0	0
PS113	Flabelligeridae	Therochaeta	sp. A	0	0	0	0	0	0	0	0	2	1	0	0
PS114	Glyceridae	Glycera	sp.	13	33	23	3	6	1	39	22	23	10	9	6
PS115	Glyceridae	Hemipodus	sp.	0	0	0	0	0	0	3	2	0	0	0	0
PS116	Goniadidae	Bathyglycinde	sp. B	0	0	0	1	0	0	0	0	0	0	0	0
PS117	Goniadidae	Goniada	maculata	0	0	0	0	0	0	1	0	0	0	2	0
PS118	Goniadidae	Goniadella	sp. A	0	3	1	2	0	0	0	0	0	0	0	0
PS119	Goniadidae	Ophioglycera	sp. A	0	0	0	1	0	0	0	0	0	0	0	1
PS120	Goniadidae	Progoniada	regularis	0	0	0	0	0	0	1	0	0	0	0	0
PS121	Hesionidae	Genus A	\	20	0	3	0	0	0	1	1	2	0	0	0
PS122	Hesionidae	Gyptis	brevipalpa	0	0	0	0	0	0	1	0	0	0	0	0
PS123	Hesionidae	Gyptis	vittata	0	0	0	0	0	0	4	0	0	0	0	0
PS124	Hesionidae	Nereimyra	sp. B	2	0	0	0	0	0	0	0	0	0	0	0
PS125	Hesionidae	Podarke	obscura	0	0	0	0	0	0	1	0	0	0	0	0
PS126	Iospilidae	Phalacrophorus	pictus	0	0	0	2	0	0	0	0	0	0	0	0
PS127	Longosomatidae	Heterospio	longissima	0	3	1	0	2	0	0	58	21	0	0	2

Table 26. - Continued

	Family	Genus	Species	C1	C7	C4	C14	C12	S5	MT1	MT2	MT3	MT4	MT5	MT6
PS128	Lumbrineridae	Augeneria	bidens	0	0	0	0	0	0	2	4	1	0	1	0
PS129	Lumbrineridae	Lumbrinerides	acuta	0	5	0	5	1	0	0	0	0	5	0	1
PS130	Lumbrineridae	Lumbrinerides	dayi	1	2	3	4	3	0	0	0	0	4	0	2
PS131	Lumbrineridae	Lumbrinerides	sp. A	0	0	0	0	0	0	0	0	2	0	1	0
PS132	Lumbrineridae	Lumbrineriopsis	paradoxa	0	0	3	0	2	0	1	0	4	0	0	0
PS133	Lumbrineridae	Lumbrineris	brebipes	0	1	0	0	0	0	0	0	0	0	0	0
PS134	Lumbrineridae	Lumbrineris	brevipes	0	3	0	0	0	0	1	1	0	0	0	0
PS135	Lumbrineridae	Lumbrineris	candida	0	0	0	0	0	0	6	1	0	2	0	0
PS136	Lumbrineridae	Lumbrineris	coccinea	0	1	0	0	0	0	1	0	0	0	0	0
PS137	Lumbrineridae	Lumbrineris	latrielli	0	0	0	0	0	0	0	1	0	0	0	0
PS138	Lumbrineridae	Lumbrineris	sp. A	0	0	0	0	0	0	0	0	1	0	0	0
PS139	Lumbrineridae	Lumbrineris	sp. B	0	0	1	0	0	0	3	0	2	0	0	0
PS140	Lumbrineridae	Lumbrineris	sp. C	0	2	0	0	1	0	0	0	0	0	0	0
PS141	Lumbrineridae	Lumbrineris	sp. D	0	0	0	0	0	0	0	1	0	0	0	1
PS142	Lumbrineridae	Lumbrineris	verrilli	0	4	1	0	0	2	73	3	9	0	0	0
PS143	Lumbrineridae	Ninoe	sp. A	1	1	0	0	0	0	18	1	3	1	0	0
PS144	Lumbrineridae	Ninoe	sp. C	0	0	0	0	0	0	1	0	0	0	0	0
PS145	Magelonidae	Magelona	sp. G	2	0	0	0	0	0	0	0	0	0	0	0
PS146	Magelonidae	Magelona	sp. J	0	0	1	0	0	0	0	0	0	0	0	0
PS147	Maldanidae	Asychis	atlanticus	0	1	0	0	0	0	0	0	0	0	0	0
PS148	Maldanidae	Axiothella	sp. A	0	3	0	0	0	0	0	0	0	0	0	1
PS149	Maldanidae	Euclymene	sp. A	0	1	0	0	0	0	0	0	0	0	0	0
PS150	Maldanidae	Lumbriclymeninae	sp.	0	0	0	0	0	0	0	0	0	0	0	1
PS151	Maldanidae	Maldane	glebifex	4	5	4	0	0	0	0	1	29	7	0	0
PS152	Maldanidae	Maldane	sp. A	0	2	0	0	0	0	4	3	20	0	0	0
PS153	Maldanidae	Micromaldane	sp.	1	9	14	0	0	0	5	20	35	39	3	0
PS154	Maldanidae	Petaloproctus	sp.	0	0	0	0	0	0	0	0	0	0	0	6

Table 26. - Continued

	Family	Genus	Species	C1	C7	C4	C14	C12	S5	MT1	MT2	MT3	MT4	MT5	MT6
PS155	Maldanidae	Sub Lumriclymeninae	sp.	0	0	0	0	0	0	0	0	0	0	0	8
PS156	Nephtyidae	Aglaophamus	circinata	0	0	0	2	0	0	0	0	2	0	0	0
PS157	Nephtyidae	Aglaophamus	verrilli	6	0	0	0	0	0	267	15	0	0	0	0
PS158	Nephtyidae	Gymnonereis	sp.	0	0	0	0	0	0	0	0	3	0	0	0
PS159	Nephtyidae	Micronephtys	minuta	5	4	1	0	0	3	26	0	1	0	0	0
PS160	Nephtyidae	Nephtys	picta	0	0	0	0	0	0	0	0	1	0	0	0
PS161	Nephtyidae	Nephtys	squamosa	0	0	0	0	0	0	16	0	1	0	0	0
PS162	Nereididae	Ceratocephale	loveni	1	4	1	0	2	1	0	0	3	7	3	0
PS163	Nereididae	Ceratocephale	oculata	1	12	3	0	0	0	0	1	4	6	1	0
PS164	Nereididae	Ceratocephale	websteri	0	1	1	0	0	0	0	0	0	0	0	0
PS165	Nereididae	Gymnonereis	sp.	0	0	0	0	0	0	1	0	0	1	4	0
PS166	Onuphidae	Hyalinoecia	sp.	0	0	0	0	0	0	1	0	0	0	0	0
PS167	Onuphidae	Kinbergonuphis	proalopus	0	0	0	0	0	0	1	0	0	0	0	0
PS168	Onuphidae	Kinbergonuphis	sp. A	0	2	0	0	0	0	0	1	0	0	0	0
PS169	Onuphidae	Nothria	sp.	1	0	0	0	0	0	0	0	0	0	0	0
PS170	Onuphidae	Paradiopatra	abranchiata	0	0	0	0	0	0	0	0	0	1	0	0
PS171	Onuphidae	Rhamphobrachium	atlanticum	0	0	1	0	0	0	0	0	0	0	0	0
PS172	Onuphidae	Sarsonuphis	hartmanae	3	25	2	0	1	0	10	1	0	3	4	2
PS173	Onuphidea	\	sp.	0	0	0	0	0	0	0	1	0	0	0	0
PS174	Opheliidae	Armandia	agilis	0	1	0	0	0	0	0	0	0	0	0	0
PS175	Opheliidae	Armandia	maculata	0	6	1	1	1	1	2	0	1	4	4	0
PS176	Opheliidae	Kesun	sp. A	0	3	0	0	2	0	0	1	0	0	0	0
PS177	Opheliidae	Ophelina	acuminata	0	0	0	0	0	0	0	1	1	0	0	0
PS178	Opheliidae	Ophelina	cylindricaudata	2	2	0	2	1	1	2	1	7	3	0	0
PS179	Opheliidae	Ophelina	sp. A	0	0	0	1	0	0	3	0	0	0	0	0
PS180	Opheliidae	Ophelina	sp. B	0	0	0	0	0	0	0	0	1	0	0	0

Table 26. - Continued

	Family	Genus	Species	C1	C7	C4	C14	C12	S5	MT1	MT2	MT3	MT4	MT5	MT6
PS181	Opheliidae	Ophelina	sp. C	0	0	0	0	0	0	0	0	5	0	0	1
PS182	Opheliidae	Ophelina	sp. E	0	2	0	0	0	0	0	0	0	0	0	0
PS183	Opheliidae	Ophelina	sp . F	0	1	0	0	0	0	0	0	1	0	0	0
PS184	Opheliidae	Polyophthalmus	sp. B	0	1	0	0	0	0	0	0	0	0	0	0
PS185	Opheliidae	Tachytrypane	jeffreysii	0	4	0	0	1	0	0	2	0	0	0	0
PS186	Opheliidae	Tachytrypane	sp. A	42	28	2	11	4	2	0	28	121	0	1	3
PS187	Opheliidae	Tachytrypane	sp. C	0	2	1	3	0	2	0	0	3	0	0	0
PS188	Opheliidae	Tachytrypane	sp. D	0	0	0	0	2	0	0	0	2	0	0	0
PS189	Orbiniidae	Califia	calida	1	1	0	0	0	0	0	2	0	1	0	0
PS190	Orbiniidae	Leitoscoloplos	fragilis	1	0	0	0	0	0	0	0	0	7	0	0
PS191	Orbiniidae	Leitoscoloplos	robustus	1	9	0	1	0	0	0	0	5	4	0	0
PS192	Orbiniidae	Leitoscoloplos	sp. A	0	0	0	0	0	0	0	0	0	2	0	0
PS193	Orbiniidae	Naineris	grubei	0	0	0	0	0	0	0	0	2	0	0	0
PS194	Orbiniidae	Naineris	laevigata	0	0	0	0	0	0	0	0	0	1	0	0
PS195	Orbiniidae	Orbinia	americana	0	0	0	0	0	0	0	0	0	4	0	0
PS196	Orbiniidae	Orbinia	riseri	2	0	1	0	0	0	0	0	1	1	0	0
PS197	Orbiniidae	Proscoloplos	sp.A	0	0	0	0	0	0	0	0	1	0	0	0
PS198	Orbiniidae	Scoloplos	rubra	0	3	0	0	0	0	0	0	1	0	0	0
PS199	Oweniidae	Myriochele	heeri	0	2	5	0	0	0	0	7	0	1	0	0
PS200	Oweniidae	Myriochele	oculata	0	1	2	0	0	0	0	1	0	0	0	1
PS201	Oweniidae	Myriochele	sp. A	0	0	1	0	0	0	0	0	1	4	0	1
PS202	Oweniidae	Myriowenia	oculata	0	1	0	0	0	0	0	0	0	0	0	0
PS203	Oweniidae	Myriowenia	sp. A	0	4	2	0	0	0	0	10	4	6	1	0
PS204	Oweniidae	Owenia	sp. A	0	0	0	0	0	0	0	0	1	0	0	0
PS205	Paralacydoniidae	Paralacydonia	paradoxa	3	10	1	0	0	0	17	6	30	3	1	0
PS206	Paraonidae	Aedicira	belgicae	1	1	7	0	0	0	53	27	1	0	0	0
PS207	Paraonidae	Aedicira	sp.	10	9	17	3	5	0	110	107	0	14	0	0

Table 26. - Continued

	Family	Genus	Species	C1	C7	C4	C14	C12	S5	MT1	MT2	MT3	MT4	MT5	MT6
PS208	Paraonidae	Aedicira	sp. A	0	0	0	0	0	0	39	0	0	0	0	0
PS209	Paraonidae	Aedicira	sp. B	0	0	0	0	0	0	0	0	0	5	0	0
PS210	Paraonidae	Aricidea	abranchiata	0	0	0	0	0	0	0	0	15	0	0	0
PS211	Paraonidae	Aricidea	alisdairi	0	0	0	0	0	0	1	0	0	0	0	0
PS212	Paraonidae	Aricidea	catherinae	0	2	0	0	0	0	87	0	2	0	0	0
PS213	Paraonidae	Aricidea	cerrutii	0	0	5	0	0	0	21	1	7	1	0	0
PS214	Paraonidae	Aricidea	fragilis	0	8	5	0	1	1	37	8	1	10	0	3
PS215	Paraonidae	Aricidea	lopezi_lopezi	4	0	1	0	1	0	20	23	4	10	0	0
PS216	Paraonidae	Aricidea	minuta	0	0	0	0	0	0	1	0	0	0	0	0
PS217	Paraonidae	Aricidea	mirifica	9	4	3	0	0	0	225	41	20	3	0	0
PS218	Paraonidae	Aricidea	quadrilobata	0	0	0	0	0	0	1	0	0	0	0	0
PS219	Paraonidae	Aricidea	simplex	37	18	3	0	1	1	27	36	142	1	1	4
PS220	Paraonidae	Aricidea	suecica	14	42	13	1	4	0	213	55	40	17	4	2
PS221	Paraonidae	Aricidea	trilobata	0	0	0	0	0	0	0	1	14	2	0	0
PS222	Paraonidae	Aricidea	wassi	0	0	0	0	0	0	1	0	0	0	0	0
PS223	Paraonidae	Cirrophorus	abranchiatus	0	3	8	0	1	0	0	1	1	3	0	2
PS224	Paraonidae	Cirrophorus	branchiatus	0	2	3	0	0	0	0	0	1	0	0	1
PS225	Paraonidae	Cirrophorus	brevibranchiatus	0	1	0	0	0	0	0	0	0	0	0	0
PS226	Paraonidae	Cirrophorus	brevicirratus	0	0	0	0	0	0	0	4	0	0	0	0
PS227	Paraonidae	Cirrophorus	forticirratus	0	2	0	0	0	0	0	0	1	0	0	0
PS228	Paraonidae	Cirrophorus	lyra	0	5	3	0	0	1	0	1	2	0	0	0
PS229	Paraonidae	Cirrophorus	neapolitanus	0	1	0	0	0	0	0	0	0	0	0	0
PS230	Paraonidae	Levinsenia	brevibranchiata	30	3	0	2	0	0	10	1	21	0	0	0
PS231	Paraonidae	Levinsenia	gracilis	6	2	0	2	0	0	82	6	3	1	0	1
PS232	Paraonidae	Levinsenia	oculata	0	0	0	0	0	0	1	0	0	0	0	0
PS233	Paraonidae	Levinsenia	oligobranchiata	25	6	0	0	0	0	65	14	4	1	0	0
PS234	Paraonidae	Levinsenia	reducta	0	0	0	0	0	0	0	0	1	0	0	0

Table 26. - Continued

	Family	Genus	Species	C1	C7	C4	C14	C12	S5	MT1	MT2	MT3	MT4	MT5	MT6
PS235	Paraonidae	Levinsenia	uncinata	11	28	12	9	7	0	27	5	27	11	4	3
PS236	Paraonidae	Paraonella	monilaris	0	20	50	40	49	26	24	8	4	25	6	16
PS237	Paraonidae	Paraonella	nordica	0	0	1	0	0	0	0	0	0	0	0	0
PS238	Paraonidae	Paraonella	sp. A	0	12	3	2	3	1	22	0	0	8	0	1
PS239	Paraonidae	Sabidius	cornatus	0	2	0	27	0	23	4	5	20	0	0	0
PS240	Paraonidae	Sabidius	sp. A	15	1	2	0	1	0	10	1	4	0	0	0
PS241	Pectinariidae	Pectinaria	gouldi	0	1	2	0	0	0	0	1	0	2	0	0
PS242	Phyllodocidae	Anaitides	groenlandica	0	0	0	0	0	0	1	0	0	0	0	0
PS243	Phyllodocidae	Anaitides	mucosa	0	0	0	0	0	0	1	2	0	1	0	0
PS244	Phyllodocidae	Eteone	heteropoda	0	0	2	0	3	1	0	0	6	4	0	0
PS245	Phyllodocidae	Eteone	lactea	0	1	0	0	0	0	0	0	0	0	0	0
PS246	Phyllodocidae	Genetyllis	castanea	0	0	1	0	0	0	0	0	0	0	0	0
PS247	Phyllodocidae	Hesionura	sp. A	0	0	0	0	0	0	0	0	2	0	0	0
PS248	Phyllodocidae	Mystides	borealis	0	0	0	0	0	0	1	2	0	0	0	0
PS249	Phyllodocidae	Mystides	monilaris	0	0	0	0	0	0	0	0	0	2	0	0
PS250	Phyllodocidae	Paranaitis	polynoides	0	0	0	0	0	0	1	0	0	0	0	0
PS251	Phyllodocidae	Paranaitis	speciosa	0	0	1	0	0	0	0	0	0	0	0	0
PS252	Phyllodocidae	Protomystides	bidentata	1	4	3	0	1	1	0	0	6	1	0	3
PS253	Pilargidae	Ancistrosyllis	sp. A	1	0	0	0	0	0	1	0	2	0	0	1
PS254	Pilargidae	Ancistrosyllis	sp. B	4	0	0	0	0	0	0	0	0	0	0	0
PS255	Pilargidae	Litocorsa	antennata	0	38	0	0	0	0	0	0	0	0	0	0
PS256	Pilargidae	Sigambra	bassi	1	0	0	0	0	0	2	0	0	0	0	0
PS257	Pilargidae	Sigambra	tentaculata	4	2	0	4	3	1	31	28	2	0	0	6
PS258	Pilargidae	Sigambra	wassi	0	0	0	0	0	0	3	2	0	0	0	0
PS259	Pilargidae	Synelmis	albini	0	0	0	0	0	0	2	0	0	0	0	0
PS260	Pilargidae	Synelmis	klatti	4	4	0	13	0	15	4	5	9	4	2	0
PS261	Pilargidae	Synelmis	sp. B	0	0	0	0	0	0	0	1	1	0	0	0

Table 26. - Continued

	Family	Genus	Species	C1	C7	C4	C14	C12	S5	MT1	MT2	MT3	MT4	MT5	MT6
PS262	Poecilochaetidae	Genus A	\	0	0	0	0	0	0	0	0	0	0	0	1
PS263	Poecilochaetidae	Poecilochaetus	fulgoris	0	0	1	0	0	0	0	0	0	0	0	0
PS264	Poecilochaetidae	Poecilochaetus	vitjazi	0	1	0	0	0	0	0	0	0	0	0	0
PS265	Polynoidae	Harmothoe	sp.	0	1	1	0	0	0	0	0	0	0	0	0
PS266	Sabellariidae	Phalacrostemma	elegans	0	0	0	0	0	0	0	0	0	0	0	3
PS267	Sabellariidae	Phalacrostemma	sp. A	0	1	0	0	0	0	0	0	0	0	0	0
PS268	Sabellidae	Chone	americana	0	1	0	0	0	0	6	0	0	1	0	0
PS269	Sabellidae	Chone	sp. A	2	2	1	0	0	0	1	0	0	0	0	0
PS270	Sabellidae	Chone	sp. B	0	0	0	0	0	0	2	0	0	0	0	0
PS271	Sabellidae	Chone	sp. E	0	0	0	0	0	0	1	0	0	0	0	0
PS272	Sabellidae	Chone	sp. F	0	0	0	0	0	0	2	0	0	0	0	0
PS273	Sabellidae	Chone	sp. G	0	0	0	0	0	0	2	0	0	0	0	0
PS274	Sabellidae	Chone	sp. H	0	0	0	0	0	0	1	0	0	0	1	0
PS275	Sabellidae	Chone	sp. I	0	0	1	0	0	0	0	0	0	0	0	0
PS276	Sabellidae	Chone	sp. N	0	0	0	0	0	0	0	0	0	1	0	0
PS277	Sabellidae	Euchone	incolor	0	4	0	0	0	0	0	0	0	0	0	0
PS278	Sabellidae	Euchone	sp. A	0	3	0	0	0	0	0	0	0	0	0	0
PS279	Sabellidae	Fabricia	sp. B	0	1	1	0	0	0	0	0	0	0	0	0
PS280	Scalibregmatidae	Asclerocheilus	beringianus	0	1	0	0	0	1	0	0	0	0	0	0
PS281	Scalibregmatidae	Scalibregma	inflatum	0	0	0	0	0	0	0	0	5	0	0	0
PS282	Scalibregmatidae	Sclerocheilus	sp. A	0	0	0	0	0	0	0	0	1	0	0	0
PS283	Sigalionidae	Ehlersileanira	incisa	0	3	0	0	0	0	0	1	0	0	0	0
PS284	Sigalionidae	Genus A	\	0	0	0	0	0	0	1	0	0	0	0	0
PS285	Sigalionidae	Pholoe	sp. A	0	0	0	0	0	0	0	0	2	0	0	0
PS286	Sigalionidae	Pholoe	sp. B	0	16	0	0	0	0	0	0	12	0	0	0
PS287	Sigalionidae	Pholoe	sp. C	0	0	0	0	0	0	1	2	2	0	0	0
PS288	Sigalionidae	Sthenelais	sp. A	1	6	0	1	1	0	3	5	0	2	0	0

Table 26. - Continued

	Family	Genus	Species	C1	C7	C4	C14	C12	S5	MT1	MT2	MT3	MT4	MT5	MT6
PS289	Sigalionidae	Sthenolepis	sp. A	0	1	3	0	0	2	0	0	45	0	1	0
PS290	Sigalionidae	Thalenessa	sp. A	0	2	0	0	0	0	0	0	1	0	0	0
PS291	Sphaerodoridae	Ephesiella	sp. A	0	0	1	0	0	0	0	0	0	0	0	0
PS292	Sphaerodoridae	Sphaerephesia	sp. A	4	0	1	0	1	0	0	0	3	0	0	0
PS293	Sphaerodoridae	Sphaerodoridium	sp. A	3	0	0	0	0	0	2	0	0	0	0	0
PS294	Sphaerodoridae	Sphaerodoropsis	sp. A	4	4	1	0	0	0	1	0	1	2	2	1
PS295	Spionidae	Apopriospio	pygmaea	0	0	0	0	0	0	2	0	0	0	0	0
PS296	Spionidae	Aurospio	dibranchiata	0	0	0	0	1	0	0	3	0	0	0	0
PS297	Spionidae	Autospio	dibranchiata	0	0	0	0	0	0	2	0	0	0	0	0
PS298	Spionidae	Boccardiella	sp. A	0	0	0	0	0	0	0	1	0	0	0	0
PS299	Spionidae	Dispio	sp.	0	0	0	0	0	0	1	0	1	0	0	0
PS300	Spionidae	Genus B	\	2	17	8	0	1	0	4	1	31	4	0	1
PS301	Spionidae	Laonice	cirrata	0	1	4	2	1	0	23	0	12	0	0	1
PS302	Spionidae	Malacoceros	sp.	0	1	0	0	0	0	0	1	6	1	0	0
PS303	Spionidae	Microspio	pigmentata	0	0	0	0	0	0	0	0	1	0	1	0
PS304	Spionidae	Nerinides	sp.	0	0	0	0	0	0	0	0	1	0	0	0
PS305	Spionidae	Prionospio	aluta	0	0	0	0	0	0	3	0	0	0	0	0
PS306	Spionidae	Prionospio	cirrifera	61	16	17	6	3	4	315	115	69	13	2	1
PS307	Spionidae	Prionospio	cirrobranchiata	31	0	0	0	0	0	41	20	8	6	0	0
PS308	Spionidae	Prionospio	cristata	3	0	0	0	0	0	23	1	0	0	0	0
PS309	Spionidae	Prionospio	delta	0	0	0	0	0	0	15	0	0	0	0	0
PS310	Spionidae	Prionospio	ehlersi	4	1	2	0	0	0	374	6	1	1	0	0
PS311	Spionidae	Prionospio	fauchaldi	0	0	0	0	0	0	2	0	0	0	0	0
PS312	Spionidae	Prionospio	heterobranchia	0	0	0	0	0	0	88	0	0	0	0	0
PS313	Spionidae	Prionospio	japonica	2	0	0	0	0	0	0	0	0	0	0	0
PS314	Spionidae	Prionospio	laciniosa	0	0	0	0	0	0	3	0	0	0	0	0
PS315	Spionidae	Prionospio	multibranchiata	0	0	0	0	0	0	3	5	0	0	0	0

Table 26. - Continued

	Family	Genus	Species	C1	C7	C4	C14	C12	S5	MT1	MT2	MT3	MT4	MT5	MT6
PS316	Spionidae	Prionospio	perkinsi	0	0	0	0	0	0	2	0	0	0	0	0
PS317	Spionidae	Prionospio	steenstrupi	0	0	0	0	0	0	51	0	1	0	0	0
PS318	Spionidae	Prionospio	wireni	0	0	0	0	0	0	0	0	1	0	0	0
PS319	Spionidae	Prionospio Minuspio	sp. A	1	2	0	0	0	0	6	0	2	0	1	0
PS320	Spionidae	Prionspio	ehlersi	0	0	0	0	0	0	0	0	1	0	0	0
PS321	Spionidae	Rhynchospio	sp.	0	0	0	0	0	0	0	0	3	0	0	0
PS322	Spionidae	Scolelepis	sp.	0	0	0	0	0	0	0	0	0	0	1	0
PS323	Spionidae	Spio	pettiboneae	0	1	0	0	0	0	4	0	2	0	0	0
PS324	Spionidae	Spiophanes	berkeleyorum	11	16	7	3	4	1	156	44	55	6	1	4
PS325	Spionidae	Spiophanes	bombyx	0	1	0	0	0	1	0	0	1	1	1	0
PS326	Spionidae	Spiophanes	kroyeri	0	0	0	0	0	0	4	0	0	1	0	0
PS327	Spionidae	Spiophanes	missionensis	0	0	0	0	0	0	0	0	0	0	1	0
PS328	Spionidae	Spiophanes	sp. A	0	0	0	0	0	0	0	0	1	0	0	0
PS329	Spionidae	Spiophanes	sp. D	11	6	5	0	0	0	4	13	33	8	2	1
PS330	Spionidae	Streblospio	sp.	0	0	0	0	0	0	0	0	1	0	0	0
PS331	Spirorbidae	Spirobis Janua	corrugatus	0	0	0	0	0	0	4	0	0	0	0	0
PS332	Syllidae	Autolytus	sp. A	0	1	0	0	0	0	0	0	0	0	0	0
PS333	Syllidae	Brania	swedmarki	0	0	0	0	0	0	0	0	0	0	1	0
PS334	Syllidae	Eusyllis	lamelligera	0	14	0	0	0	0	0	0	0	0	0	0
PS335	Syllidae	Exogone	atlantica	3	0	0	0	0	0	0	0	8	3	12	0
PS336	Syllidae	Exogone	dispar	9	4	3	12	12	0	0	0	23	10	6	1
PS337	Syllidae	Exogone	longicirrus	2	14	6	0	2	0	0	0	1	9	0	1
PS338	Syllidae	Exogone	lourei	0	0	0	0	0	0	0	0	0	0	0	1
PS339	Syllidae	Exogone	sp. A	2	46	8	10	9	7	0	1	42	17	3	3
PS340	Syllidae	Exogone	sp. B	0	14	8	0	0	0	0	0	9	12	16	1
PS341	Syllidae	Exogone	sp. C	0	7	0	0	2	0	0	0	0	1	0	0

Table 26. - Continued

	Family	Genus	Species	C1	C7	C4	C14	C12	S5	MT1	MT2	MT3	MT4	MT5	MT6
PS342	Syllidae	Exogone	sp. D	4	8	4	5	3	0	0	1	1	8	0	0
PS343	Syllidae	Exogone	sp. F	19	2	2	11	1	1	0	0	0	0	0	0
PS344	Syllidae	Exogone	sp. H	0	4	0	0	0	0	0	0	2	0	0	0
PS345	Syllidae	Exogone	sp. I	0	0	0	4	0	0	0	0	0	0	0	0
PS346	Syllidae	Exogone	sp. J	0	3	0	1	0	2	0	0	0	0	0	0
PS347	Syllidae	Exogone	sp. K	0	2	2	3	0	0	0	0	0	0	0	0
PS348	Syllidae	Prionosyllis	sp. B	0	1	0	0	0	0	0	3	0	0	0	0
PS349	Syllidae	Sphaerosyllis	aciculata	0	0	0	0	0	0	0	0	1	0	0	0
PS350	Syllidae	Sphaerosyllis	glandulata	2	0	0	0	0	0	0	0	5	0	0	0
PS351	Syllidae	Sphaerosyllis	longicauda	5	0	0	0	0	0	0	0	1	0	0	0
PS352	Syllidae	Sphaerosyllis	piriferopsis	0	5	3	0	0	0	2	0	2	1	0	0
PS353	Syllidae	Sphaerosyllis	renaudae	1	0	1	0	0	0	0	0	0	0	5	0
PS354	Syllidae	Sphaerosyllis	sp. B	0	0	0	0	0	0	0	0	0	1	0	0
PS355	Syllidae	Sphaerosyllis	taylori	0	7	5	0	0	0	0	0	3	6	3	0
PS356	Syllidae	Syllides	floridanus	0	1	0	0	0	0	0	0	17	0	0	0
PS357	Syllidae	Syllides	sp. A	0	1	0	0	0	0	0	0	0	0	0	0
PS358	Syllidae	Syllis	cornuta	0	4	0	0	0	0	2	1	0	0	0	0
PS359	Syllidae	Syllis (Ehlersia)	ferrugina	0	11	3	0	0	0	0	0	9	0	0	0
PS360	Syllidae	Syllis (Ehlersia)	sp. A	0	1	0	0	0	0	1	0	0	0	0	0
PS361	Syllidae	Syllis (Syllis)	sp.	0	0	0	0	0	1	0	0	0	0	0	0
PS362	Syllidae	Syllis (Typosyllsi)	sp.	0	1	0	0	0	0	0	0	0	0	0	0
PS363	Terebellidae	Genus A	\	0	0	0	0	0	0	1	0	0	0	0	0
PS364	Terebellidae	Neoleprea	sp. A	0	0	0	0	0	0	0	0	0	0	1	0
PS365	Trichobranchidae	Terebellides	atlantis	0	0	4	0	0	0	7	6	5	2	0	0
PS366	Trichobranchidae	Terebellides	distincta	3	2	11	2	0	0	47	46	8	5	0	1
PS367	Trichobranchidae	Terebellides	stroemi	0	0	0	0	0	0	1	0	0	0	0	0
PS368	Trichobranchidae	Trichobranchus	glacialis	0	0	0	0	0	0	1	0	0	0	0	0

Table 26. - Continued

	Family	Genus	Species	C1	C7	C4	C14	C12	S5	MT1	MT2	MT3	MT4	MT5	MT6
PS369	Trochochaetidae	Trochochaeta	sp.	0	0	0	0	0	0	0	0	0	0	1	0
PS370	Typhloscolecidae*	Travisiopsis	dubia	0	0	0	0	0	0	0	0	1	0	0	0
PS371	Typhloscolecidae*	Travisiopsis	lobifera	0	0	0	0	0	0	0	0	1	0	0	0

Note: * species usually is considered as planktonic species.

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