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Abundance and Diversity of Deep-Sea Crustaceans of Bear Seamount, New England Seamount Chain

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HALMOS COLLEGE OF NATURAL SCIENCES AND OCEANOGRAPHY

Abundance and Diversity of Deep-Sea Crustaceans of Bear Seamount, New England Seamount Chain

By

Valerie Miranda

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Abstract

Bear Seamount (39° 55’ N; 67° 30’ W) is the westernmost peak of extinct undersea volcanoes in the New England Seamount Chain (Moore et al., 2003). It is located on the continental slope off Georges Bank, and is governed by unique environmental factors and currents that may be unlike those of the other seamounts (Moore et al., 2003). Previous cruises to this seamount have been successful in capturing abundant fishes, cephalopods and invertebrates (Moore et al., 2003; Moore et al., 2004; Moore et al., 2008), but only the distribution patterns of the fishes and cephalopods have been examined, leaving a lack of information on the deep-sea crustaceans. The diversity, catch per unit effort (CPUE) and biogeography of trawl-vulnerable micronekton in the vicinity of Bear Seamount were investigated, with primary focus on baseline data collection. Sixty-six species of pelagic Crustacea (Decapoda, Lophogastrida, and Euphausiacea) were collected at 35 trawl stations in the spring of 2003 and 2004 and fall of 2014 with the International Young Gadoid Pelagic Trawl (IYGPT) and a Polytron Midwater Rope Trawl (PMRT). Depths sampled ranged from the surface to 1700 m, with most trawls sampling primarily below 1000 m. When comparing relative biogeography of the nekton in IYGPT samples, the assemblage on the south side of the seamount was the most diverse, while the summit assemblage was the most abundant and species rich. In the PMRT samples, the summit assemblage was the most diverse and species rich while the assemblage on the west side had the greatest abundance. Overall CPUE was dominated by cold temperate species, typical of mid- to higher latitudes in the North Atlantic. *Eusergestes arcticus* and *Meganyctiphanes norvegica* were particularly dominant in both the IYGPT and PMRT samples. At least two species were new records for Northwest Atlantic waters and may have traveled by means of currents and/or from nearby seamounts.

Key words: seamount, Bear Seamount, deep sea, crustaceans, currents, frontal zones

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1 *Introduction*

1.2 *Background*

Seamounts constitute a distinctive deep-sea environment, characterized by substantially enhanced currents (Auer, 1987), exposed rocky bottom (Genin et al., 1986), and a fauna that is dominated by unique pelagic and benthic communities (Samadi et al., 2007). Seamounts are steep-sided submerged mountains of volcanic origin that are broadly spread throughout the world's oceanic depths. Seamounts are produced near mid-ocean spreading ridges, in plate interiors over upwelling mantle plumes and in island-arc convergent zones (Staudigel and Clague, 2010). Estimates of the total number of seamounts range to >100,000 worldwide (Wessel et al., 2010). Most of the knowledge we have about seamounts comes from satellite observations that sense them indirectly from the centimeter-size deflections they impose on sea surface topography (Wessel et al., 2010). This indirect method reliably identifies only features larger than 1500 m, likely underestimating seamount abundances, as many are shorter than 1500 m (Craig and Sandwell, 1988; Smith and Cann, 1992; Wessel et al., 2010). The most direct way of identifying and characterizing seamounts is by bathymetric mapping, although less than 10% (at 1 minute resolution) of the ocean is mapped as such (Becker et al., 2009; Staudigel and Clague, 2010).

Seamounts can have a major influence on the physical structure of the water column (Rogers, 2004), thereby affecting the local environment and biogeographical conditions in several ways. Seamounts have the potential to form eddies of water, called Taylor columns (Hide and Ibbetson, 1966), that are associated with the upwelling of nutrient rich waters, leading to increased productivity (Rogers, 2004; Boehlert and Genin, 2013) in the euphotic zone (0-200 m water depth in clearest oceanic water (Kirk, 1994)). Due to the earth's rotation, topographic irregularities such as seamounts cause hydrodynamic disturbances at great depths, forcing water upward as far as the surface (Hide and Ibbetson, 1966). As the water accelerates towards the surface, it may retain pelagic assemblages over these topographies. These effects depend on many factors, including the size (height and diameter) of the seamount relative to water depth, its latitude, and the character of the flow around the seamount (White et al., 2007; William and Mohn, 2010). Therefore, due to limited resources in the open ocean, seamounts function as important habitats, feeding grounds and sites of reproduction for many open-ocean and deep-sea species (Boehlert, 1993; Lehodey et al., 1997).

Seamount faunas are often highly distinct with endemic organisms limited to a single geographic region, a seamount chain or even a single seamount location (Rogers, 1994; Richer de Forges et al., 2000; Rogers, 2004). The benthic fauna includes species that create structural habitat diversity and essential habitats for deep-sea fishes and crustaceans. The enhanced currents winnow away the sediment, providing hard substrate necessary for most suspension feeders to settle and attach. The benthos are dominated by suspension feeders such as cold-water corals, gorgonians, sea anemones, hydroids, sponges, sea pens and crinoids (Koslow et al., 2001). Other invertebrates such as shrimp, crabs and lobsters are present among seamount walls and summits. These undersea topographies are also able to maintain large stocks of seamount-associated micronekton and demersal fishes, suggesting that they are locations for high rates of energy transfer (Genin and Dower, 2007; Morato et al., 2009; Boehlert and Genin, 2013). Consequently, deep pelagic micronekton provide an essential trophic link in seamount ecosystems (Porteiro and Sutton, 2008).

Despite many studies suggesting seamount endemicity (Richer de Forges et al., 2000; Rogers, 2004), new studies demonstrate that this does not apply to all seamounts; many have no endemic fauna, or some combination of cosmopolitan and endemic (Samadi et al., 2006; McClain, 2007; McClain et al., 2009; Thoma et al., 2009; Howell et al., 2010; Castelin et al., 2011). McClain et al. (2009) examined the faunal composition of the Davidson Seamount off the central California coast and found that the macrofauna was similar to that of the surrounding habitats. A large percentage of the surveyed species was cosmopolitan with ranges extending over much of the Pacific Ocean Basin. Similarly, Samadi et al. (2006) found no local endemism among galatheid crustaceans in a comparison of their geographic distribution patterns between the New Caledonia slope and Norfolk Ridge Seamounts. Their results suggest that the Norfolk Seamounts, rather than functioning as areas of endemism, may instead be highly productive zones that can support numerous species. However, even in this intensively explored area, the richness and the geographic patterns of diversity are still poorly characterized.

Fishing activities (Johnston and Santillo, 2004), mineral mining (Martino and Parson, 2012) and pollution (Ramirez-Llodra et al., 2011) are just a few anthropogenic dangers affecting seamounts. Seamount biota are particularly sensitive and vulnerable to human disturbance and exploitation (Clark et al., 2010). More than 70 fish taxa have been commercially exploited around seamounts (Rogers, 1994), although the number of species that are found exclusively or principally on seamounts is closer to 13-16 (Clark and Koslow, 2007; Watson et al., 2007). Some species, such as the pelagic armorhead, alfonsino, oreos and orange roughy, are efficient targets for fisheries (Koslow, 2016). Added to the disturbance potentially attributable to fishing activities, mining of deep water resources of minerals, oil and gas and gas hydrates are jeopardizing seamount diversity (Valbracht et al., 1997; Mengerink et al., 2014). These are reflected in the growing necessity for species and habitats requiring conservation actions and the need for new management implementation for the deep-ocean.

1.3 *New England Seamount Chain*

The New England Seamount Chain (NESC) is the longest seamount chain in the North Atlantic and consists of more than 30 major extinct volcanic peaks (Duncan, 1984; Moore et al., 2003). It extends southeast from Georges Bank for about 1200 km across the Sohm Abyssal Plain to the eastern end of the Bermuda Rise (Figure 1). The chain is 40-60 km in width with summit depths from 900 to 2300 m below the surface (Moore et al., 2008). The NESC is a result of hot spot activity during the early opening of the central Atlantic (Uchupi et al., 1970; Morgan, 1983). Hotspots often leave volcanic trails on the lithospheric plates passing across them (Duncan and Richards, 1991). Approximately 300 km east of the Nashville Seamount, the furthest southeast seamount in the NESC, the Corner Rise Seamounts form a cluster of peaks midway between the eastern end of the NESC and the Mid Atlantic Ridge. Both the New England Seamounts and the Corner Rise Seamounts resulted from a mantle-plume hotspot, which has traveled eastward under the Mid Atlantic Ridge and now resides underneath the Great Meteor Seamount, south of the Azores in the Northeast Atlantic (Sleep, 1990; Tucholke and Smoot, 1990)

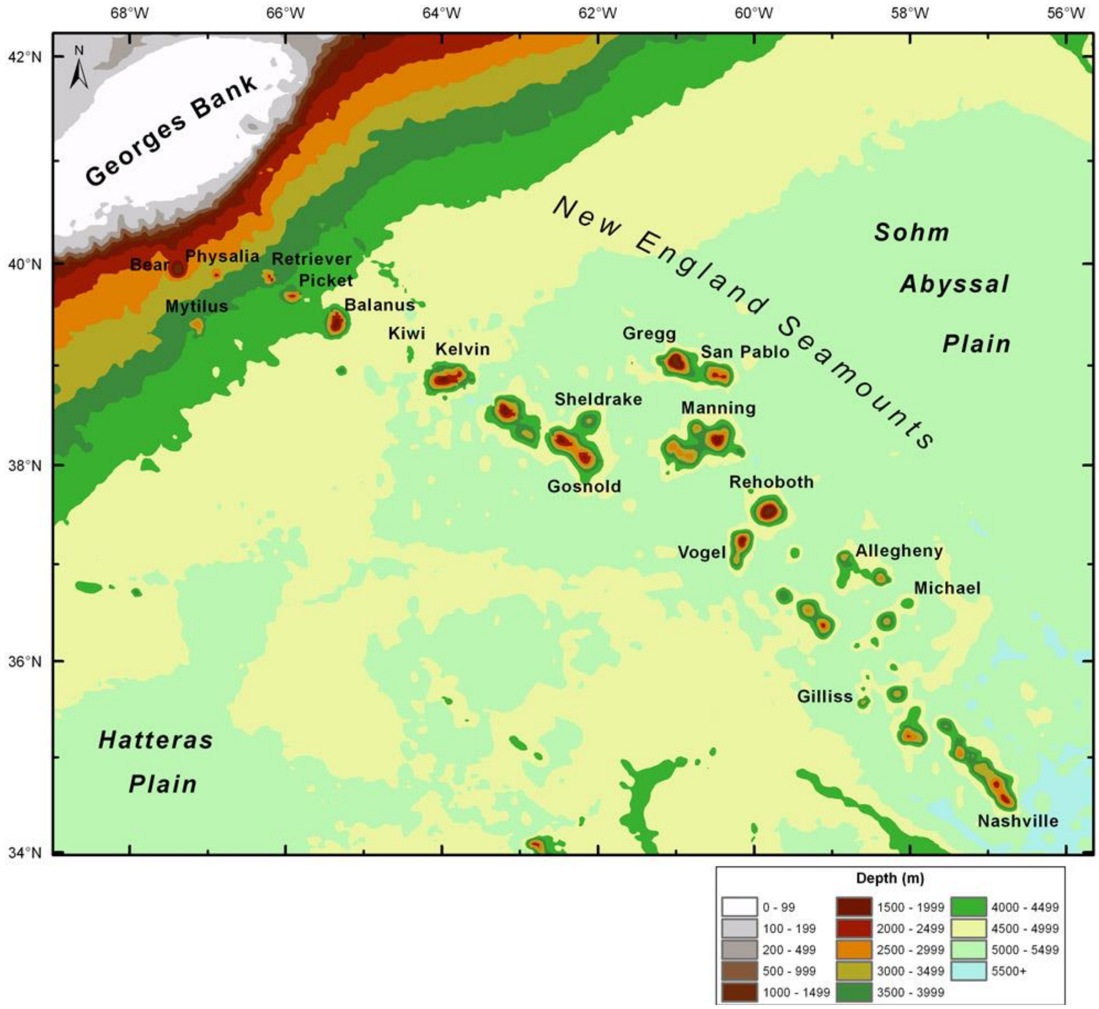


Figure 1. Bathymetric chart of the New England Seamount chain showing color-coded depths (m) (from U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Geophysical Data Center, 2006. 2-minute Gridded Global Relief Data (ETOPO2v2) http://www.ngdc.noaa.gov/mgg/fliers/06mgg01.html)

1.4 *Currents and Gyres*

The NESC lies perpendicular to two major currents: the Gulf Stream, which flows to the northeast, and the Deep Western Boundary Current (DWBC), which flows southwesterly beneath the Gulf Stream along the continental slope (Hamilton et al., 1996; Moore et al., 2003).The Gulf Stream crosses the NESC approximately 1000 km east of Cape Hatteras, bringing with it warm waters from the Gulf of Mexico and Sargasso Sea (Hurlburt and Thompson, 1984). Past Cape Hatteras, the Gulf Stream often exhibits large meanders which occasionally pinch off, forming warm-core rings or, alternatively, cold-core rings (Hansen, 1970). The energy carried by the current can be effectively measured by the eddy kinetic energy (EKE) change around the NESC. The highest levels of EKE were found in the Gulf Stream, south of the chain (Fratantoni, 2001). A five-year climatological survey of the Gulf Stream found that warm-core eddies formed most frequently in the NESC region (Auer, 1987).

Observations have shown that the Gulf Stream is dominated by a broad spectrum of temporal and spatial changes (Cornillon, 1986). As the Gulf Stream emerges from the Straits of Florida, it is bound on the west by the continental margin and flows northward at depths of 500 to 800 m (Teague and Hallock, 1990). Downstream of Cape Hatteras, the stream no longer follows the shelf break but continues northeastward at depths of greater than 4000 m. Gulf Stream variability is primarily the result of the lateral meandering of the current. Gulf Stream meanders east of 67°W are typically 100-200 km in amplitude (Hansen, 1970) and their characteristics change east of the NESC (Richardson, 1983; Cornillon, 1986). Anticyclonic or warm-core rings are formed from pinched-off meanders north of the Gulf Stream in the slope water region (Saunders, 1971; Lai and Richardson, 1977). The movement of warm core rings is generally westward and is confined to a relatively small triangular region bounded on the south by the Gulf Stream and on the north by the continental slope. Auer (1987) found an average of 22 Gulf Stream warm-core rings are formed and absorbed annually between 75°and 44°W with the largest frequency of warm-core ring formations seen near the NESC. Furthermore, the deep-water of the Northwest Atlantic below 750 m is made up of three water masses; Labrador Sea Water overlies Northeast Atlantic Deep Water, derived from the overflow of the Scotland-Iceland Ridge, and this in turn overlies Northwest Atlantic Bottom Water (Lee and Ellett, 1967). The latter is derived from the mixing of water overflowing the Iceland-Greenland Ridge with Atlantic water and modified Labrador Sea Water in the vicinity of the ridge. Mixing of the Northeast Atlantic Deep Water with Northwest Atlantic Bottom Water is thought to give rise to the well-known North Atlantic Deep Water. The shallowest layer is completely entrained by the Gulf Stream and has the ability to affect both meso- and bathypelagic species assemblages (Pickart, 1992). Due to the coupling of these two great currents and their deep circulation, Hogg et al. (1984) found that they form a pronounced barotropic cyclonic gyre called the Northern Recirculation Gyre (NRG). The NRG can be seen between Cape Hatteras and the Grand Banks, and has been observed just to the north of the Gulf Stream path (Hogg et al. 1986). The path of the Gulf Stream and the strength of the cyclonic NRG significantly affect the surface heat flux in the western North Atlantic (Zhang and Vallis, 2007). Moore et al. (2004) found four species of fish (*Hydrolagus pallidus*, *Apristurus microps*, *Gaidropsarus argentatus* and *Bathypterois dubius)* known from the Grand Banks of Greenland and hypothesized that they were dispersed by way of the DWBC to Bear Seamount, as they are more common in boreal waters and from the eastern Atlantic.

In addition, the Antarctic Bottom Water (AABW) flows at the bases of the eastern end of the chain, possibly influencing further recruitment of benthic and pelagic organisms. The AABW is distinguishable by a high-silicate, high-nutrient, low-salinity, low-oxygen signal which gradually warms, mixes and shoals to transform from AABW into Lower North Atlantic Deep Water before recirculating southwards (Dickson and Brown, 1994). This water mass's intensity decreases past the Sohm Abyssal Plain and even more so in the Newfoundland Basin (McCartney and Curry, 1993). Although this deep current may have some effect on the NESC, its general depth range is below 4000 m, which is beyond the depth range sampled in this study.

1.5 *Bear Seamount*

Bear Seamount (39° 55' N; 67° 30' W) is the westernmost extinct volcano in the NESC and lies inside the U.S. Exclusive Economic Zone near Georges Bank. The summit lies at a depth of approximately 1100 m, while the base of the seamount reaches down to depths of 2000-3000 m onto the continental slope (Figure 2, Moore et al., 2003). Bear, which formed about 100 to 103 million years ago, is the oldest constituent of the chain (Duncan, 1984). The seamounts get progressively younger to the south and east; the Nashville Seamount at the southeastern end is only 83 million years old. Bear is a largely flat summit, roughly 8 km across and likely produced by erosion from surface waves, categorizing it as a guyot (Herzer, 1971). The summit is covered in many places with thick sediment, outcrops of basaltic volcanic rock and dispersed Pleistocene glacial erratics of various sizes (Huggett, 1985; Moore et al., 2003). Thus, the seamount's isolated location on the continental slope, unique topography and the three major currents that flow in its vicinity may generate a fauna different from that of the other New England seamounts.

Biogeographically, seamount faunas commonly appear to be related to the faunas of adjacent basins, canyons, ridges, plateaus or continental slopes (Kaufmann et al., 1989; Mironov and Krylova, 2006; O’Hara, 2007; Priede et al., 2013). Seamount faunas also respond to many of the same large-scale oceanographic gradients and anomalies as slope or abyssal faunas (O’Hara, 2007). Seamount-associated fish biogeographical patterns appear to follow the distribution of dominant water masses, such as the North Atlantic Deep Water and Antarctic Intermediate Water (Koslow et al., 1994; Genin, 2004). The dominant genera and families of deep-sea demersal and midwater fishes tend to have more global distributions, while the seamount associated fishes are from entirely different

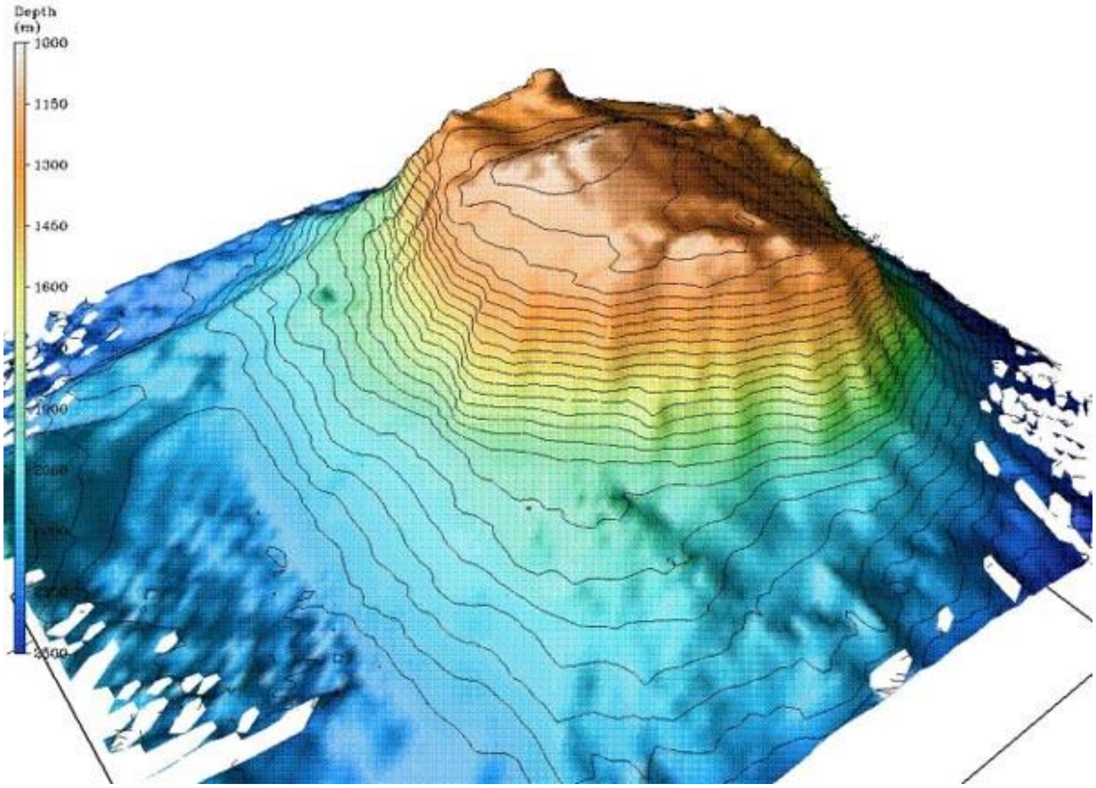


Figure 2. A multibeam swath bathymetric image of Bear Seamount produced on the NOAA OER sponsored Deep East mission in 2001. U.S. Department of Commerce, National Oceanic and Atmospheric Administration (Watling, 2004)

genera, families and orders (Koslow, 2016). Wilson and Kaufmann's (1987) literature review of biota from 100 seamounts found the biota to be dominated by organisms inhabiting the nearest continental areas, especially at higher latitudes. Kelly et al. (2010) also found that Bear Seamount and the Continental Rise had similarities ranging between 25-38% using Bray-Curtis presence/absence data. Consequently, species richness or similarity between seamount assemblages has been found to decrease with distance from the continental margin for some seamount chains and taxonomic groups.

Migratory patterns of the resident fauna reflect the path of local ocean currents and internal waves, as well as topography (Genin and Dower, 2007). Diel vertical migrations (DVM) of micronekton, zooplankton and nekton are often observed above seamounts, shelf breaks or canyons (Genin, 2004). Light is generally regarded as the primary proximate causal factor controlling the movement of diel vertical migrators (Ringelberg, 1964; Forward, 1976; Cohen and Forward, 2005a, b). The most common DVM is an ascent at sunset and a descent at sunrise, which minimizes exposure to visual predators (Gliwicz, 1986; Clark and Levy, 1988; Bollens and Frost, 1989). In deep oceanic and mesopelagic systems, migrations may be modified by endogenous factors such as state of satiation and physiological rhythms (Waterman et al., 1939; Cohen and Forward, 2005b). State of satiation modifies migration such that if an organism is still satiated from the previous night, it would not migrate the next night or would sink after satiation (Forward, 1988; Pearre, 2003). Cohen and Forward (2005b) observed an endogenous rhythm of vertical migration in the marine copepod *Calanopia americana* from the Newport River estuary in North Carolina, by conducting *in situ* and analogous laboratory experiments of their diel migrations. Their results showed significant migrations in the laboratory during a 24-hour dark cycle, suggesting physiological rhythms, with laboratory movements positively correlated with field observations of twilight DVM (Cohen and Forward, 2005b).

These vertical migrations over seamounts often result in horizontal migrations as well, due to prevailing currents. At the Hancock Seamount in the Pacific, the lophogastrid *Gnathophausia longispina* migrated nightly over the seamount and was often carried by a current an average of 6-7 km downstream per night (Wilson and Boehlert, 2004). Additionally, a large number of crustacean species identified from the vicinity of Bear Seamount are known to vertically migrate in other regions, such as decapods (Heffernan and Hopkins, 1981; Flock and Hopkins, 1992), and euphausiids (Mauchline, 1959; Brinton, 1967; Barange, 1990). Vertical migrations coupled with the unique current systems might foster high levels of retention over topographic features such as seamounts.

Decapod crustaceans are distributed worldwide and are well diversified in deep-water communities (Heffernan and Hopkins, 1981; Domanski, 1986; Cartes et al., 1993; Boyko, 2006; Cartes et al., 2007; Castilho et al., 2008). They are major components of pelagic oceanic ecosystems and, as such, would be expected to play an important role in trophic dynamics at intermediate levels in the food web (Hopkins et al., 1994). Another dominant group of the pelagic oceanic systems are euphausiids, which contribute to the intermediate levels of trophic dynamics of the food web (Tarling et al., 1999; Falk-Petersen et al., 2000; Ware and Thomson, 2005). As such, any modeling of the trophic dynamics for the food web at Bear Seamount must include information on the distribution and abundance of micronekton crustaceans, which will be presented in this thesis.

1.6 *Previous Data Collection*

Until this past decade, the fauna associated with the New England Seamounts was basically unknown. Bear was first identified, named and sonar mapped during a series of surveys by Woods Hole Oceanographic Institution vessels in 1954 (Zeigler, 1955). In 1968, the *Alvin* submersible visited the seamount twice for exploratory dives. Further investigations included more sonar mapping, one chain-bag dredge haul and one camera lowering in 1962 on RV *Atlantis* cruise A-281 (Pratt and Thompson, 1962). A commercial exploratory trawl by FV *Matthew Melissa* in 1997 collected specimens deposited at the Peabody Museum of Natural History, Yale University.

Moore et al. (2003) examined the results of exploratory trawling over Bear Seamount by the US National Marine Fisheries Service (NMFS) in 2000. Twenty trawls conducted on and over the seamount captured 115 fish, 26 cephalopod and at least 46 crustacean species. A large number of decapods, amphipods, isopods and euphausiids were recorded, although most were only identified to family or genus (Appendix 1A). Potentially exploitable crustaceans included the scarlet shrimp, *Aristaeopsis edwardsiana*, the glass shrimp, *Pasiphaea* spp. and the porcupine stone crab, *Neolithodes grimaldii*. Appendix 1B lists crustaceans (and pycnogonids) collected during a second cruise in July of 2002 (DE02-

06). Decapoda and Amphipoda were the most abundant crustaceans during the 2002 cruise, but again, identifications were incomplete for the crustaceans, while most fishes were identified to species. Several additional cruises to the NESC followed and are listed in Table 1. Previous surveys at Bear Seamount have recorded some rare species and many new distributional records (Moore et al., 2003; Kensley, 2004; Moore et al., 2004; Hartel et al., 2008). Kensley (2004) re-described a rare isopod *Syscenus atlanticus* previously only known from the Reykjanes Ridge in the mid-North Atlantic. Moore et al. (2004) found new distributional records for 13 species of fish, the squid *Chiroteuthis spoeli*, the seastar *Porcellanaster ceruleus* and the solitary coral *Caryophyllia ambrosia*. They also described how different systems, such as the Gulf Stream, seem to be one of the major vectors for these species distributions. Hubbs (1959) suggested organisms use seamounts as stepping stones as a way of dispersal. Almost all of the new fishes added to the faunal list were typically tropical to subtropical mesopelagic species likely carried by the Gulf Stream. In addition, several species typically found in the eastern Atlantic (*Hydrolagus pallidus*, *Coryphaenoides guentheri* and *Epigonus telescopus*) may have dispersed from the Corner Rise Seamounts. It is important to develop a baseline for the crustacean species occurring at Bear Seamount because they very likely play a critical role in the trophic dynamics. In addition, Bear is located within the U.S. Exclusive Economic Zone and may host species that may be commercially important.

Table 1. Previous cruises to Bear Seamount (Jon A. Moore, pers. comm.). Cruise number is in the following format: letters designate vessel, next two numbers are the year, and last two numbers are the vessel cruise number. Ship abbreviations: DE = R/V *Delaware II*, AT = R/V *Atlantis*, RB = R/V *Ron Brown*, PC = R/V *Pisces*. Years with (*) signify cruises for which the data are not yet published

Cruise Number	**Year**	**Gear Utilized**	**Seamounts Visited**
DE03-04	2003	Midwater/Bottom Trawling	Bear
AT08-01	2003	Alvin/ABE/TowCam Camera Sled	Bear, Manning, Kelvin
DE04-09	2004	Midwater/Bottom Trawling	Bear
RB04-04*	2004	ROV Hercules	Bear, Retriever, Balanus, Manning, Kelvin
DE09-08*	2009	Midwater/Bottom Trawling	Bear
PC12-05*	2012	Midwater/Bottom Trawling	Bear

1.7 *Objectives*

This study examines the pelagic crustacean community from intensive trawling cruises conducted in the vicinity of Bear Seamount in 2003, 2004 and 2014. Patterns of pelagic community composition (species richness, CPUE and diversity) and distribution with respect to geographical location (i.e., on the north, south, east, west and summit) and gear differences were analyzed. These data are compared to results from other regions to determine if the distribution of crustaceans can be correlated to geographical location or environmental influences, as has been done for fish and cephalopods (Moore et al., 2003; Moore et al., 2004; Auster et al., 2005b; Hartel et al., 2008; Moore et al., 2008).

2. *Methods*

Contact with investigators and scientists was made in pursuit of as many samples as possible from previous cruises to Bear Seamount. Bear Seamount crustacean samples from 2003 (DE03-04, 11 stations), and 2004 (DE04-09, 2 stations) were preserved at the Smithsonian Museum of Natural History and sent by Dr. Martha Nizinski to the Halmos College of Natural Science and Oceanography's Deep Sea Biology Laboratory for identification and analysis. Cruise DE03-04 and DE04-09 on the RV *Delaware II* were conducted 13-23 May, 2003 and 2-11 June, 2004. These were a part of a series of exploratory cruises to record species that typically reside below 200 m, from the Scotian Shelf at 43°N to the Mid Atlantic Bight at about 38°N and west of 63°W (Hartel et al., 2008). A large portion of the sampling was concentrated around Bear Seamount. These two cruises utilized an International Young Gadoid Pelagic Trawl (IYGPT) to conduct oblique midwater sampling with the same protocols on both cruises. The IYGPT net typically has a mouth opening of 15×7 m (105 m^2) when fishing and has a mesh size of 100 mm in the front tapering to 10 mm at the codend (Heessen, 1996; Koslow et al., 1997; Koubbi et al., 2011). Each tow was for 60 minutes once the net had reached the selected depth. Tow depths ranged from 300-1700 m with most tows focusing below 1000 m. Trawling was conducted at various locations around the seamount (ie; north, south, east, west and summit). A conductivity-temperature-depth recorder (CTD) was mounted on the head rope to provide temperature and salinity data. Although the CTD may have collected temperature and salinity values at all depths, only maximum net depth salinity and temperature data were available for analysis.

In addition, I participated upon a follow-up cruise to Bear Seamount during 14-26 October, 2014 (PC14-04), aboard the NOAA RV *Pisces*. Cruise PC14-04 sampled 20 midwater stations with two trawls conducted during the day and two at night at each station, one shallow and one deep. The shallow trawl targeted a depth of 700 m and the deep trawl targeted a depth of 1400 m. For this study, we considered shallow trawls to be those that fished above 700 m and deep to be those that fished below 1000 m. Actual tow depths ranged between 596-2238 m, shown by "max net depth" in Table 2. The net utilized for cruise PC14-04 was a Polytron Midwater Rope Trawl (PMRT) manufactured by Superior Trawl in Narragansett, RI. The net had diamond-shaped knotless mesh of 102 × 320 cm at the front, with the mesh at the codend decreasing to 6 cm (60 mm). The codend is the narrow end of a tapered trawl net that catches the organisms, and the inner mesh was 0.25 in (6.35 mm). The midwater trawl doors that helped keep the net open were 3.5 m^2 Series 2000, manufactured by Nets Systems in Bainbridge Island, WA. The ship's speed was maintained at a constant 3.0-3.5 knots during fishing, which provides for optimal function (Koeller and Carrothers, 1981). Some trawling was conducted using the SIMRAD FS70/Turtle/Third Wire Monitoring System. The system provided real time information from the trawl sonar head and the associated sensors to the bridge, thus maximizing fishing efficiency. Ship's officers recorded the time, date, navigational, and station data in the ship's Scientific Computer System (SCS) for each trawl. *In situ* temperature data were recorded via a temperature-depth-recorder (TDR) sensor mounted on the head rope during most deployments. Temperature profiles were used to determine if temperatures near sea surface or at different depths varied at the different stations. Temperature at the maximum net depth was recorded and used to determine which currents were in the vicinity of Bear Seamount. As with the *Delaware II* cruises, sampling took place at various locations around Bear (ie; north, south, east, west and summit). However, trawls averaged 41 minutes while trawls on cruises DE03-04 and DE04-09 averaged 60 minutes.

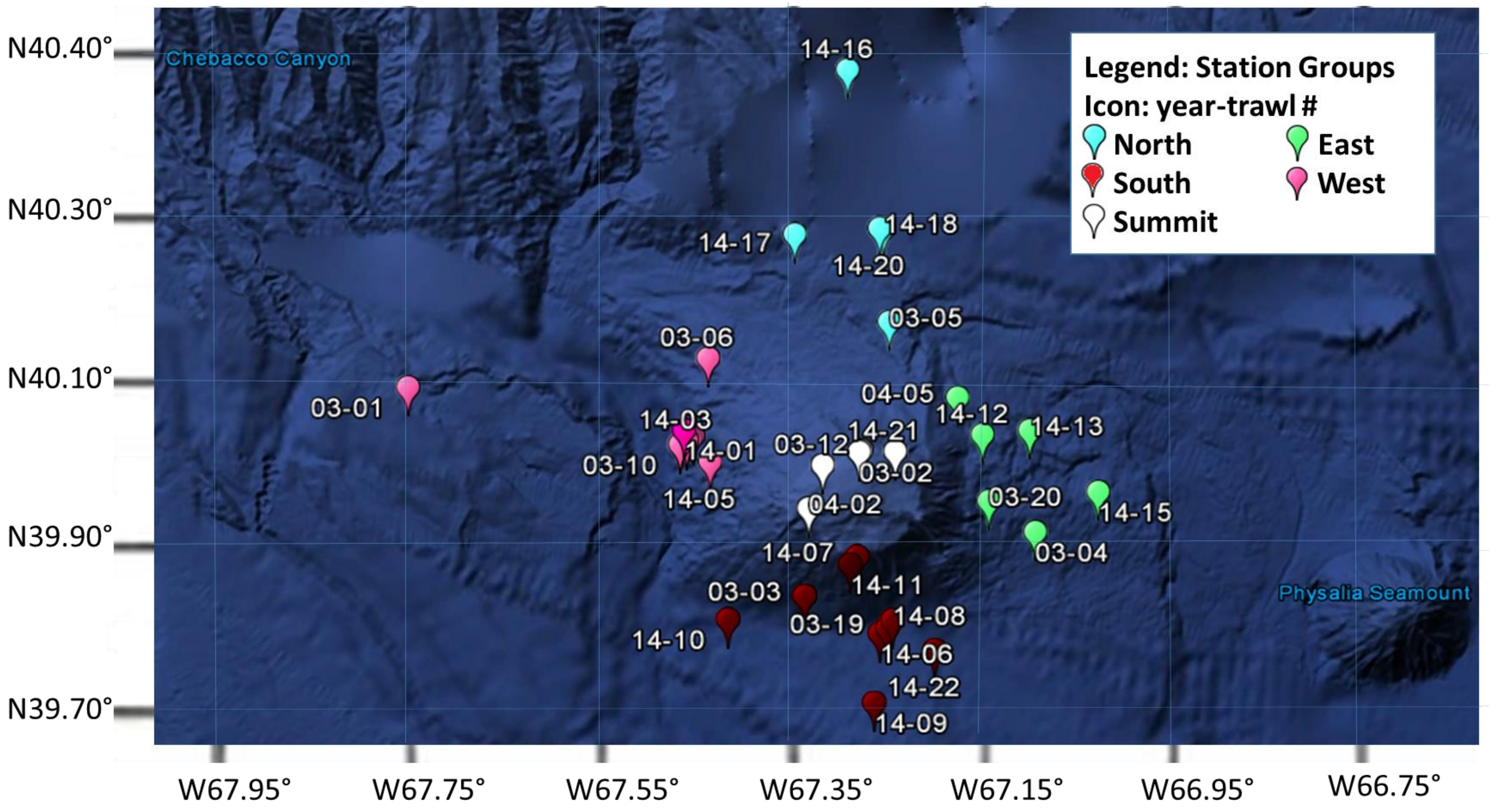


Figure 3. Map of 33 midwater stations trawled on or over Bear Seamount in 2003, 2004 and 2014 on RV *Delaware II* and RV *Pisces*. (Map made using software provided by Google Earth). Icons = Year – Trawl #

All 33 stations were sorted into five locations: north, south, east, west and summit as seen in Figure 3. The gear types used for these cruises were not opening/closing nets that fish at discrete depths, but instead, were oblique trawls that fished large portions of the water column. Therefore, depth specific analyses were not possible.

Table 2. Station data in the vicinity of Bear Seamount from cruises DE03-04, DE04-09 on RV "*Delaware II*" and PC14-04 on RV "*Pisces*". N/A under net depth indicates these data were not available because the TDR or CTD did not work properly or was lost during that trawl

Trawl and Station No.	Start Tow - Date & Time	End Tow – Date & Time	Starting Lat. and Long.	Ending Lat. and Long.	Max Net Depth (M)	Temp at Max Net Depth (C°)
DE03-04-01	05/14/03 1:29:48	05/14/03 2:29:42	39°57.07N 67°79W	39°93N 67°84W	1300	3.977
DE03-04-02	05/14/03 7:15:29	05/14/03 8:39:36	39°55.21N 67°41W	39°91N 67°34W	N/A	N/A
DE03-04-03	05/14/03 12:14:24	05/14/03 1:14:19	39°49.22N 67°45W	39°82N 67°51W	1583	3.591
DE03-04-04	05/15/03 11:00:42	05/15/03 12:00:32	39°52.15N 67°26W	39°91N 67°26W	1599	3.583
DE03-04-05	05/15/03 4:14:25	05/15/03 5:14:33	40°00.57N 67°39W	40°01N 67°45W	1409	3.807
DE03-04-06	05/15/03 9:21:29	05/15/03 10:21:23	39°58.90N 67°54W	39°94N 67°54W	1415	3.862
DE03-04-10	05/16/03 2:51:26	05/16/03 3:51:19	39°54.97N 67°56W	39°95N 57°58W	1546	3.684
DE03-04-12	05/16/03 11:22:34	05/16/03 12:22:29	39°54.83N 67°44W	39°93N 67°40W	674	5.235
DE03-04-13	05/17/03 3:03:20	05/17/03 4:03:16	39° 48.92N 67°45W	39°83N 67°40W	356	9.186
DE03-04-19	05/18/03 3:09:05	05/18/03 4:09:06	39°48.24N 67°38W	39°82N 67°34W	1779	3.459
DE03-04-20	05/18/03 10:19:51	05/18/03 11:19:45	39°53.67N 67°30W	39°91N 67°25W	1696	3.549
DE04-09-02	06/03/04 9:12:13	06/03/04 10:15:26	39°52.54N 67°45W	39°52.94N 67°30.88W	1272	3.73
DE04-09-05	06/04/04 2:00:48	06/04/04 3:00:48	39°57.63N 67°33W	39°55.32N 67°19.78W	N/A	N/A
PC14-04-01	10/15/14 12:42:36	10/15/14 13:11:18	39°55.80N 67°33.43W	39°54.33N 67°32.90W	640	5.14
PC14-04-02	10/15/14 17:15:22	10/15/14 18:13:31	39°55.38N 67°33.28W	39°52.40N 67°31.73W	1226	N/A
PC14-04-03	10/15/14 23:11:08	10/15/14 23:41:49	39°55.60N 67°32.96W	39°54.03N 67°32.23W	641	5.23

PC14-04-04	10/16/14 03:32:15	10/16/14 04:32:19	39°54.55N 67°32.05W	39°51.76N 67°30.41W	1522	4.02
PC14-04-05	10/16/14 13:13:01	10/16/14 14:13:09	39°47.78N 67°23.15W	39°45.21N 67°21.36W	1711	3.75
PC14-04-07	10/16/14 18:42:54	10/16/14 19:12:26	39°50.90N 67°24.46W	39°49.82N 67°23.05W	792	4.84
PC14-04-07	10/16/14 23:40:59	10/17/14 00:40:56	39°48.35N 67°22.55W	39°45.34N 67°21.78W	N/A	N/A
PC14-04-08	10/17/14 04:55:15	10/17/14 05:25:23	39°44.92N 67°23.27W	39°43.51N 67°22.67W	891.95	4.61
PC14-04-09	10/20/14 05:05:10	10/20/14 05:35:12	39°48.10N 67°28.79W	39°48.74N 67°30.78W	765.80	4.90
PC14-04-10	10/20/14 13:05:13	10/20/14 13:56:38	39°50.57N 67°21.32W	39°51.58N 67°24.79W	1439.68	3.93
PC14-04-11	10/20/14 18:33:44	10/20/14 19:04:17	39°56.12N 67°16.10W	39°57.17N 67°18.47W	596	5.55
PC14-04-12	10/20/14 23:31:51	10/21/14 00:01:20	39°56.37N 67°13.99W	39°57.17N 67°16.11W	728	5.16
PC14-04-13	10/21/14 04:18:15	10/21/14 05:18:12	39°53.95N 67°07.53W	39°54.04N 67°12.54W	1234.14	4.19
PC14-04-14	10/21/14 13:07:57	10/21/14 14:08:02	40°10.90N 67°26.66W	40°08.57N 67°26.08W	1961.79	3.55
PC14-04-15	10/21/14 18:32:52	10/21/14 19:03:13	40°04.04N 67°29.17W	40°02.92N 67°28.35W	1055	4.36
PC14-04-16	10/22/14 06:03:15	10/22/14 07:03:15	40°04.45N 67°27.62W	40°03.30N 67°23.89W	N/A	N/A
PC14-04-17	10/22/14 14:25:49	10/22/14 15:10:36	39°59.36N 67°25.71W	39°57.87N 67°25.34W	N/A	N/A
PC14-04-18	10/22/14 23:24:13	10/22/14 23:54:18	40°04.43N 67°25.87W	40°03.94N 67°24.10W	879	4.7
PC14-04-19	10/23/14 03:21:36	10/23/14 03:51:35	39°55.28N 67°24.51W	39°54.76N 67°22.80W	949	4.52
PC14-04-20	10/23/14 15:24:09	10/23/14 08:37:15	39°47.19N 67°22.64W	39°46.61N 67°20.37W	2238	3.20

2.1 *Sample Analysis*

For the *Pisces* samples, the catch was rough sorted onboard the ship into fish, cephalopod and crustacean groups. The crustaceans were further sorted to lowest possible taxonomic identification. Representatives of various species were preserved in ethanol as vouchers for museum specimens or genetic analysis. Each haul was counted, weighed and entered in to the Fisheries Scientific Computer System (FSCS), a digital data acquisition and storage system that recorded total species weight and number, as well as metadata for each sample. Crustaceans not identified to species were stored in 4% formalin and shipped back to the Deep Sea Biology Laboratory at Nova Southeastern University's Halmos College of Natural Sciences and Oceanography in Dania Beach, Florida, and, together with the samples received from the *Delaware II* expeditions, were identified to the lowest practical taxonomic level using various species identification keys (Chace, 1940; Holthuis, 1955; Kensley and Museum, 1971; Pequegnat and Chace, 1971; Crosnier and Forest, 1973; Farfante, 1977; Abele and Kim, 1986; de C. Baker et al., 1990; Perez Farfante and Kensley, 1997; Vereshchaka, 2000; Tavares and Cardoso, 2006; Vereshchaka, 2009).

Catch per unit effort (CPUE) (i.e., catch per minute sampling) was used as the catch rate standardization metric. The catch per unit effort technique is often used to estimate population size when it is not practical to obtain exact counts of individuals in unit-area or unit-volume. This metric was used in this study because flow-meters are not practical on graded-mesh pelagic rope trawls. The difference from the start tow time to the end tow time was used to determine total fishing duration (t). This methodology carries the assumption that the ship traveled at a consistent speed of 3.0-3.5 kts (5.6-6.5 km sec^{-1}) while sampling. This method is justified because calculating the volume of water through the net using parameters taken during the cruise (i.e., ship's position at time (x), winch speed at time (x) and wire out at time (x)) would not be feasible, nor more accurate for such gear (pers. comm. T. Sutton, based on 6-month effort by ASA scientists to calculate flow data under similar circumstances).

Sampling occurred at five locations around the seamount (ie; north, south, east, west and summit). The number of midwater stations in each location and approximate latitude and longitude for those locations by gear type are presented in Table 3. South of the seamount was the most extensively trawled location with 10 of the 33 stations in this approximate locus. East and west of the seamount were the next most extensively trawled locations, followed by the north and summit loci.

Table 3. Station data sorted into regions around the Seamount

Location	No. of Stations		Latitude (Degree, Decimal Min)	Longitude (Degree, Decimal Min)
	IYGPT	PMRT		
North	1	4	40°04.45N	67°27.62W
South	3	7	39°48.35N	67°22.55W
East	3	3	39°56.12N	67°16.10W
West	3	4	39°55.80N	67°33.43W
Summit	3	2	39°59.36N	67°25.71W

2.2 *Alpha Diversity Indices*

Species richness, diversity and CPUE were determined for the north, south, east, west and summit trawls for each gear type. Abundance was expressed as number caught (n) per minute sampling (t). The Shannon diversity index (H’) and species richness (S) were used to examine diversity at each location and by gear type. The Shannon diversity index (H’) was calculated as follows:

$$H' = -\sum p_i (\ln (p_{i'}))$$

where $p_i = n_i / N$, with n_i being the number of individuals in the i^{th} species, and N = the total number of species in all samples. Species richness (S) is the number of species in a given area. In order to demonstrate equitability, or the distribution of individuals among the species, Pielou’s evenness indices (J’ - Pielou, 1975) were calculated according to the equation:

$$J' = H'/H'_{max} = H'/\log S$$

where H'_{max} is the maximum possible value of Shannon diversity (that value achieved if all species were equally abundant). Two trawls that reached max net depths of 1961 m and 2238 m were not used in the analysis because depth is a large factor in species abundances and diversity (Sutton et al., 2008; Sutton et al., 2010), and these two trawls were depth outliers.

2.3 *Statistical Multivariate Analysis*

Data matrices analyzed consisted of CPUE of species by station and location. Due to the non-normality of the data, abundances were transformed using the log (1+x) transformation in univariate statistics: log(x) is undefined as x approaches zero, hence one can convert small x values by adding a constant before taking the log (Clarke et al., 2006). This transformation was performed to alter the performance of the Bray-Curtis coefficient so that it is less erratic for samples with few individuals, and the coefficient can be calculated from samples with complete absences of species at certain stations. It will also down-weigh the contribution of those species with high abundances which could otherwise dictate assemblage patterns (Sutton et al., 2008). Three multivariate techniques were employed to discriminate sample groups, using the Plymouth Routines In Multivariate Ecological Research (PRIMER) v.7 software package (v7: Clarke, 2015): (1) non-metric multi-dimensional scaling (NMDS) (Kruskal and Wish, 1978), (2) analysis of similarity permutation tests (ANOSIM, 9999 iterations, p<5%) (Clarke and Warwick, 1994) and (3) similarity profile permutation tests (SIMPROF; 9999 iterations, p<5%) (Clarke et al., 2008). Ordination by NMDS was employed to differentiate populations among groups. Ordination is generally superior over classification (clustering) in studies such as this due to the relative proximity of sample stations and the possibility of a steady shift in community assemblage across sampling sites in response to changes in environmental factors (Clarke and Warwick, 1994, 2001; Sutton et al., 2010). Ordination by NMDS specifically sets out to map the sites in a specified number of dimensions, again using the pairwise similarities, in such a way that ranks order of dissimilarities between the respective communities (Clarke, 1999). The rank order of dissimilarities is represented in a two-dimensional plot and is summarized in a stress value, which reflects the scatter in a plot of distance versus dissimilarity for all pairs of samples. The stress values are on a scale from 0-1 with 0 meaning absolute difference in a community and 1 meaning absolute similarity in a communty. Stress is therefore defined in terms of total scatter (Clarke, 1993). The test relies on the fact that if multivariate structure is apparent in a group of objects (samples or variables), some pairs of objects will be more, or less, similar to each other than would be expected if the data were essentially random and there was no structure (Somerfield and Clarke, 2013). Therefore, assemblage structure is presented in a series of

NMDS plots. ANOSIM was run to test the null hypothesis that there were no differences between groups of samples as a function of an *a priori* (based on theoretical deduction rather than empircal observation) defined factor. The factors utilized were the five different locations around the seamount. The R statistic produced by this test ranges from zero to one. R-values closer to zero represent no dissimilarities (more similar), while those closer to one represent complete dissimilarity (Clarke, 1990). The results of these tests were then used to explore the power of the location and depth factors and to further examine pairwise comparisons to determine where the major differences occurred. In order to assess the appropriate similarity level for assemblage discrimination, SIMPROF (Clarke et al., 2008) was run to test the null hypotheis that the samples, which were no *a priori* (i.e. based on empircal observation rather than theoretical deduction) divided into groups, did not differ from each other in multivariate struture. The similarity level is then overlain on the NMDS plots to assess natural assemblages. For all statistical tests in this study, differences were considered significant at $p<0.05$.

All methods were based on a triangular matrix of Bray-Curtis similarity coefficients. A Bray-Curtis similarity index is used due to its robust and effective strategy for analysis of multivariate ecological data (Bray and Curtis, 1957; Beals, 1984; Faith et al., 1987). The choice of a coefficient for measuring biological similarity between two samples is highly controlled. For example, the standard Euclidean distance measure that underlies principal component analysis (PCA) is often substandard as a measure of dissimilarity amongst communities (Clarke, 1999). These considerations have led to a widespread adoption of the Bray-Curtis statistic, a form of standardized absolute deviation, for which the similarity between two samples defined as:

$$S_{jk} = 100\frac{\sum_{i=1}^{p} 2\min(y_{ij}, y_{ik})}{\sum_{i=1}^{p}(y_{ij} + y_{ik})}$$

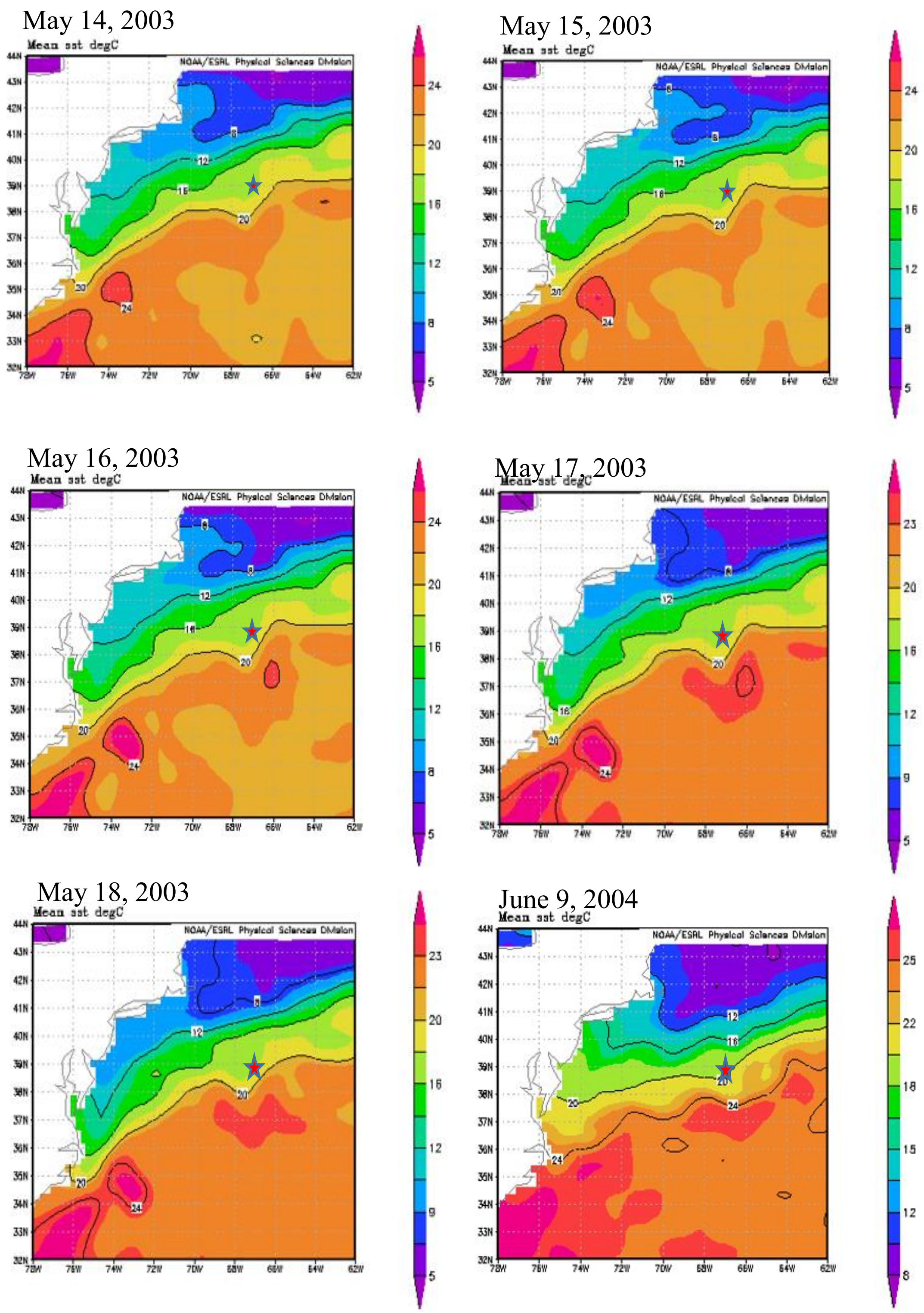
where y_{ij} represents the entry in the i^{th} row and j^{th} column of the data matrix. Similarly, y_{ik} is the count for the i^{th} species in the kth sample. The min term is the minimum of the two counts. The separate sums in the numerator and denominator are both over all rows (stations) in the matrix. Due to the small sample size for stations in 2004, and the fact that the same gear (IYGPT trawl) was used and sampling was conducted aboard the same ship

(RV *Delaware II*) for the 2003 and 2004 cruises, the 2003 and 2004 data were pooled to increase the sample size. Hereafter, I will refer to cruises DE03-04 and DE04-09 as the *Delaware II* samples and PC14-04 as the *Pisces* samples.

3. Results

3.1 *Hydrographic Setting*

SST data from the *Delaware II* cruises are presented in Figure 4. These data show that Bear Seamount is located near a frontal zone that separates SST's between 16-22°C. From May 16-18th a warm-core ring appears to be forming southeast of Bear Seamount, but does not quite cross over it. SST data show that on June 9th, 2004 the temperatures warmed up as the Gulf Stream appeared to shift a little more north than May of the previous year, which correlates to its usual seasonal north-south shift (Auer, 1987; Taylor, 1995). Although we do not have all temperatures at depth for the *Delaware II* cruises, we do have some data from certain trawls of depths at approximately 350 m, 675 m, 1400 m and 1600 m for comparison with the *Pisces* cruise. Temperature at depth for the *Delaware II* cruises was 9.2°C at 350 m, 5.24°C at 675 m, 4.0°C at 1400 m, and 3.6°C at 1600 m (Table 2). Temperature values around 3-4°C are typical of DWBC waters (Pickart, 1992). When comparing temperatures between the two gear types at these depths, on average the *Delaware II* station temperature values were similar to the *Pisces* stations, although data were limited. Temperature depth profile data from the TDR for cruise PC14-04 are presented in Table 4. Sea surface temperatures (SST) throughout the *Pisces* cruise ranged from 19.45°C -23.2°C. SST was as high as 28°C within the Gulf Stream and 22°C over the summit of Bear Seamount. SST data show a warm-core ring forming off of the Gulf Stream during October 15-17th, roughly northeast of Bear Seamount (Figure 5). A warm-core ring containing warm Sargasso Sea water typically has a temperature range from 17-19°C (Joyce et al., 1984), which eventually cools at it mixes with slope waters as the ring ages. To determine if a warm-core ring was a factor in abundance or diversity indices during the time of midwater trawling, I examined temperatures at 200 m depth. Temperatures of 15°C at 200 m are used to describe the northern or shoreward edge of the Gulf Stream (Haedrich, 1972). As shown in Table 4, the warm-core ring's presence was not obvious until the 24th and 25th when the temperature increased to 17.7°C at 200 m. On the 21st at station 15, there


May 14, 2003

May 15, 2003

May 16, 2003

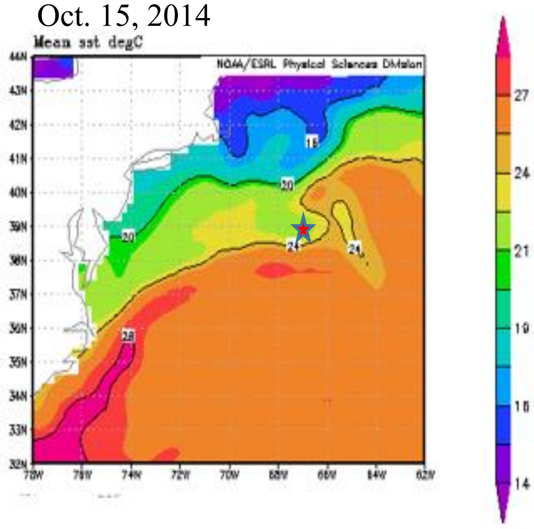
May 17, 2003

May 18, 2003

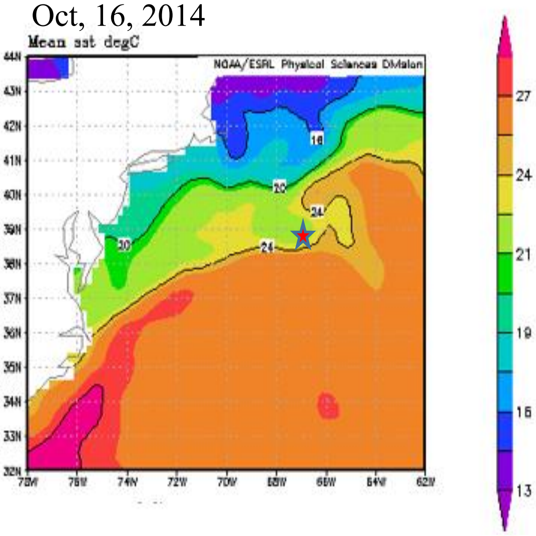
June 9, 2004

Figure 4. High resolution satellite derived sea surface temperature from May 14-18, 2003 and June 9, 2004 while oblique trawling at Bear Seamount aboard the RV *Delaware II* (signified by red star). Image provided by Physical Sciences Division, Earth System Research Laboratory, NOAA, Boulder, Colorado, from their Web site at http://www.esrl.noaa.gov/psd/

Oct. 15, 2014



Oct, 16, 2014



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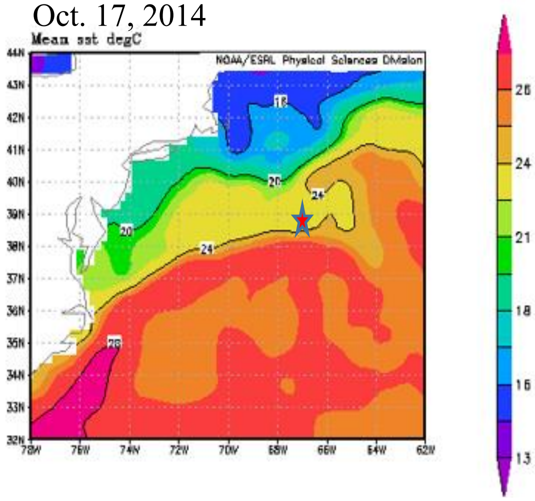

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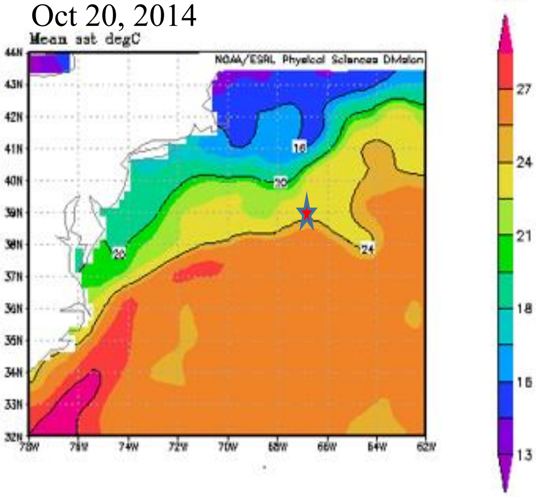

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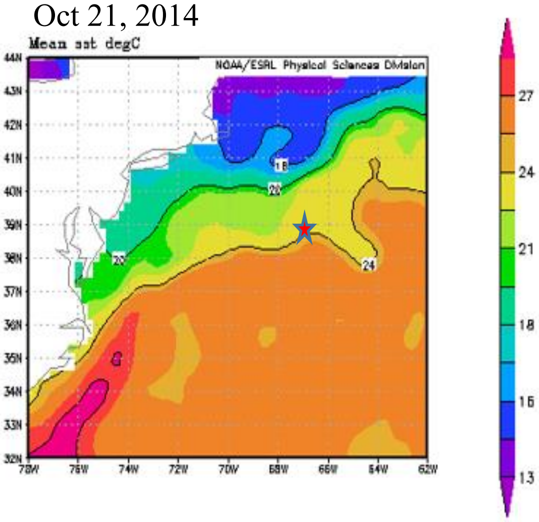

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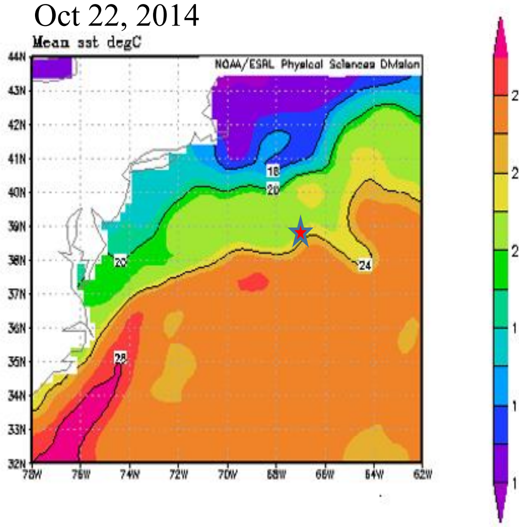

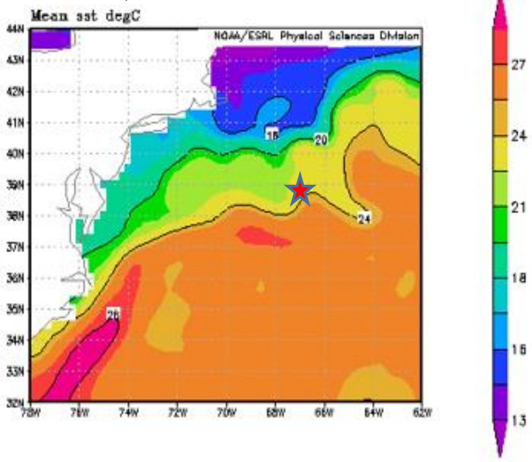
Oct 23, 2014

Figure 5. High resolution satellite derived sea surface temperature from 15-23 October, 2014, while oblique trawling at Bear Seamount aboard the RV *Pisces* signified by red star. Image provided by Physical Sciences Division, Earth System Research Laboratory, NOAA, Boulder, Colorado, from their Web site at http://www.esrl.noaa.gov/psd/

is a spike in the temperature up to 16.3°C at 200 m, however surface temperature did not increase which indicates this spike in temperature may be anomalous or a TDR malfunction. Therefore, it appears that a warm-core ring was not a factor during midwater trawling, which ended on October 23rd.

Overall maximum salinity for the *Delaware II* cruises ranged from 34.91 to 35.03, with little variation. Since salinity was not recorded for the *Pisces* cruise, differences between the different datasets were not compared

3.2 *Faunal Description*

Sixty-six species from 11 families and three orders of Crustacea were identified in the catches of 33 midwater trawl stations from the vicinity of Bear Seamount (Table 5). Overall, the sergestid *Eusergestes arcticus* (formerly *Sergestes arcticus*) and the North Atlantic krill *Meganyctiphanes norvegica* accounted for a combined 56% of the total number of individuals collected. Only nine other species each accounted for more than 1% of the total number of individuals: the decapods *Acanthephyra purpurea, Parapasiphae sulcatifrons, Sergia robusta, Sergia tenuiremis, Acanthephyra pelagica, Oplophorus spinosus, Sergestes atlanticus, Gennadas elegans* and the lophogastrid *Neognathophausia gigas* (formally *Gnathophausia gigas*), in order of greatest to least abundant. The order

Table 4. Dates and stations in October, 2014 on cruise PC14-04 during and after midwater trawling in the vicinity of Bear Seamount. All temperatures are in degree Celsius. MW = Midwater tow and B = Benthic tow

Dates	10/15/14		10/16/14			10/17/14	10/20/14				10/21/14			10/22/14	10/23/14				10/24/14	10/25/14	
Station #	3	4	5	6	7	9	10	11	12	13	15	16	17	20	21	22	23	24	26	27	28
Survey Method	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	B	B	B	B	B
Location	West	West	West	South	South	South	South	East	East	East	East	North	North	North	Summit	South	-	-	-	-	-
10m	22.6	22.8	22.5	22.7	22.8	22.8	23.1	23.3	23.2	23.8	23.5	22.9	22.9	22.4	22.4	22.5	22.6	22.2	20.3	23.0	23.1
200m	12.6	11.9	12.2	13.0	12.8	12.7	12.5	12.8	12.1	13.0	16.3	12.4	11.8	12.4	12.8	12.5	13.9	12.9	14.9	17.7	17.0
350m	8.95	8.9	9.1	8.6	8.7	8.7	8.9	9.3	8.7	9.2	11.2	8.4	8.3	9.1	8.7	8.8	9.8	9.24	10.3	12.6	12.4
675m	5.1	5.2	5.1	5.2	5.1	5.2	5.1	5.1	-	5.4	5.6	5.1	5.1	5.3	5.3	5.2	5.37	5.3	5.4	6.0	5.6
1200m	4.2	-	4.2	4.2	-	-	-	4.2	-	-	4.2	4.2	-	-	-	4.2	4.2	4.17	-	4.3	4.2
1400m	-	-	4.2	4.0	-	-	-	4.0	-	-	-	4.1	-	-	-	4.0	-	-	-	-	-
1600m	-	-	4.0	3.8	-	-	-	-	-	-	-	3.9	-	-	-	3.8	-	-	-	-	-

Decapoda contains two suborders; Dendrobranchiata and Pleocyemata. In this study, 69% of the decapods belonged to the Dendrobranchiata and 39% belonged to the Pleocyemata. Within the Dendrobranchiata, the superfamilies Penaeoidea contained 3.5% of this suborder, while Sergestoidea contained 96.5%. Within the Pleocyemata, all the decapods were in the infraorder Caridea. Three main superfamilies in the infraorder Caridea were present at Bear Seamount: Oplophoroidea, which contained 71%, Pasiphaeoidea which contained 29%, and Pandaloidea which contained 0.13% of carideans.

Oplophoridae (Caridea) was the most species-rich family present, with 19 species represented. Oplophoridae made up 29% of all species with the CPUE dominated by *Acanthephyra purpurea*. The Sergestidae was the second most species-rich family sampled, with 14 species represented, making up 21% of all species and *Eusergestes arcticus* dominating all species with 37.8% of total CPUE. Only five species of Pasiphaeidae were recorded, although; catches of *Parapasiphae sulcatifrons* exceeded those of all other crustacea except *E. arcticus*, the euphausiid *Meganyctiphanes norvegica* and *A. purpurea* (Table 5). The remaining families contributing more than two species were Euphausiidae (9), Benthesicymidae (8), Gnathophausiidae (3), Eucopiidae (2) and Solenoceridae (2). For the higher taxonomic levels, the order Decapoda was by far the most diverse order making up 77% of all catches, with 51 species recorded. Euphausiacea was the second most speciose order with 10 species recorded, followed by the Lophogastrida with five species recorded.

3.3 *Gear Assessment*

Two types of trawls were used for oblique sampling, the smaller IYGPT used on the *Delaware II* cruises and the larger PMRT used on the *Pisces* cruise. The mouth opening of the IYGPT was approximately 105 m^2, while the PMRT was approximately three times that size at 326.4 m^2, and I would hypothesize that we should be catching more and larger organisms with the bigger net. In addition, the PMRT also has a larger mesh size, and I would hypothesize that the smaller organisms would escape through the larger mesh. However, the total CPUE by family (Figures 8, 10) in each location separated out by trawling gear clearly shows that even with a larger mesh size, the PMRT was able to catch smaller species such as euphausiids and sergestids. The inner dimensions of the codend mesh were substantially smaller for the PMRT (6.35 mm) vs. the IYGPT (10 mm), meaning that the PMRT would be able to retain smaller genera once in the codend, such as *Meganyctiphanes* and *Eucopia*. The smaller mesh of the IYGPT was also able to capture approximately the same percentage of larger oplophorids (15%) as the larger mesh PMRT (16%) gear. Although there was a greater percentage of euphausiids in the smaller gear

Table 5. Crustacea collected in the vicinity of Bear Seamount from 33 midwater trawl stations with total CPUE (N/min^{-1}) × 10^{-4}. N = number of species caught, min = minutes trawling

Lowest taxon	**Order**	**Family**	**Total CPUE (N/min^{-1}) × 10^{-4}**
Eusergestes arcticus	Decapoda	Sergestidae	16221.7
Meganyctiphanes norvegica	Euphausiacea	Euphausiidae	7408.44
Acanthephyra purpurea	Decapoda	Oplophoridae	3982.53
Parapasiphae sulcatifrons	Decapoda	Pasiphaeidae	2836.15
Sergia robusta	Decapoda	Sergestidae	2226.51
Sergia tenuiremis	Decapoda	Sergestidae	1722.89
Acanthephyra pelagica	Decapoda	Oplophoridae	1219.28
Neognathophausia gigas	Lophogastrida	Gnathophausiidae	1199.4
Oplophorus spinosus	Decapoda	Oplophoridae	954.22
Sergestes atlanticus	Decapoda	Sergestidae	569.88
Gennadas elegans	Decapoda	Benthesicymidae	424.1
Nematoscelis megalops	Euphausiacea	Euphausiidae	344.58
Gnathophausia zoea	Lophogastrida	Gnathophausiidae	271.69
Sergia grandis	Decapoda	Sergestidae	251.81
Thysanopoda acutifrons	Euphausiacea	Euphausiidae	251.81
Systellaspis debilis	Decapoda	Oplophoridae	245.18
Notostomus gibbosus	Decapoda	Oplophoridae	212.05
Sergestes cornutus	Decapoda	Sergestidae	172.29
Neognathophausia ingens	Lophogastrida	Gnathophausiidae	132.53
Eucopia grimaldii	Lophogastrida	Eucopiidae	125.90
Sergia regalis	Decapoda	Sergestidae	125.90
Gennadas valens	Decapoda	Benthesicymidae	119.28
Meningodora vesca	Decapoda	Oplophoridae	119.28
Thysanopoda cornuta	Euphausiacea	Euphausiidae	106.02
Deosergestes corniculum	Decapoda	Sergestidae	106.02
Funchalia villosa	Decapoda	Penaeidae	99.40
Notostomus elegans	Decapoda	Oplophoridae	79.52
Meningodora mollis	Decapoda	Oplophoridae	72.89
Sergia splendens	Decapoda	Sergestidae	72.89
Eucopia sculpticauda	Lophogastrida	Eucopiidae	59.64
Altelatipes carinatus	Decapoda	Benthesicymidae	39.76
Janicella spinicauda	Decapoda	Oplophoridae	39.76

Hymenodora glacialis	Decapoda	Oplophoridae	33.13
Systellaspis braueri braueri	Decapoda	Oplophoridae	33.13
Acanthephyra acutifrons	Decapoda	Oplophoridae	26.51
Sergestes henseni	Decapoda	Sergestidae	26.51
Benthesicymus bartletti	Decapoda	Benthesicymidae	19.88
Meningodora compsa	Decapoda	Sergestidae	19.88
Pasiphaea multidentata	Decapoda	Pasiphaeidae	19.88
Sergia japonica	Decapoda	Sergestidae	19.88
Acanthephyra curtirostris	Decapoda	Oplophoridae	13.25
Acanthephyra eximia	Decapoda	Oplophoridae	13.25
Ephyrina bifida	Decapoda	Oplophoridae	13.25
Gennadas capensis	Decapoda	Benthesicymidae	13.25
Hepomadus tener	Decapoda	Aristeidae	13.25
Hymenopenaeus laevis	Decapoda	Solenoceridae	13.25
Parasergestes armatus	Decapoda	Sergestidae	13.25
Thysanopoda cristata	Euphausiacea	Euphausiidae	13.25
Acanthephyra stylorostratis	Decapoda	Oplophoridae	13.25
Allosergestes sargassi	Decapoda	Sergestidae	6.63
Bentheogennema intermedia	Decapoda	Benthesicymidae	6.63
Ephyrina benedicti	Decapoda	Oplophoridae	6.63
Ephyrina ombango	Decapoda	Oplophoridae	6.63
Eupasiphae gilesii	Euphausiacea	Pasiphaeidae	6.63
Euphausia krohnii	Euphausiacea	Euphausiidae	6.6265
Gennadas bouvieri	Decapoda	Benthesicymidae	6.6265
Gennadas scutatus	Decapoda	Benthesicymidae	6.6265
Heterocarpus ensifer	Decapoda	Pandalidae	6.6265
Hymenopenaeus debilis	Decapoda	Solenoceridae	6.6265
Pasiphaea hoplocerca	Decapoda	Pasiphaeidae	6.6265
Pasiphaea merriami	Decapoda	Pasiphaeidae	6.6265
Stylopandalus richardi	Decapoda	Pandalidae	6.6265
Systellaspis cristata	Decapoda	Oplophoridae	6.6265
Thysanopoda egregia	Euphausiacea	Euphausiidae	6.6265
Thysanopoda pectinata	Euphausiacea	Euphausiidae	6.6265
Thysanopoda tricuspidata	Euphausiacea	Euphausiidae	6.6265

(IYGPT - 38%) than the larger gear (PMRT - 18%), this finding may be skewed due to the large percentage of sergestids caught with the larger trawl (58%) versus the smaller trawl (10.4%), making up a greater proportion of that net’s total percentage.

There were numerous species recorded in the PMRT net (which has the larger mesh size) that were not caught in the IYGPT net, as seen in Table 6. The most abundant species were *Sergestes atlanticus*, *Sergestes cornutus*, *Deosergestes corniculum* and *Eucopia sculpticauda*, all of which are relatively small species. The IYGPT gear caught five species that were not captured in the PMRT gear, four of which from the order Euphausiacea. *Nematoscelis megalops* was especially abundant in the IYGPT gear from one summit station tow (DE0304-02), while only two other individuals of *N. megalops* were collected, also on the summit (DE0409-02) from another tow with the IYGPT. There were eight species that were caught in two PMRT trawls that fished below 1900 m that were not found at any other stations (Table 6). These species were not included in any statistical analysis because these were the only two tows that went to these depths.

Table 6. Raw counts of species that were only caught with one trawl type and species that were only caught at two PMRT stations that fished below 1900 m

PMRT	N	IYGPT	N	Below 1900 m with PMRT	N
Acanthephyra eximia	2	*Euphausia krohnii*	1	*Acanthephyra stylorostratis*	1
Bentheogennema intermedia	2	*Hymenopenaeus laevis*	2	*Allosergestes armatus*	1
Deosergestes corniculum	17	*Nematoscelis megalops*	52	*Benthesicymus bartletti*	3
Ephyrina benedicti	1	*Thysanopoda pectinata*	2	*Ephyrina ombango*	1
Eucopia sculpticauda	10	*Thysanopoda tricuspidata*	1	*Hepomadus tener*	2
Eupasiphae gilesii	1			*Sergia japonica*	1
Gennadas scutatus	1			*Systellaspis cristata*	1
Heterocarpus ensifer	1			*Thysanopoda egregia*	1
Hymenopenaeus debilis	1				
Janicella spinicauda	6				
Parasergestes armatus	2				
Pasiphae hoplocerca	1				
Pasiphae merriami	1				
Pasiphae multidentata	3				
Sergestes atlanticus	86				
Sergestes cornutus	26				
Sergestes henseni	4				
Sergia splendens	11				
Stylopandalus richardi	1				
Systellaspis braueri braueri	5				

3.3.1 *Diversity as a Function of Gear Type*

In order to assess the effects of gear type on the spectrum of crustaceans sampled, Shannon diversity indices were calculated for all trawl samples by location and a Shapiro-Wilk test was ran to assess normality, followed by a Bartlett's test to determine equality of variances. Due to the north location only having one station in the *Delaware II* samples, the north locus was excluded from statistical analysis diversity comparisons. All location data were determined to be normally distributed and had equal variances. A Welch's Two

Sample t-test was conducted for each location against gear type. As shown in Table 7, there were no significant differences between any locations by the gear type utilized. Furthermore, in order to assess overall diversity by gear type, I calculated diversity indices for all trawl samples by gear type and ran a Shapiro-Wilk and Bartlett's test to determine normality and equality of variances. Both of these test's showed normality and equal variances. A Welch's Two Sample t-test revealed that the mean diversity index of the larger trawl (H'=1.90) was not significantly (p=0.647) higher than that of the smaller (H'=1.81).

Table 7. Statistical results of Shannon Wiener diversity (H') between the two gear types utilized in collection of specimens from Bear Seamount by location

Location	H' IYGPT Mean	H' PMRT Mean	P-value
East	1.46	2.21	0.195
West	1.87	1.47	0.478
South	2.03	1.73	0.08
Summit	1.81	2.26	0.411

3.3.2 *Alpha Diversity Indices as a Function of Trawl Type*

A total of 6448 crustacean specimens was collected, representing 66 species (33 genera) from 11 families. Fifty-nine species were taken in oblique PMRT tows and 37 species were taken with IYGPT tows. A complete species list with CPUE can be viewed in Table 5. All locations with respect to gear type were compared for species richness, diversity and evenness. The Shannon Weiner Diversity index (H') and Pielou's Evenness

Table 8. Indices by net type of average diversity, CPUE ($\times 10^{-2}$ min^{-1}), equitability and species richness among oblique trawling gear samples from Bear Seamount

Gear	Location	S	CPUE ($\times 10^{-2}$ min^{-1})	H'	J'
IYGPT	South	11.3±0.7	144±34	2.03±0.04	0.84±0.01
	East	11.3±1.2	140±59	1.46±0.40	0.62±0.19
	West	11.3±3.5	85.33±25	1.87±0.42	0.79±0.08
	Summit	14.3±4.9	187.67±39	1.81±0.30	0.69±0.09
PMRT	South	10.2±1.4	218.4±62	1.73±0.13	0.76±0.04
	East	17.7±3.3	278.33±71	2.19±0.16	0.77±0.02
	West	18.5±3.4	2971.5±1697	1.47±0.30	0.50±0.09
	Summit	14.5±1.5	145.5±31	2.26±0.08	0.85±0.01
	North	17±3.5	224.67±27	2.22±0.26	0.79±0.04

(J') was recorded for each location to determine if Bear Seamount species have a preference for relative biogeography Averages were analyzed, as these are stronger estimates because of the moderately large nets and long distances towed, serving to homogenize dissimilarities (Hargreaves, 1985b). Due to the north locus only containing one station during IYGPT trawling, it was excluded from alpha diversity indices.

Richness (S) was highest at the summit stations during the *Delaware II* (IYGPT) cruises with an average of 14.3 species recorded (Table 8). Species richness by family utilizing the IYGPT can be seen in Figure 6, showing that Oplophoridae was the most species rich family followed by Euphausiidae. Diversity (H') and evenness (J') were highest south of the seamount on the *Delaware II* cruises, suggesting the species were well distributed here. In comparison, the west locus of the seamount on the *Pisces* cruise (PMRT trawl) had the greatest species richness with 18.5 species on average recorded (Table 8). The west side of the seamount also had, by far the highest CPUE (Table 8), however, it exhibited the lowest H' and J', indicating the high CPUE was due to a few individual species. The most speciose family on the *Pisces* cruise was Oplophoridae followed by Sergestidae (Figure 7). H' was highest on the summit with evenness also relatively high

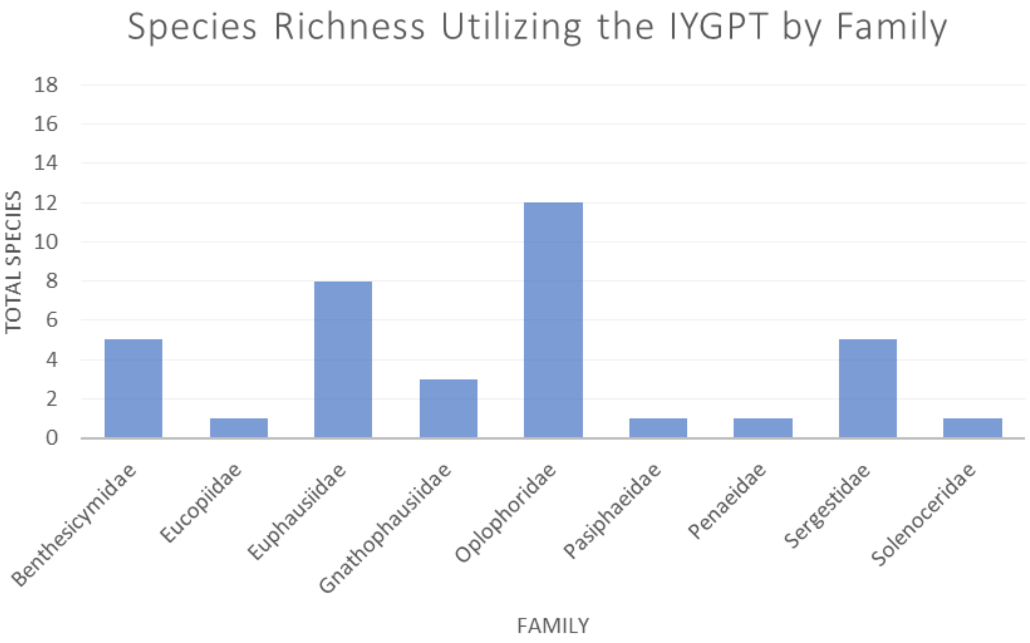

Figure 6. Species richness (S) by family utilizing the IYGPT in the spring around Bear Seamount aboard RV *Delaware II*

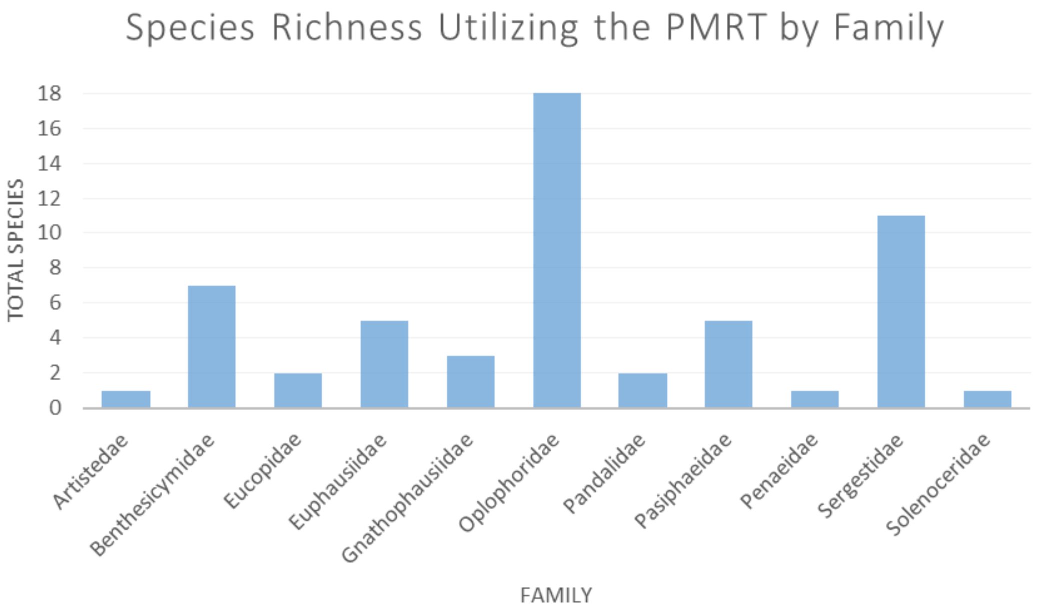

Figure 7. Species richness (S) by family utilizing the PMRT in the fall around Bear Seamount aboard RV *Pisces*

showing equitability, although, it was also the least surveyed locus (2 stations) during this cruise.

3.3.3 *CPUE as a Function of Gear Type*

In order to assess the effects of gear type on the abundance of crustaceans sampled, CPUE for all trawl stations by location was calculated and a Shapiro-Wilk test was ran to assess normality of the data, followed by a Bartlett's test for equality of variances. Because the samples taken with the IYGPT only contained one north side station, the north samples were excluded from the analysis. A Shapiro-Wilk normality test and Bartlett's variance test demonstrated the data from the east and summit stations were normally distributed and had equal variances between both datasets. A Welch's two sample t-test was performed on the data from those locations. In the east, this analysis revealed the *Pisces* mean CPUE (μ=2.78) was not significantly (p=0.21) different than that of the *Delaware II* (μ=1.40) for those locations. Likewise, on the summit stations the mean CPUE on the *Pisces* cruise (μ=1.46) was not significantly (p=0.46) different than that of the *Delaware II* cruise (μ=1.88). Due to the non-normality of the south and west side station data, Wilcoxon-Mann-Whitney U tests were performed on these data. In the south, this analysis revealed that the mean CPUE between the two gear types was not significantly different (p=0.25). In comparison, the west side Wilcoxon-Mann-Whitney U test revealed that the means were barely not significantly different (p=0.057), but due to the near significance, a Kruskal-Wallis Rank Sum Test was performed to further examine the results. This test revealed a significantly different (p=0.034, chi-square value= 4.5) rank sum value which tells us that the data from the west side of the Seamount are actually significantly different between the two gear types. To examine differences between CPUE by gear type incorporating data from all locations, a Wilcoxon-Mann-Whitney U test was utilized due to the non-normality of the data. This analysis revealed significant differences (p=0.012) between the two gear types although this difference may be due to a few outliers from the west side stations. Due to the great abundance of certain species on those west side stations, the analysis was rerun excluding the west side stations. In spite of removing what may be outliers, this analysis revealed a statistically significant (p=0.036) difference between the two CPUE means of the IYGPT (μ=1.39) and PMRT (μ=2.24) gear utilized in this study. Therefore, due to the CPUE being significantly different between gear types, seasonal differences could not be analyzed, and further analysis were conducted within one gear type.

3.3.4 *Delaware II CPUE*

A great range of families were present, with a few species present in great abundance (Figure 8). Oplophoridae made up 45% of all families in the samples with Euphausiidae comprising 26%. Euphausiidae were by far present in the greatest numbers in the east and summit stations, while at the south stations, nearly equal abundances of all families were present. Oplophoridae, Pasiphaeidae and Sergestidae were the only families that were present at all locations around the seamount. CPUE by location varied by species present as well as in total CPUE. As can be seen in Figure 9 the y-axis has a greater range, meaning a larger abundance of species in east and summit stations compared to the other three locations. In the east stations, *Meganyctiphanes norvegica* was present in large numbers, but was only found in small numbers at the summit and south stations. *Nematoscelis megalops* was particularly abundant in the summit stations and was not found in any other location.

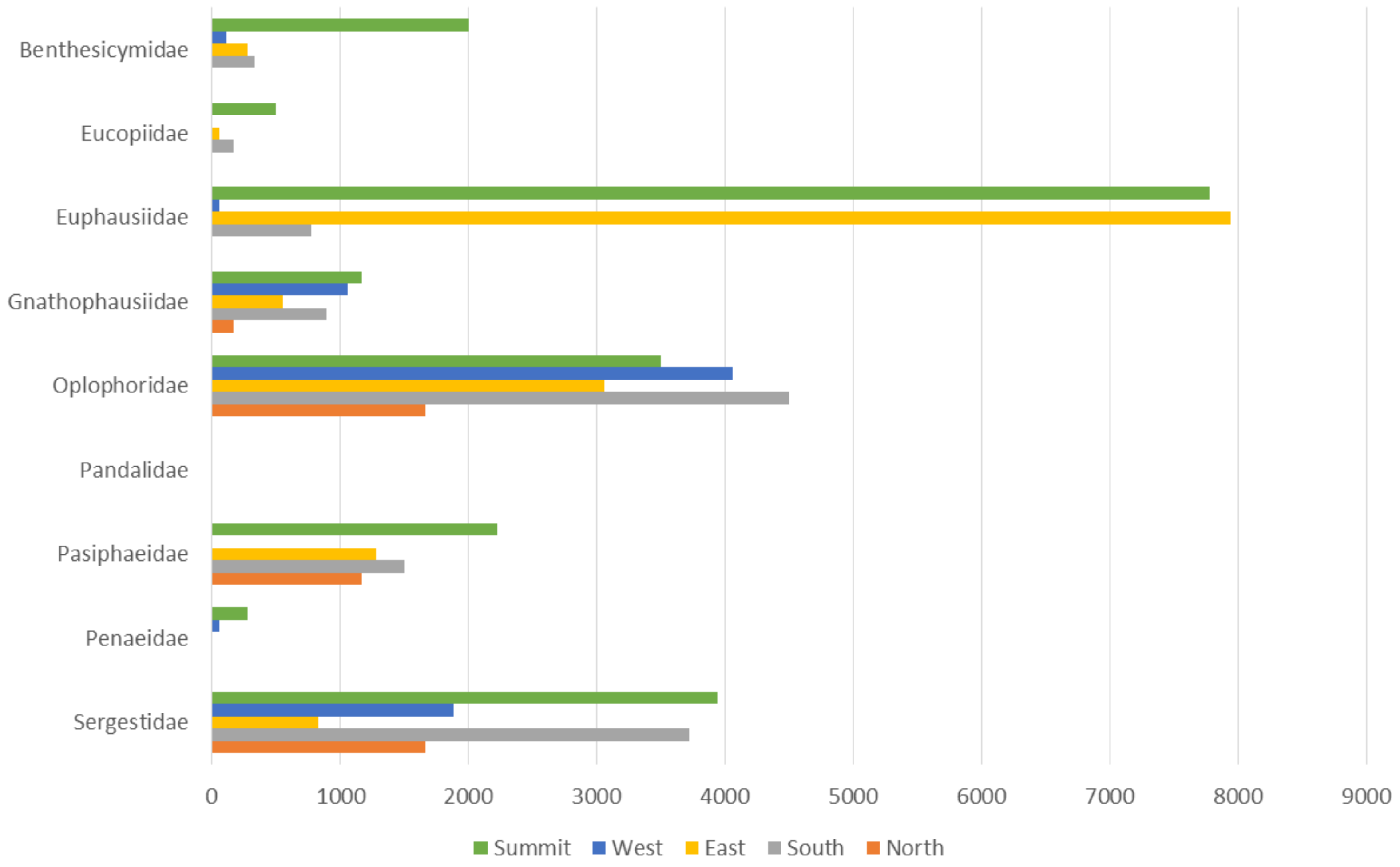

Figure 8. CPUE of all families at each location in the vicinity of Bear Seamount aboard *RV Delaware II* cruises DE03-04 from 11-24 May, 2003 and DE04-09 from May 29-12 June, 2004 utilizing IYGPT gear

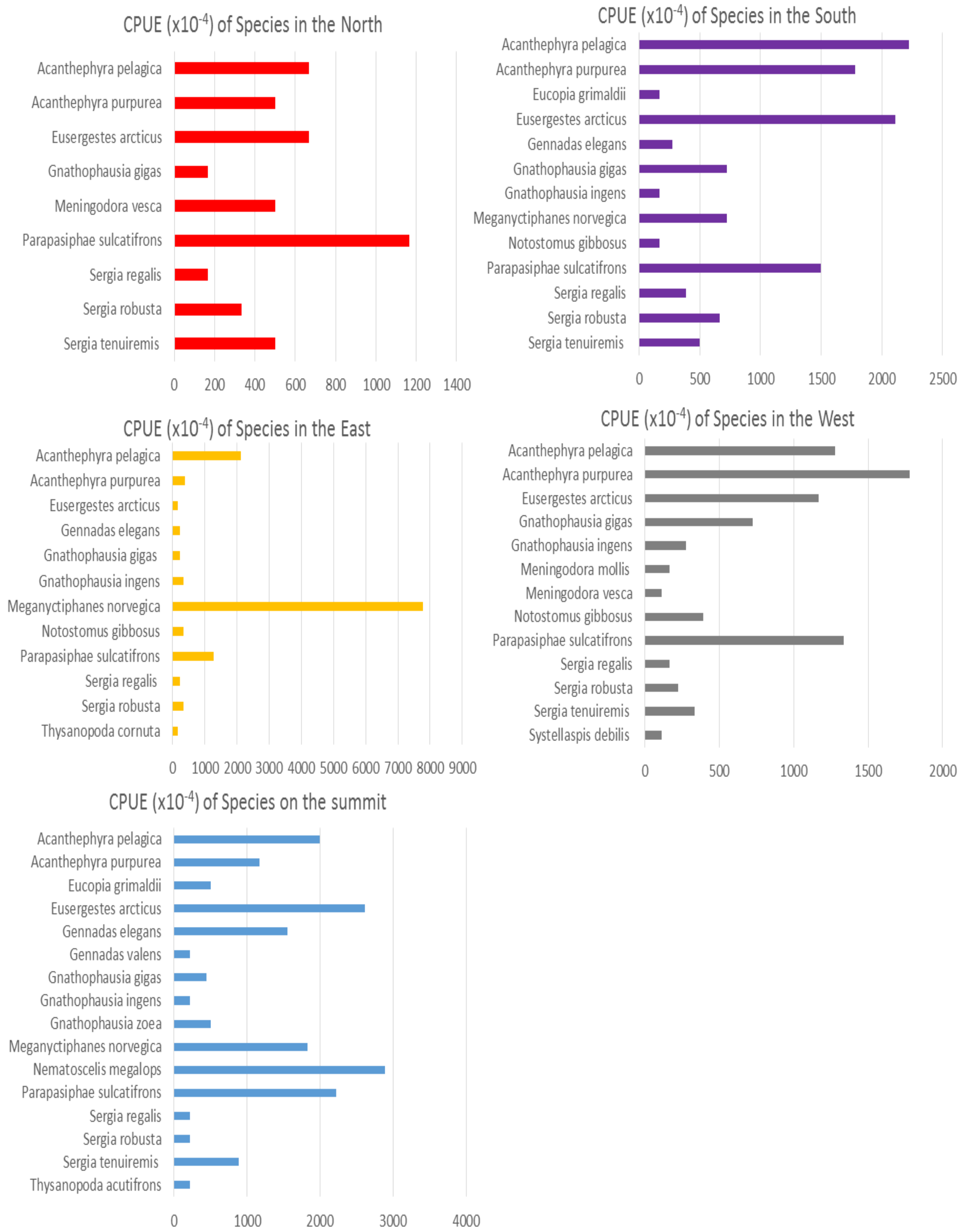

Figure 9. Total CPUE for species comprising >1% of total CPUE in each location for cruises DE03-04 and DE04-09 taken aboard the RV *Delaware II utilizing the IYGPT*

3.3.5 *Pisces CPUE*

The CPUE by family was dominated in shear abundances by Sergestidae and Euphausiidae. This was particularly evident at the west side stations where *Eusergestes arcticus* and *Meganyctiphanes norvegica* were highly abundant (Figure 10). Sergestidae made up 58% of total families followed by Euphausiidae (18%) and Oplophoridae (16%). As can be seen in Figure 11, the CPUE of the individual species varied greatly, as did the range of abundances of species. The y-axis range (indicting the range of abundances) is by far the largest on the west side (Figure 11). Only seven species made up greater than 1% of the total CPUE in the west side samples, with *E. arcticus* making up 58% of the total catch at that locus. The oplophorid *Acanthephyra purpurea* was also very abundant at all locations.

3.4 *Comparison of Pisces CPUEs for "Deep" versus "Shallow" Tows as a Function of Depth*

Analysis was conducted on the differences within trawls that were "shallow" (0-700 m), vs. "deep" (0-1700 m), for only the *Pisces* cruise due to the greater number of stations. Due to the non-normality of the shallow datasets, as determined by the Shapiro-Wilk test, a log transformation was performed, which resulted in a normal distribution. The Bartlett's variance test indicated equal variances, and a one-way ANOVA indicated that the data were significantly different (p=0.02). A Tukey's post-hoc test was performed to determine where the differences arose from. Significant differences between shallow and deep trawls were present between the west and east (p=0.04), west and north (p=0.04) and west and south (p=0.02). Data from deep trawls were also log transformed due to non-normality. The only locations that were sampled more than once were the summit, west and south loci, so these were the only stations included in the analysis. The data were significantly different (One-way ANOVA, p=0.02, Figure 12). A Tukey's post-hoc test revealed that the west against the summit (p=0.03) and the west against the south (p=0.02) were significantly different when comparing the deep stations. Fourteen species were only present in the deep tows from the *Pisces* cruise (Table 9). Most of these species are non-vertical migrators in other parts of the world, as well as residing in the bathypelagic zones.

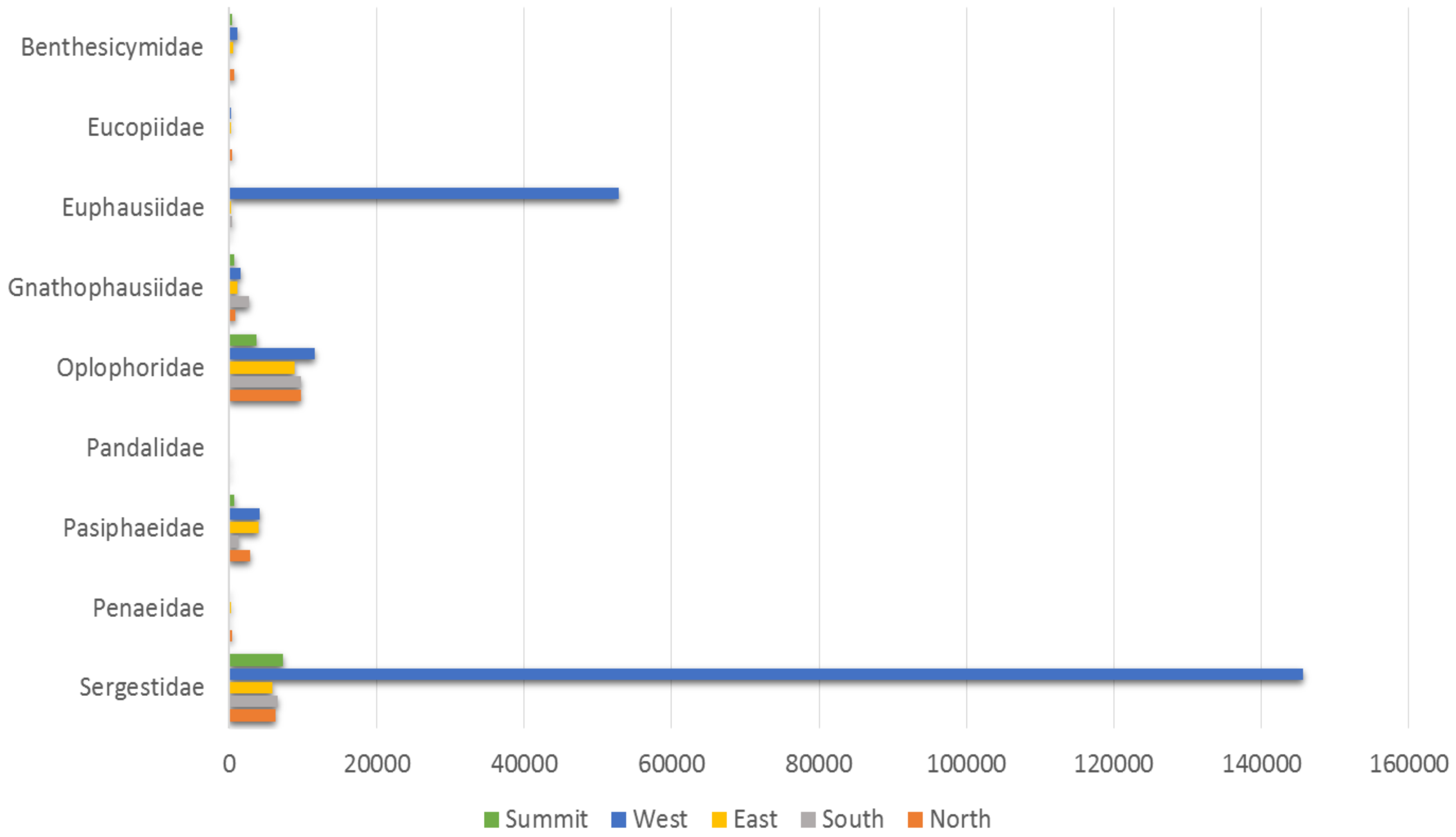

Figure 10. CPUE of all families at each location in the vicinity of Bear Seamount aboard *RV Pisces* cruise PC14-04 from October 14-26, 2014

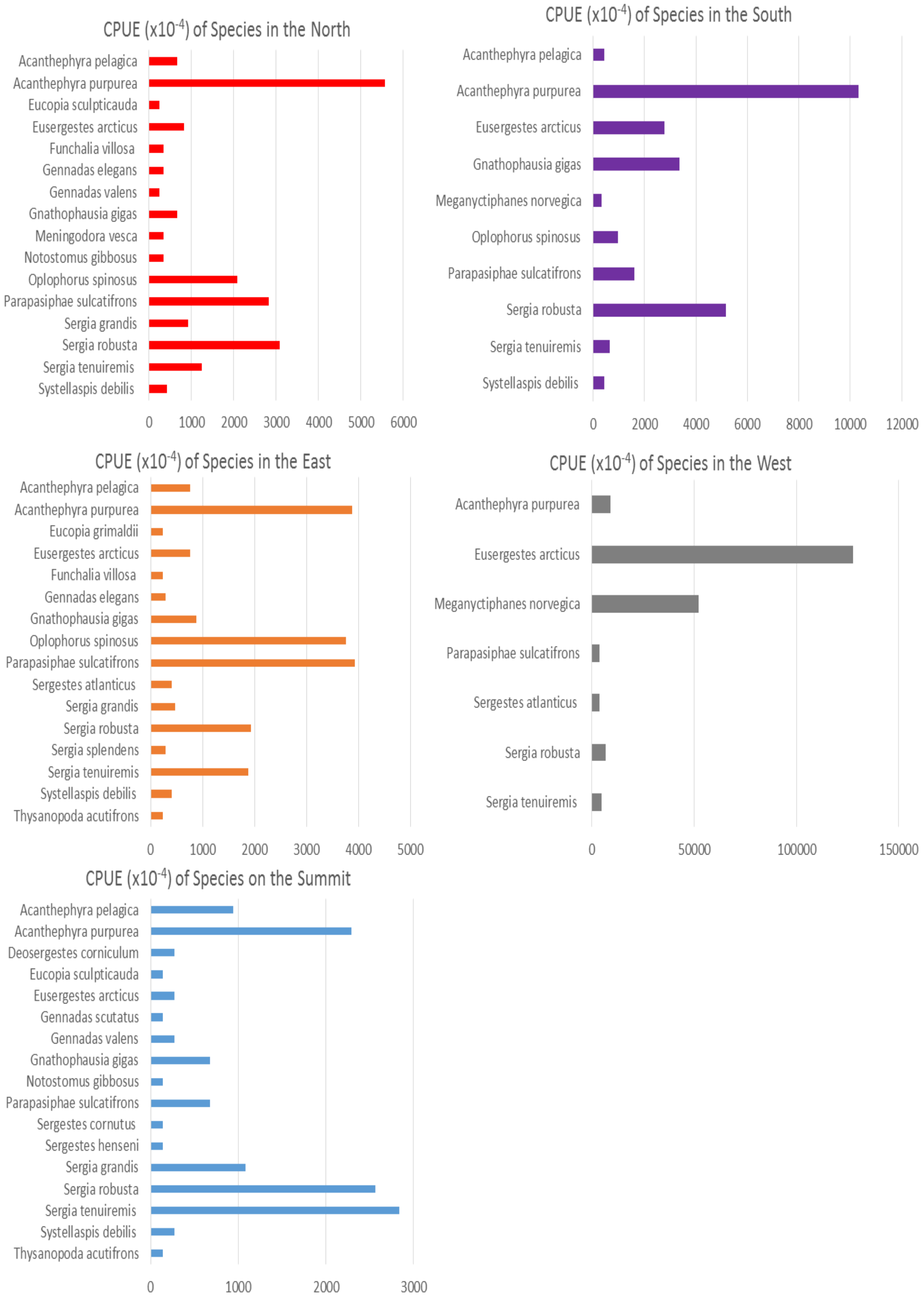

Figure 11. Total CPUE for species comprising >1% of total CPUE in each location for cruise PC14-04 taken aboard the RV *Pisces* utilizing the PMRT

Figure 12. Bar graphs of CPUE showing variance for comparison of the shallow tows (0-700 m) respectively, and the deep tows (0-1700 m) by location for the *Pisces* cruise PC14-04 from October 15-23, 2014 utilizing the PMRT. Only locations that had more than one station were used for comparison

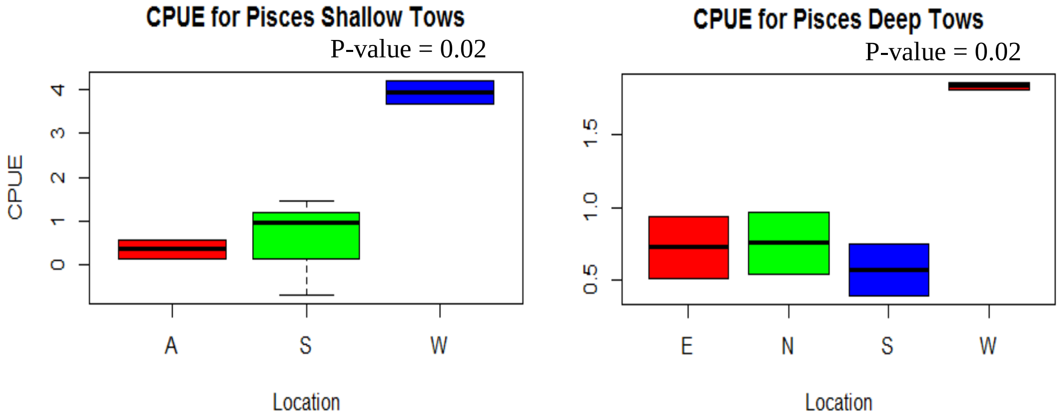

Table 9. Species only caught within the deep (0-1700 m, respectively) tows conducted during cruise PC14-04 in October, 2014 in the vicinity of Bear Seamount, as well as their published depth distributions in other regions

Species	Depth distribution	Sources
Acanthephyra acutifrons	Mesopelagic and Bathypelagic species, non-vertical migrator	Foxton (1972), Donnelly et al. (1993)
Acanthephyra eximia	Mesopelagic and Bathypelagic species 200-4500 m	Jones et al. (2003), Hendrickx and Estrada-Navarrete (1989), Cartes (1993)
Bentheogennema intermedia	Mesopelagic and Bathypelagic species, non-vertical migrator	Heffernan and Hopkins (1981), Domanski (1986)
Ephyrina benedicti	Bathypelagic species 2000-3285 m	Pequegnat and Wicksten (2006), Foxton (1971)
Eupasiphae gilesii	Bathypelagic species 1000-1500 m	Mincks et al. (2000), Crosnier and Forest (1973), Hendrickx and Estrada-Navarrete (1989)
Gennadas capensis	Bathypelagic species 1000-1500 m	Burghart et al. (2007)
Gnathophausia zoea	Bathypelagic species, non-vertical migrator	Hargreaves (1985), Mauchline and Gordon (1991)
Hymenodora glacialis	Bathypelagic species, 1500-4000 m	Burghart et al. (2007), Domanski (1986), Mauchline and Gordon (1991)
Meningodora mollis	Bathypelagic species, 1044-3300 m	Kikuchi and Omari (1985), Hargreaves (1985)
Neognathophausia ingens	Mesopelagic species, 400-800 m	Sanders and Childress (1990)
Pasiphaea hoplocerca	Mesopelagic species, 525 m	Iwasaki (1990), Chace (1940)
Stylopandalus richardi	Mesopelagic species	Domanski (1986)
Systellaspis braueri braueri	Mesopelagic and bathypelagic species, 500-2000 m	Foxton (1970); Hendrickx and Estrada-Navarrete (1989)
Thysanopoda cornuta	Mesopelagic, bathypelagic and abyssopelagic	Brinton (1967)

3.5 *Multivariate Community Analysis*

3.5.1 *RV Pisces PMRT Stations*

Species by station CPUE data matrix with location as a factor were log (x+1) transformed, averaged and plotted using Bray-Curtis similarity indices. A cluster analysis produced a dendrogram with stations on the Y-axis and similarity on the X-axis, illustrating similarities based on location with main groups clustering at 42% similarity (Figure 13; red lines indicate statistically similar groups). When creating a dendrogram by cluster analysis of the overall locations, a cophenetic correlation coefficient is produced. The cophenetic correlation coefficient is the distance at which clusters are combined in and between individual sites (Farris, 1969). Cophenetic correlation coefficients closer to zero indicate that the dendrogram poorly portrays the pairwise differences, while closer to one shows a good representation of dissimilarities in the dendrogram. For the PMRT gear, the cophenetic correlation coefficient was 0.84, which is fairly high, indicating that the dendrogram is a good representation of the visual dissimilarities. Figure 14 displays the corresponding Non-metric Multidimensional Scaling (NMDS) plot with three clusters at 43% similarity and five clusters at 48% similarity. When NMDS stations represented in

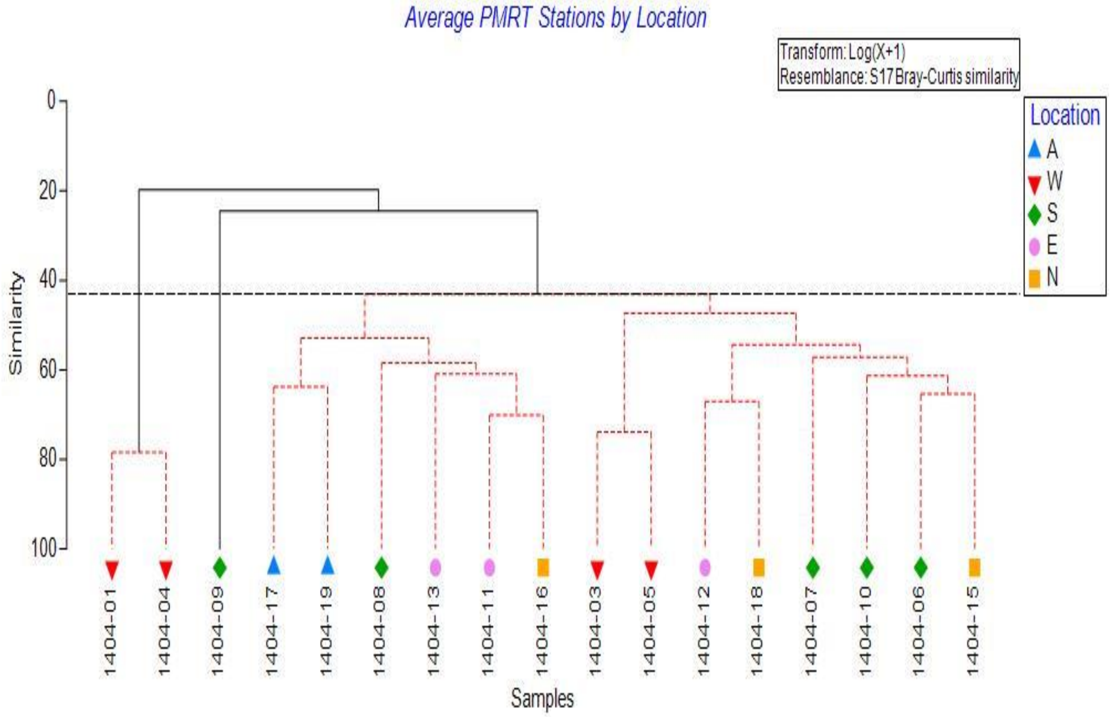

Figure 13. Dendrogram by cluster analysis of *Pisces* PC14-04 stations from Bear Seamount by location. Resemblance at 43% similarity discriminated by SIMPROF

two dimensions were grouped according to 48% similarity, overlap was apparent (Figure 14). The small 2-dimensional stress value (stress=0.1) suggested that NMDS provided a useful 2-d representation of assemblage structure. Stress values were not drastically improved (decreased) via a 3-dimensional ordination (stress=0.05). The first station that separated was PC1404-07, a south side station, which was the most dissimilar. The second and third stations that clustered together are two west location stations, (PC14-04-02 and PC14-04-04) which were grouped alone as they were not similar to any other stations. The last two groups contained all other stations at about 43% similarity, as they did not possess enough differences to be separated any further. Though, these last two main groups showed some similarities between the south side stations as well as the summit locations. The ANOSIM test of species by location found an overall significant separation of loci (p-value=0.037) although with a low R value (R=0.234), indicating that the community data were weakly related to the qualitative location categories for the *Pisces* cruise.

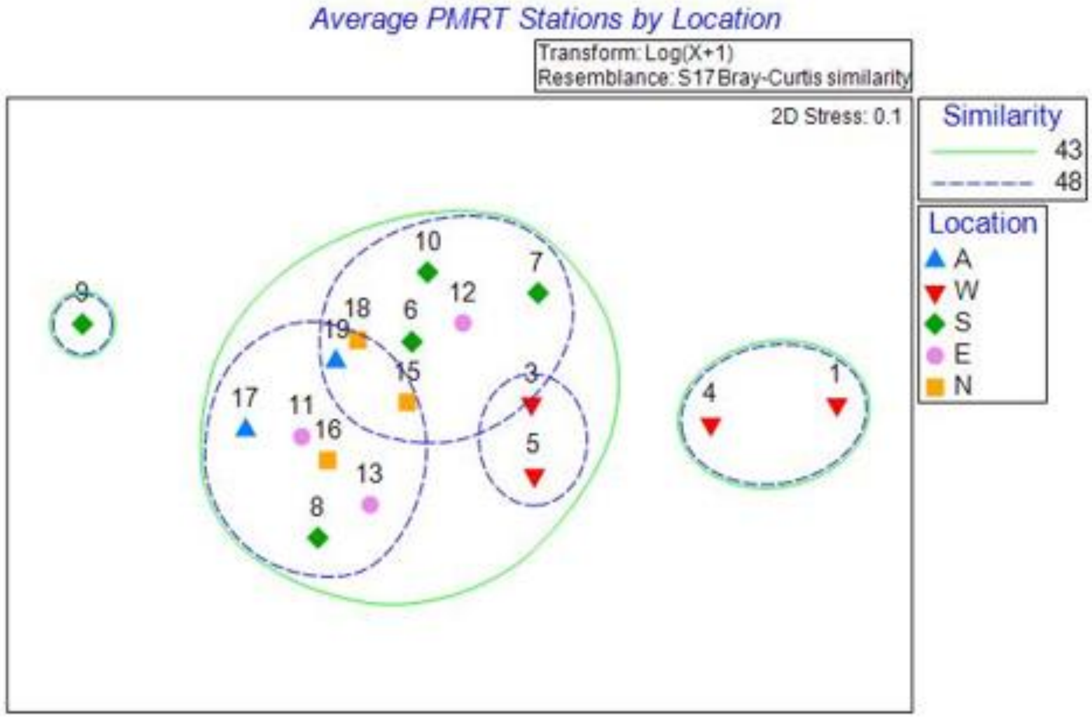

Figure 14. Non-metric multidimensional ordination scaling plot of Bear Seamount deep-pelagic samples collected during cruise PC14-04. Circled groups are based on the classification results discriminated at the 43% and 48% similarity

Species by station data analyzed using a one-way Analysis of Similarities Pair-wise analysis revealed some locations showed significant -differences as well. The west verses the north loci had the R statistic closest to 1 (R=0.704, p-value=0.029), indicating that the location factor was a discriminating factor in assemblage differences, as well as that these two locations being the most dissimilar. The west verses the east showed significant differences (R-value=0.593, p-value=0.029) with a fair R value indicating the location factor explained approximately 60% of the assemblage differences. The west verses the south stations had a lower R value (R= 0.425) although the p-value was highly significant (p-value=0.016) indicating location was less of a factor for the differences seen. The west verses the summit loci showed a high R value (R=0.75) although the p-value was just above significance (p-value=0.067). The R values were of greater significance when looking at pairwise differences using ANOSIM, so, although these two stations were barely above significance, location did explain a great portion of the assemblage differences. In some cases, when working with environmental variables, slightly negative R-values result due to the high variability of the data or possibly an outlier in the data.

Table 10. ANOSIM species by location results, using pair-wise testing to analyze local biogeography. Bold groups indicate significance (<0.05). R-values range between -1 to 1, closer to 1 means complete dissimilarity

Groups	R Statistic	P value
West, South	**0.425**	**0.016**
West, East	**0.593**	**0.029**
West, North	**0.704**	**0.029**
West, Summit	**0.75**	**0.067**
South, East	-0.036	0.536
South, North	-0.149	0.804
South, Summit	-0.073	0.571
East, North	-0.444	0.10
East, Summit	0.167	0.40
North, Summit	0.167	0.50

3.5.2 *RV Delaware II IYGPT Stations*

A cluster dendrogram with stations on the X-axis and similarity on the Y-axis illustrates similarities based on location with two main groups, exhibiting weak overall similarity at 20% (Figure 15). One group consisted of DE0304-02, a summit station and DE0304-04, an east station. Furthermore, the other grouping at 31% similarity contained two main groups, although location was scattered among them, indicating there was not much variation between these trawls. Figure 16 displays corresponding NMDS plots with two clusters at 20% similarity and three clusters at 31% similarity. The NMDS stress value (stress=0.12) was not radically improved via 3-d ordination (stress=0.07). Data may be variable due to the low sample size from each of the locations.

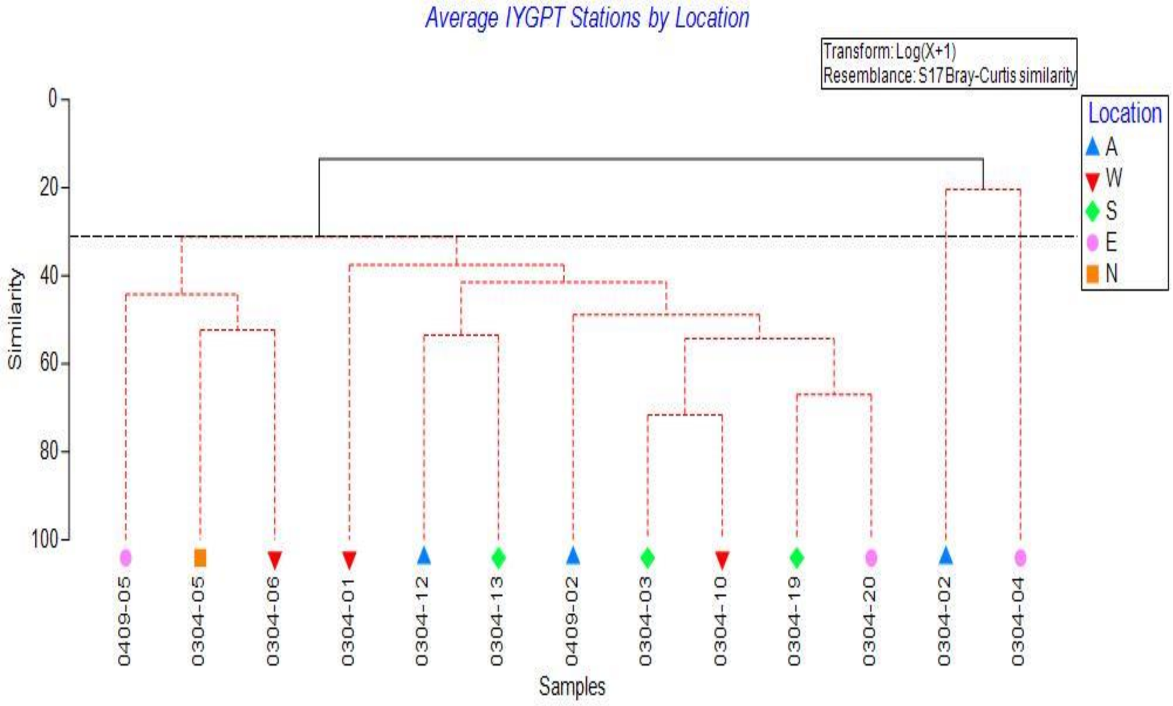

Figure 15. Dendrogram by cluster analysis of Delaware II stations from Bear Seamount on DE03-04 and DE04-09 by location. Resemblance at 31% similarity by SIMPROF

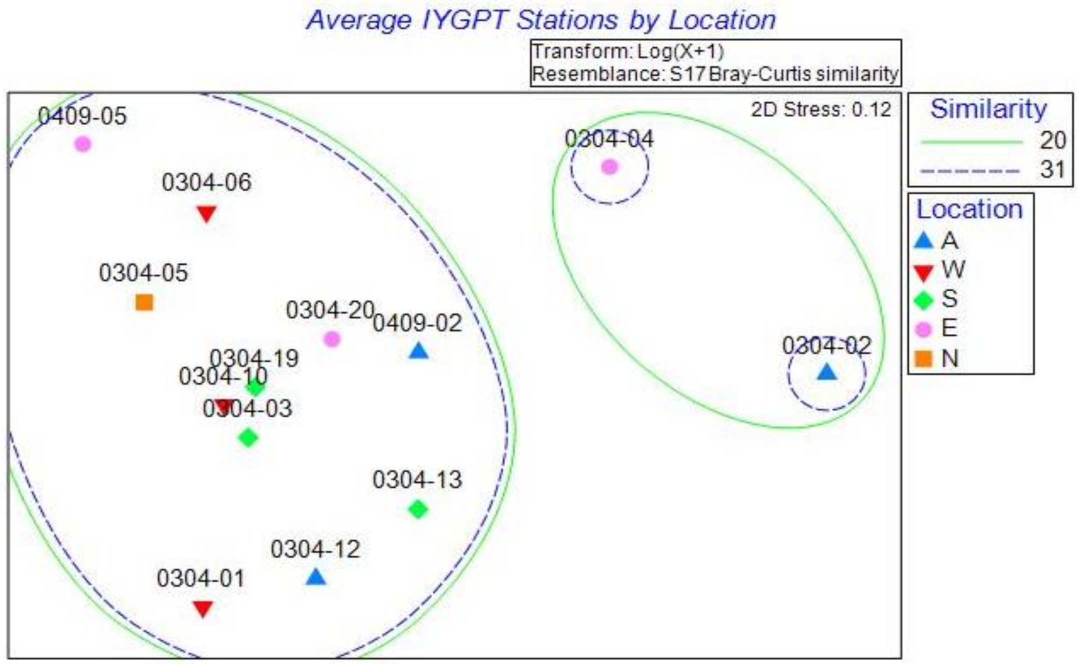

Figure 16. Non-metric multidimensional ordination scaling plot of Bear Seamount deep-pelagic samples collected during cruises DE03-04 and DE04-09. Circled groups are based on the classification results discriminated at the 20 and 31% similarity

Table 11. ANOSIM species by location results, using pair-wise testing to analyze local biogeography. Bold groups indicate significance (<0.05)

Groups	R Statistic	P value
West, South	-0.296	1.0
West, East	-0.074	0.7
West, North	-0.556	1.0
West, Summit	-0.296	1.0
South, East	0.185	0.1
South, North	0.333	0.5
South, Summit	0.037	0.5
East, North	-0.556	1.0
East, Summit	-0.074	0.7

An ANOSIM was conducted on the data with location as a factor and revealed no overall global significant differences seen between the stations (R-value=-0.056, p-value=0.653) with a negative R-value, indicating no suggestion of a location effect on the *Delaware II* assemblage. Similarly, when the stations were broken down into pairwise groups, no two locations showed significant differences (Table 11).

4. *Discussion*

This study is the first description of the local assemblage of deep-sea pelagic crustaceans over and around Bear Seamount. The focal bias to discuss is the utilization of two different net types during collection of crustacean specimens. Statistical analysis of abundance by gear type revealed significant differences between the PMRT (larger mesh) and IYGPT (smaller mesh) gear, which meant that analyses had to be completed separately according to gear type. In addition to using different gear types, the cruises were also trawled in different seasons, with the *Delaware II* cruises occurring in the spring, and the *Pisces* cruise taking place in the fall. Although seasonality cannot be analyzed within this dataset, it may have played a role in some of the differences in species assemblages that had to be attributed to different gear types, as discussed below.

4.1 *Hydrology*

The current structure, transport and water mass properties of the Gulf Stream vary geographically and temporally (Cornillon, 1986), with seasonal (Hitchcock et al., 1985), mesoscale and inter-annual fluctuations (Taylor and Stephens, 1998). The New England Seamount chain appears to be centrally located within spatial gradients across the Northwest Atlantic Ocean, especially with respect to oceanic currents. Most of the deep sea lacks *in situ* primary production and thus relies on these oceanic currents to yield nutrients. Sea surface satellite images indicated a warm-core ring pinched off of the Gulf Stream at approximately 40°N 65°W (Figure 5) during the week of sampling in October 2014. While examination of temperature at depth indicated the warm-core ring's presence was not a factor during midwater trawling, stations 26-28 (where benthic trawling took place) from cruise PC14-04 appeared to be affected by a warm-core ring (Table 4). This warm-core ring was detected by the gradual increase in temperature at 200 and 350 m for these stations. While we only had limited temperature data at depth for specific stations on the *Delaware II* cruises, these data did not show increased temperatures that would indicate the presence of a warm-core ring. Correspondingly, when examining SST data, no warm-core rings appeared to be present at the time of trawling. However, Bear Seamount appears to be central to frontal zones, in which oceanic parameters such as temperature and salinity change abruptly over short distances. These sharp changes may be the reason for the species assemblage present at Bear. So while a warm-core ring was not present during midwater trawling in this study, it is important to discuss the impacts that warm-core rings have upon topographic features, such as seamounts, as they are often an occurrence in the vicinity of Bear Seamount and most often at the NESC region (Richardson, 1981; Auer, 1987; Ezer, 1994). Warm-core rings are generally characterized by oligotrophic waters and low biomass, although they often interact with the slope and shelf waters, increasing mixed layers and indirectly increasing production (Cornillon, 1986). Zooplankton in warm-core rings are often directly related to water exchanges with the shelf waters due to interaction with the slope, as well as mixing due to surface cooling (Roman et al., 1985). As the warm-core ring exchanges water with the slope, shelf phytoplankton are enveloped into the ring, leading to enhanced phytoplankton biomass within the core and along the ring periphery in an otherwise low productive regime (Smith and Baker, 1985; Yentsch and Phinney, 1985; Ryan et al., 2001). As a result, advection of pigment-rich water from the shelf by warm-core rings is a principal cause of variability in satellite-observed chlorophyll concentrations in and around warm-core rings (Ryan et al., 1999). In addition to filaments of chlorophyll-rich shelf water drawn offshore by warm-core rings circulation, pigment-enhanced filaments can develop along the shelf break in coincidence with warm-core rings entrainment. Although, spatial and temporal degrees of enhancements vary interannually, and expression is intermittent intraannually (Ryan et al., 1999). Yentsch (1985) found that growth in populations of phytoplankton at warm-core ring centers occurred as pulses, responding to changes in the depth of the mixed layer due to convection and stabilization. During the spring and summer the water is more stratified, while during the fall and winter the mixed layers extend deeper due to atmospheric cooling (Joyce, 1976). It’s hypothesized that CPUE’s and possibly diversity would be greater during the fall *Pisces* cruise versus the spring *Delaware II* cruises, and this is what the data show, but because of differences in the gear utilized this cannot be attributed to seasonality at this point. The greater CPUE during the *Pisces* cruise may be due to the larger net area and mesh size at the front of the PMRT net, although some of the differences seen may also be due to seasonality. It would be interesting to look at seasonality differences at Bear Seamount utilizing the same gear type and protocols.

4.2 *Alpha Diversity Indices*

Most of our knowledge of biodiversity and its causes in the deep sea stems from regional-scale sampling studies of the macrofauna, such as the one in this study. Diversity and evenness was highest on the south side during the *Delaware II* cruises, which takes into account abundance. The high diversity on the south may be a response to the upwelled waters of the DWBC flowing southwesterly past Bear Seamount. As the current flows around the base and summit of the seamount from the northeast, these loci may serve as a downstream current refuge for midwater species. Planktivorous species often position themselves downstream of an impinging current to increase the flux of food particles and nutrients delivered to them, as seen for fishes and filter-feeding species (Hobson, 1991; Auster et al., 2005a). Also, because many meso- and bathypelagic micronekton must actively swim against the prevailing current to remain in association with the seamount (Porteiro and Sutton, 2007), they may be advected downstream of the current resulting in their south side position near Bear. The summit had the greatest species richness during the *Delaware II* cruises, which could perhaps be explained by the phenomena of Taylor columns (Hogg, 1973), in which currents at depth meet great topographic features and nutrient rich deep-water is upwelled above the seamount, essentially trapping and concentrating these vertically and non-vertically migrating species (Genin and Boehlert, 1985). However, wide and flat seamounts, such as Bear, show more limited ability to amplify, and topographic deviations from “optimal” symmetric shape serve to reduce the size of trapped flows (William and Mohn, 2010). Taylor columns are also variable in time and space as decreasing current speeds may breakdown the vortex, whereas excessive speeds can result in eddies being shed downstream (Owens and Hogg, 1980; Boehlert and Mundy, 1993). Letessier et al. (2009) conducted a comparable study in which euphausiid species’ abundance was examined over and on either side of the Mid-Atlantic Ridge. Their results demonstrated that the ridge influenced euphausiid species abundance, which may be explained by variations of sea surface temperature and modification of currents by the ridge.

Average H’ diversity was highest on the summit during the *Pisces* cruise, further supporting the effects of currents and possibly localized jets produced by upwellings such as Taylor columns (Hide and Ibbetson, 1966; Owens and Hogg, 1980; Porteiro and Sutton, 2007). The west locus had the highest species richness on average, although it showed the lowest diversity due to its particularly low evenness and high abundance of a few species.

When comparing diversity between each location during the *Delaware II* cruises, no significant differences were present overall, which may be due to the short distances between the samples sites. Likewise, the diversity for the *Pisces* samples did not show significant differences by location, which may be a result of the large variance in some locations. A larger sample size would possibly provide better statistical results when comparing diversity among locations. Overall, 66 decapod, euphausiid and lophogastrid species were collected at Bear Seamount.

Decapoda was by far the most speciose order of nektonic Crustacea at Bear Seamount. Although this study involves two different gear types and two different seasons, Decapoda and Euphausiacea were the most abundant orders for both gear types, suggesting these two orders are especially important as trophic links in this regional ecosystem. The most abundant species composition differed between net types: *Meganyctiphanes norvegica*, *Acanthephyra purpurea* and *Parapasiphae sulcatifrons*, in that order, were the most abundant species in the IYGPT samples, whereas, *Eusergestes arcticus* followed by *M.norvegica* and *A.purpurea* accounted for a larger percentage of the catches with the PMRT. Since the PMRT trawl was equipped with an inner mesh net that had a smaller mesh size (6.35 mm) compared to the IYGPT codend mesh (10 mm), this may have aided in the retention of smaller individuals. However, as the data show, the smaller net (IYGPT) was better at capturing the smaller euphausiid species which may be due to the smaller mesh at the opening and intermediate portions of the net. Most small organisms may pass thru the larger mesh in the opening of the PMRT, whereas they may be retained and captured by the codend of the smaller net (Heino et al., 2011). Though *Eusergestes arcticus* was not in the top three most abundant species for the IYGPT trawl, it was still relatively abundant, suggesting this variation may be due to species-specific deviation, not just gear differences. Therefore, while gear type may be responsible for some of this variation another factor may be involved such as seasonality.

4.3 *CPUE by Gear Type*

During the *Delaware II* cruise, the highest CPUE was at the summit of the seamount with six families represented in the top 95% of the catch. Euphausiidae had the greatest CPUE in this location dominated by vertically migrating *Nematoscelis megalops* and *Meganyctiphanes norvegica* (Figure 9). In comparison, the family Sergestidae dominated species abundances for the two summit stations during the *Pisces* cruise. In contrast, south of the seamount was dominated by vertically migrating oplophorids such as *Acanthephyra purpurea* and *A. pelagica* during the *Delaware II* cruises. Interestingly, *A. pelagica* were in greater abundance on the *Delaware II* cruise, while *A. purpurea* were in greater abundance at this location on the *Pisces* cruise. As they are very similar in size and in life history dynamics (Foxton, 1972), the reason for this difference remains to be determined, but it is unlikely due to the different gear types. Sardou et al. (1996) observed similar differences for species of the genus *Pasiphaea*, in which *Pasiphaea sivado* and *P. multidentata*, both of similar sizes and life history traits, occurred in maximum numbers at different times of the year in the northwestern Mediterranean Sea. This suggests that seasonality may be a factor for the *Acanthephyra* differences in the current study. The south location during the *Delaware II* cruises also had a high catch of Benthesicymidae (mainly *Gennadas elegans*), and Sergestidae (mainly *Eusergestes arcticus*), suggesting that decapods in the suborder Dendrobranchiata are key-stone species in this deep-sea seamount system.

During the *Pisces* cruise the stations with the most abundant crustaceans were on the west side, with only three families making up 95% of the total catch. These three families were Sergestidae, Euphausiidae and Oplophoridae, consisting mostly of *Eusergestes arcticus*, *Meganyctiphanes norvegica* and *Acanthephyra purpurea* (Figure 7). Myslinksi et al., (2005) also found *E. arcticus* and *M. norvegica* as their most abundant species from Oceanographer Canyon, a submarine canyon off the Gulf of Maine, approximately 92 km northwest of Bear Seamount. The presence of frontal zones in the vicinity of Bear Seamount may have caused such a great abundance of *E. arcticus* and *M. norvegica* at the west side stations. Again, though we used different gear types, these three species were abundant in both, nets which suggests that factors other than gear type may be responsible for these differences, such as seasonality. The position of the Gulf Stream as it leaves the coast changes throughout the year. In the fall it shifts north, while in the winter and early spring it shifts south (Auer, 1987). During the spring *Delaware II* cruises, SST data showed evidence of this shift, with colder sea surface temperatures over Bear Seamount than during the October *Pisces* cruise. During the *Pisces* fall cruise, there appears to be a higher variability of temperature ranges over Bear Seamount which suggests frontal zones may be a factor for the high CPUE on the west side locations. Letessier et al. (2011) found that higher surface production near frontal zones results in greater abundances at depth. Frontal zones have been known to cause shallow and midwater species to concentrate at the edge of a water front (Olson and Backus, 1985; Laubscher et al., 1993). This concentration at frontal zones may be a result of an enhancement of *in situ* production by selected components of the phytoplankton assemblage (Laubscher et al., 1993). Olsen and Backus (1985) found that a concentration of mesopelagic fish species was apparent at the front of warm-core rings off of the Gulf Stream in the months of April and June. The mechanism concentrating mesopelagic species is the coupling of vertically migrating species and depth-keeping species. Whether vertical migrator or not, mesopelagic species appear to keep depth by swimming up and down in the water column so as to stay within a range of intensities (or isolume) of ambient light subsequently linked to the diel cycle (Olson and Backus, 1985). When such species are subjected to converging or diverging horizontal flow at the level at which they are swimming, they are concentrated. Since many of the abundant species at Bear are strong and moderate vertical migrators, these fronts may have the ability to concentrate epi- and mesopelagic nekton. Comparable to Olson and Backus (1985), the *Delaware II* stations were also surveyed in spring months and may be the cause for high CPUE of certain species such as *Nematoscelis megalops*. Therefore, the Gulf Stream’s frontal zones may result in an increase in both CPUE and species richness on the west and south sides of the seamount, as these currents come from the southwest and flow northeasterly between the continental shelf and the abyssal plains.

4.4 *Multivariate Community Analysis*

Multivariate analysis for the *Delaware II* cruises revealed that location was a fairly weak factor in defining community structure among pelagic nekton during the *Delaware II* cruises in the spring, although a larger sample size may be needed to see significant differences. The NMDS plot for the *Delaware II* stations showed three clusters at 31% similarity, in which two stations were separated from all the others. These two stations had a great abundance of *Nematoscelis megalops* and *Meganyctiphanes norvegica*, which were only seen in small numbers at a few other stations. Glover (1952) found *M. norvegica* moved towards coastal areas during the period from January to May, whereas they spread towards more oceanic areas between June and December. His results agree with our findings as *M. norvegica* was found in higher abundances during our *Pisces* October cruise in the fall. Again, although different nets were utilized, this species was caught in higher abundances for PMRT gear but was also the species caught in the greatest abundance with the IYGPT net, suggesting a possible species-specific seasonal difference in abundance. The population movements may be associated with breeding, with the spring aggregations being a precursor to mating and spawning (Mauchline, 1959; Tarling et al., 2010). Northern krill play an important ecological role, both as a contributor to the carbon pump via conveyance of fecal material to the deep, and as a key prey item for fish, squid, whales and seabirds (Tarling et al., 1999). In the Gulf of Maine, this species is usually found in waters of between 3 to 4°C and is known to congregate around the 100-m contour further offshore, around Georges Bank. MacIsaac *et al*. (2014) concluded that two dominant species, *M. norvegica* and the hyperiid amphipod *Themisto gaudichaudii*, showed an inter-annual variation in abundance. Since our cruises occurred in different years, the shift in abundances may be caused by an inter-annual variation, although, this is not a factor that could be examined (different net gear) took precedence. *Eusergestes arcticus*, the other dominant species at Bear has also been a well-studied species in the North Atlantic Ocean. Hargreaves (1985) found it to be a strong vertical migrator occurring above 200 m at night in Northeast Atlantic. As the overall most abundant species shifted from the *M. norvegica* in the spring to *E. arcticus* in the fall in the current study, the differences may be due to species-specific seasonal or annual differences as opposed to gear type only. Thus, taxon-specific variations in different seasons may be occurring at Bear Seamount.

The *Pisces* station NMDS plot grouped five clusters at 48% similarity. The west side stations clustered together as they were the most similar. These stations had a large abundance of a couple of species and may be the reason for the differences in multivariate structure. ANOSIM revealed an overall significant difference (p=0.037) between locations although with a low R value (R=0.234), indicating that the community data were weakly related to the qualitative location categories for the *Pisces* cruise. Other factors such as depth may have played a bigger role in the differences seen. Pairwise differences by ANOSIM did show significance; west against south (R=0.313), west against east (R=0.481) and west against north (R=0.704). The small R-value suggested that location had a small impact on structure, whereas the high value indicated structure by location was a good indicator of what drives the differences between the west and north stations. While the R-values were not highly significant for the location factor, the west side of the seamount was clearly unlike all other locations during the *Pisces* cruise, suggesting a unique factor may be contributing to the differences we see in multivariate analysis. The shear abundances of *Eusergestes arcticus* and *Meganyctiphanes norvegica* played a role in these differences. The depth of trawling was a more robust factor although these data are not as reliable as the depth ranges were huge - 0 to 700 m and 0 to 1700 m. Fourteen species were only present in the deep tows that went below 1000m from the *Pisces* cruise (Table 9). Most of these species are non-vertical migrators in other parts of the world, as well as residing in the bathypelagic zones (Chace, 1940; Hendrickx and Estrada-Navarrete, 1989; Mauchline and Gordon, 1991; Burghart et al., 2007), indicating that this is the reason why these species were only caught in the deeper trawls. More discrete trawling may result in significant differences as a greater range of depths will allow for better multivariate results.

Two pasiphaeid species, *Pasiphae hoplocerca* and *P. merriami*, were new records for Northwest Atlantic waters and may be “natural invaders” as posited by Jon Moore for fishes (2004). Pasiphaeid *P. hoplocerca* was previously known only from the Northeast Atlantic Ocean off Morocco (Abbes and Casanova, 1973), Madeira (Figueira, 1957), Canary Islands (Foxton, 1970), Bermuda (Chace, 1940) and Caribbean (Iwasaki, 1990), and may have migrated by the way of nearby seamounts from its native locations. Pasiphaeid *P. merriami*, which had previously only been reported in the western Atlantic and Gulf of Mexico (Tavares and Cardosa, 2006), may have traveled by means of the Gulf Stream and warm-core rings to the Northwest Atlantic Ocean.

4.5 *Future Studies*

The data presented here suggest that there are seasonal differences in the crustacean assemblage at Bear Seamount. Although different net types were used, the abilities of both net types to catch the species that showed seasonal differences suggest that other factors are involved, as discussed above. Future studies should focus on seasonal differences, as well as depth-specific variations in species abundance, diversity and local biogeography. This would require using trawling gear such as a Multiple Opening and Closing Net Environmental Sensing System (MOCNESS) net, which allows discrete-depth towing to determine diel vertical migrations as well as environmental parameters at depth. Methods of sampling make all the difference when targeting specific taxonomic groups or examining certain parameters. Sampling would optimally take place in all seasons over several years to determine if there is a shift in abundance and diversity at Bear Seamount. Our ability to comprehend the deep sea is hindered by a lack of sufficient data for many taxonomic assemblages, which in part is due to sampling biases, life-history characteristics of target species, and the lack of trained taxonomists (Kelly et al., 2010). Advances in molecular techniques may provide a sharper understanding of diversity and population connectivity at these under-sampled topographies as well.

5. *Conclusion*

The results of statistical and multivariate analysis for the *Pisces* cruise indicated that there are distinct differences in abundances and species present between the west sides of the seamount compared to all other locations. One main causal factor may be the presence of frontal zones between the Gulf Stream and continental slope, essentially concentrating species at these oceanographic gradients. The two most abundant species, *Eusergestes arcticus* and *Meganyctiphanes norvegica* are cold-temperature species known from mid-to-higher latitudes, which prefer cooler waters near the surface and essentially use the frontal zones as a barrier. Multivariate analysis revealed that location was not a robust factor that determined groupings for both datasets as revealed by the low R-values, though differences in depth may be a much stronger influencing grouping factor. Diversity and evenness indices were not significantly different for any one location, however, the summit and south side stations were on average the most diverse for both the spring and fall datasets. The west and summit of the seamount were the most species-rich, showing a local biogeographic preference, which may be a factor of biophysical coupling. Deep-sea currents such as the DWBC may be the reason for the great diversity increase, as water may be vertically accelerated towards the surface as it encounters Bear Seamount. The detailed nature of these results offers a baseline for future community assessments and comparison of seamount diversity. This thesis will also serve to show the current community assemblage of pelagic Crustacea at Bear Seamount, which is of particular importance if future exploitation of the seamount ensues. Bear Seamount is an ecologically critical undersea region as it lies in the U.S Exclusive Economic Zone (EEZ) and is most available to fisheries exploitation. Due to the seamount's close proximity to the continental slope, it may foster a unique assemblage unlike any of the other seamounts and in turn its close proximity may make it vulnerable to deep-sea fisheries and anthropogenic effects.

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Appendices

Appendix I. Arthropod taxa collected on or over Bear Seamount during NMFS cruise DE00-11 from 2-7 December, 2000 (Moore et al., 2003)

Taxa	**Count**	**Taxa**	**Count**
Syscenus atlanticus	27	*Oplophorus* sp.	>51
Bopyrid isopod	1	*Systellaspis* sp.	>41
Hyperiid amphipods	>49	Euphausiids	>130
Hyperia galba	2	*Heterocarpus ensifer*	1
Phronima sp.	2	*Stylopandalus* sp.	7
Unidentified large red amphipod	1	*Pentacheles laevis*	12
Scalpellum sp.	1	*Stereomastis nana*	6
Aristaeopsis edwardsiana	10	Polychelid spiny form	2
Acanthephyra sp. (4 spp.)	>78	*Munidopsis* sp.	8
Glyphocrangon sculpta	>10	*Galathea rostrata*	1
Notostomus sp.	4	*Munidopsis curvirostra*	1
Pasiphaea sp. (3 spp.)	>51	Mysids	>69
Gennadas sp. (3-4 spp.)	>41	*Gnathophausia zoea*	>24
Sergestes sp. (10 spp.)	>130	*Parapagurus pilosimanus*	46
Homolids	2	*Neolithodes grimaldii*	1

Appendix II. Preliminary list of arthropods collected from Bear Seamount during cruise DE02-06 RV "Delaware II" in July, 2002. Pelagic taxa were from stations within 10 km of Bear Seamount (Moore et al., 2004)

Taxa	**Count**	**Taxa**	**Count**
Small white pycnogonid	1	*Oplophorus gracilirostris*	1
Colossendeis colossea	11	*Notostomus* sp.	7
Unidentified crustaceans	9	*Meningodora vesca*	1
Amphipod	9	*Pandalus* sp.	1
Large red amphipod	20	*Stylopandalus richardi*	2
Lanceola sp.	3	*Pasiphaea* sp.	1
Small dark amphipod	1	*Parapasiphae* sp.	2
Eurythenes gryllus	3	*Parapasiphae sulcatifrons*	30
Cystisoma sp.	24	*Sergia* sp.	125
Phronima sp.	826	Sergestidae	1
Phrosima sp.	33	*Sergestes* sp.	137
Themisto sp.	15	Unidentified shrimp	12
Cymothoida isopod sp.1	2	Unidentified euphausiids	18
Cymothoida isopod sp.2	1	*Bentheuphausia amblyops*	1
Syscenus atlanticus	10	Decapod sp.1	1
Gigantocypris sp.	1	*Nematoscelis megalops*	7
Scalpellum sp.	7	*Chaceon quinquedens*	1
Aristeidae	1	Heterocarpus-like shrimp	1
Acanthephyra sp.1	27	Majid crab	2
Acanthephyra sp.2	50	Lithodid	1
Acanthephyra curtirostris	1	*Neolithodes grimaldii*	1
Acanthephyra purpurea	449	*Parapagurus pilosimanus*	3
Benthesicymus bartletti	7	*Pagurus* sp.	1
Funchalia sp.	2	*Polychelid juvenile*	4
Funchalia villosa	7	*Pentacheles laevis*	3
Gennadas sp.	12	*Stereomastis nana*	1
Janicella sp.	44	*Munidopsis curvirostra*	1
Gnathophausia sp.	28	*Neognathophausia ingens*	10