Meiofauna Communities of the Pacific Nodule Province: abundance, diversity and community structure

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1.1 Meiofauna

Definitions

Meiofauna have been known since the early days of microscopie in the 18th century (Higgins and Thiel, 1988; Giere, 1993) but the term *meiofauna* itself was introduced by Mare in 1942 to define an assemblage of benthic invertebrates defined by their size class (Thiel, 1983; Giere, 1993). This term is derived from the Greek's "meios" which means smaller. It refers to the organisms which are smaller than the lower size limit of the macrofauna (Higgins and Thiel, 1988). This term originated primarily in conjunction with the methods used for sampling and processing benthic samples and have to be viewed together with the concepts of macro- and megafauna (Thiel, 1983). Gray (1981) suggest that meiofauna is composed by organisms which have an intermediate size between macrofauna and microfauna. In this study the term meiofauna will be used as a synonym of meiobenthos.

The quantitative study of benthic fauna has been restricted to the organisms which are retained on sieves for washing the fine sediment particles. In meiofauna studies the sieve mesh size used differs strongly between researchers, but today, the mesh size generally used in meiofauna studies has an upper size limit of 1 mm and a lower size limit of 65 to 42 μm (Thiel, 1983). So organisms passing the 1 mm size sieve, but being retained on the lower size sieve are considered as belonging to the meiofauna. Twenty-two of the 33 metazoan phyla have at least some representatives of meiobenthic size, some of them are exclusive and permanent meiobenthic throughout their life cycle, e.g: Gastrotricha, Gnathostomulida, Kinorhyncha, Loricifera, Tardigrada, Mystacocarida, some representatives of Rotifera, Nematoda, Polychaeta, Copepoda, Ostracoda, Turbellaria, Halacaroida, and some specialized members of Hydrozoa, Nemertina, Entoprocta, Gastropoda, Aplacophora, Brachiopoda, Holothuroidea, Tunicata, Priapulida, Oligochaeta and Sipuncula. Some animals, usually larvae of the macrofauna, are part of the meiofauna only during their juvenile stages (temporary meiofauna) (Coull, 1988).

Distribution of Meiofauna

Meiofauna lives in a wide diversity of habitat. They could be found both in freshwater and marine habitats, from high altitude of the mountains to the deepest depths of the ocean. Meiofauna occurs in many kind of sediment types(Coull, 1988), e.g. between sand grains (e.g. interstitial), within soft muddy sediments (Coull and Wells, 1981), hard coral substrates (Gheerardyn, 2007), rocky substrates (Danovaro and Fraschetti, 2002);, or phytal habitat e.g. seagrass meadows (Bell *et al*., 1984). Meiofauna organisms inhabiting different sediment

types display adaptations in their morphology, e.g. the sand-dwellers tend to be slender as they must fit and move through the interstitial spaces between the sand grains, whereas the fauna living on muddy habitats is not restricted to a particular morphology but are generally larger, and species living on phytal environments have developed some clasping organs to attach to the substrate, preventing being washed out by the waves.

In marine environments meiofauna also colonizes extreme habitats including hydrothermal vents (Ivanenko and Ferrari, 2002, Heptner and Ivanenko, 2002), manganese nodule crevices (Thiel *et al*., 1993) and are associated with larger animal, e.g. associated with holothurians, sponges and cnidarians (Humes, 1974). In freshwater environments meiofauna organisms also inhabit groundwater aquifers, river shores, cave pools and lakes, even semi-terrestrial habitats likes forest litter and phytothelmata (Giere, 1993).

Quantitative studies on deep-sea meiofauna began with Wigley and McIntyre (1964). Coull (1972) reported increasing meiofauna diversity with increasing depth, later, Shirayama (1983) reported decreasing meiobenthos abundance with increasing water depth. Furthermore, Thiel (1983) presented a thorough review of meiofaunal depth distribution.

It is commonly known that benthic organisms inhabit the surface layer of the sediments. This is were they can find more food (as food is normally coming from the water column) and sufficient oxigen. For deep-sea meiobenthos, their distribution is concentrated in the upper 5 cms of the sediment, although they could be found up to 12 cm sediment depth (Coull *et al*, 1977; Thiel, 1983; Shirayama, 1984).

Abundance and Diversity of Deep-Sea Meiofauna

In this study deep-sea is defined as the region between the continental shelf and the upper limit of trenches, it includes the continental slope, continental rise and abyssal plain, with the depth between 200 m to 6000 m (Thiel 1975; Gage and Tyler, 1991). Within the deep-sea, the abyssal plains are different from other marine environment as they are (1) a vast area with relatively few barriers to dispersal, (2) have no photo-autotrophic primary productivity, so they are extremely oligotrophic, and (3) relatively constant environmental conditions, which regards temperature, salinity, sediment composition and pressure (Grassle, 1989).

It has already been known that the deep-sea harbours an astonishingly high species diversity (Hessler and Sanders, 1967; Grassle, 1989; Grassle, 1991; Grassle and Maciolek, 1992, Smith *et al.*, 1998; Gray 2002) and that most of the species diversity consist of invertebrates residing in (infauna) and on (epifauna) the sediments. This invertebrates include megafauna, macrofauna, meiofauna and the poorly known microbiota (Snelgrove, 1999).

Much attention and efforts have been directed to study the diversity of deep-sea environments and numerous studies reported the high diversity of meiofauna (Lambshead *et al.*, 1994; Gutzmann *et al.*, 2004; Soltwedel *et al.*, 2003; Shirayama and Kojima, 1994; Vanreusel *et al.*, 1995; Vanhoeve *et al*., 1995) and macrofauna (Jumars, 1975; Gage *et al*., 1995; Cosson-Saradin *et al.*, 1998) from different ocean regions.

Meiofauna is an important component in the deep-sea ecosystem (Thiel, 1983). Nematodes are usually the most abundant meiofaunal taxon in deep-sea sediments, followed by harpacticoid copepods. However, harpacticoids become numerically abundant as the particle size of the sediment increases (Hicks and Coull, 1983; Trebukhova, 2003) and in terms of biomass they even exceeded the nematodes (Hicks and Coull, 1983). Vincx *et al.* (1994) reported that more than 80% of metazoan meiobenthos from different deep-sea areas in the Northeast Atlantic are nematodes, while copepods and nauplii together represent up to 10% of all metazoan meiobenthos.

The abundance of meiofauna in the deep sea is correlated with the availability of organic matter (Thiel, 1983; Shirayama, 1989), bathymetric depth (Thiel, 1983; Alongi and Pichon, 1988; Tietjen 1992; Baguley 2006), and type of sediment (Carman *et al.*,1987).

The deepsea is food limited, most of deep-sea communities rely on the sinking of particulate organic matter from surface water production (Baguley 2006). With increasing water depth, only few percent of the primary production produced by photosynthesis reaches the deepsea floor (Gooday *et al*., 1990). This condition explains the observed decreasing of abundance of meiofauna with depth and the tendency of meiofauna to be more abundant in the surface layers of the sediment (Shirayama, 1984). Shirayama (1984) also pointed out that oxygen is a limiting factor for meiofaunal maximum vertical depth distribution.

Meiofaunal abundance is highest in fine silt sediments and lowest in very fine silt sediments. (Coull *et al*., 1977).

Most publications on deep-sea environments focused on megafauna or macrofauna (Thistle, 2003) because meiofaunal taxonomy is less well studied than that of larger organisms (Gage and Tyler, 1991; Lambshead, 1993; Thistle, 2003). For example, nematodes, are recognized as the most diverse metazoan taxon in deep-sea environments with an estimated species richness of over 1 million (Lambshead and Boucher, 2003), however, only about 4000 marine nematodes species have been formally described and most of them are from European shallow waters and to a lesser extent to northeast American coastal waters (Lambshead, 1993).

For meiofauna, biological (predation) and physical disturbance plays an important role in maintaining its local diversity (Thistle, 1979; Thistle, 1998). Meiofaunal diversity is also correlated with bathymetric depth (Boucher and Lambshead, 1995; Baguley *et al*., 2006) as the rates of physical and biological disturbance decrease with depth (Thistle, 1983). Besides, the unequal distribution (patchiness) of food resources are likely to be more important in maintaining high species richness (Grassle, 1991).

Abundance and diversity of deep-Sea harpacticoid

Harpacticoida, an order within subclass Copepoda. They occurs in almost all aquatic habitats (marine, brackish and freshwater) and are ubiquitous in marine environments, occurring from tidal-pools to the hadal zone (Hicks and Coull, 1983). They are small, predominantly less than 1 mm long, and are usually the second most abundant metazoan group (after nematodes) in benthic meiofaunal communities (Huys *et al*., 1996). Harpacticoid copepods are the most abundant arthropods in the deep-sea benthos and in terms of biomass, they may even exceed nematodes (Seifried, 2004). Like nematodes, harpacticoid copepods have been little studied (Gage and Tyler, 1991).

Harpacticoid copepods have successfully colonized deep-sea environments, (Thistle, 2001). The maximum densities in intertidal sediment are in the order of 100.000 to 1.000.000 per square meter, but density decrease with water depth (Danovaro *et al*., 1995), so that the total number of harpacticoid copepods might be only 10.000 per square meter in the deep sea (Boxshall and Halsey, 2004).

In the deep-sea harpacticoid copepods are thought to feed mainly on sedimented organic aggregates (Gage and Tyler, 1991)

Taxonomy of deep-sea harpacticoid is poorly known (Thistle, 1983; Seifried, 2004), in deep-sea studies comparison between sites can only be achieved using working species working species, because most of the species are new to science (Thistle, 1983; Thistle, 1988). While harpacticoid copepods densities in the deep-sea is greatly reduced, dominance by one or several species, a phenomenon common in shallow water systems, does not occur (Hicks and Coull, 1983). Coull (1972) reported increasing diversity of harpacticoid copepods in continental shelf to abyssal depth. However, after certain depth the diversity of harpacticoid show the tendency to decrease with increasing water depth (Baguley *et al*., 2006) due to decreasing of the food supply to the seabed (Thistle, 2001). So along the continental slope, there is an unimodal, rather than a linear decrease of diversity with increasing depth, with maximal values at bathyal depth, (Baguley *et al*., 2006)

1.2. Polymetallic Nodule

History

Polymetallic nodules (**Figure 1**), also called manganese nodules, together with micronodules and encrustations, are ferromanganese oxide deposits which contain variable amounts of other elements (Cronan, 2001). Polymetallic nodules being more important than

Figure 1 Polymetallic nodule (Copyright. IFREMER)

micronodules and encrustations regarding to its economic value. Marine polymetallic nodules lay on the surface of the deep-sea floor or are embedded in the top layer of the bottom sediment (**Figure 2**).

The first ferromanganese concretions were discovered in 1868 in the Kara sea, Arctic Ocean off Siberia (Russia). During the scientific expedition around the world of the H.M.S. Challenger (1873-1876) a large quantities of nodules displaying a wide range of morphological and internal structures were collected from the Atlantic, Indian and Pacific

Oceans. Following the Challenger period, studies on polymetallic nodules have been conducted extensively. Other major early polymetallic nodule collecting expeditions were those of the Valdivia in the 1890 and the Albatross in the early 1900. Between the two World Wars little work was done on nodules, although samples were collected during a number of an oceanographic cruises. After the second World War studies on polymetallic nodules have rapidly expanded (Glasby, 1977; Cronan, 1980).

A better understanding of composition, distribution and genesis of deep-sea polymetallic nodules is important to assess their economic potential as a valuable sources of metal ores. Deep-sea mining on polymetallic nodules will predictably begin in two or more decades (Thiel *et al.*, 2005).

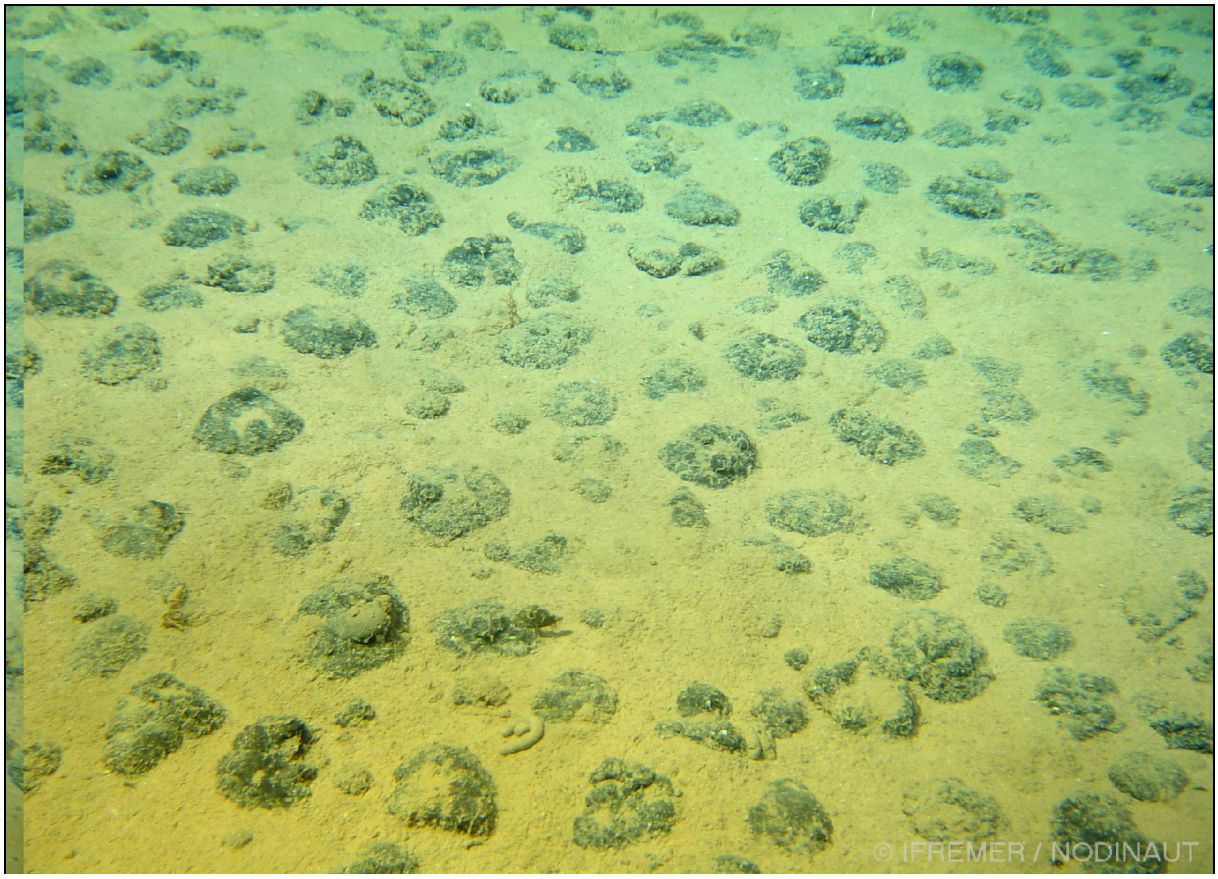


Figure 2 Distribution of polymetallic nodule on the deep-sea floor (Copyright IFREMER)

Morphology

Morphology and mineralogical composition of abyssal nodules reflect different sources of metals and different environments of growth (Halbach and Fellerer, 1980). Polymetallic nodules exhibit a wide range of morphology based on shape, size and surface

texture. No widely used scheme of morphological classification exists, so individual investigators have resolved to use general terms : spherical, ellipsoidal, discoidal, etc. to describe the shape of nodules from particular study areas (Raab and Meylan, 1977; von Stackelberg, 2000).

Halbach and Fellerer (1980) who worked with nodules from the Pacific Ocean stated that nodules which have spherical to ellipsoid shapes are mainly accumulating on the sediment surface and occur on slopes and in the vicinity of the seamounts.

In their surface structure, polymetallic nodules commonly exhibit a mammilated appearance (hemispherical protrusions). The size of mammilae vary greatly in proportion to the overall size of nodules. Other polymetallic nodules show no visible pattern – smooth surfaces (Cronan, 1980). In another cases, the surface of polymetallic nodules appears to be composed of sand-size and finer particles which are loosely attached to the nodules (Raab and Meylan, 1977).

Moorby (1978) who are working on Indian Ocean nodules, as quoted by Cronan (1980), reported a wide range of nodules diameters varying from less than 1 cm to more than 25 cm, with the average diameters is between 3 and 6 cm. According to Jauhari and Pattan (2000) the difference in nodule's size is influenced by the depth. Nodules from relatively shallow depths are larger in size, contain rock fragments as nuclei and are rich in Co and Fe in contrast to nodules from deeper depths.

Nodules greater than 6 cm were found to be mammillated with rough botryoidal surface texture on the upper surface and smooth to microbotryoidal surface texture on the lower surface. These nodules are mostly spheroidal to irregularly spheroidal and sometimes discoidal. Nodules of the size class 2 to 6 cm are mostly ellipsoidal to discoidal with a mammilated and microbotryoidal upper surface and a mammillates smoother lower surface (von Stackelberg, 2000).

All polymetallic nodules show some pattern in their internal structure. The main feature of the internal structure of nodules is concentric banding which is develop to a greater or lesser extent in most of them. The bands represent thin layers of varying reflectivity in polished section, the more highly reflective layers being generally richer in manganese than the more poorly reflective ones. They are thought to possibly represent varying growth conditions (Cronan, 2001).

Radial or random fracture is also commonly observed in polymetallic nodule's interior. This fracture appears to be an extension feature having the greatest separation toward the centre of the nodule and tapering to the edges. Many of these fractures do not emerge at

the nodule surface but some are open toward the side which faced the sediment (Raab and Meylan, 1977). Fracturing of nodules is a process which can lead to their break up on the seafloor, in some cases as a result of the activity of benthic organisms (Cronan, 2001).

Though reported to have a great variety in appearance, in general, polymetallic nodules from a single sites are very similar in appearance, building so called facies, but they differ in size, form and internal appearance to those of other locations (Glasby, 1977).

Composition

Polymetallic nodules consist of complex mixture of materials, including crystallite of several minerals of detrital and authigenic origins, organic and colloidal matter, and igneous and metamorphic rocks of varying degrees of degradation. Some of the constituents appear to be essential for the nucleation and growth of the component minerals (Burns and Burns, 1977). They are also chemically heterogenous, both within individuals nodules over small distances on the seafloor, as well as on a world-wide scale. Study of their chemistry is important not only from the scientific point of view, but also because metals such as Ni, Cu and Co can be enriched in some deposits to ore grade. An understanding of the processes by which this enrichments occurs will simplify the task of locating such deposits elsewhere on the seafloor (Cronan, 1980). Manganese is the principal metallic constituent of polymetallic nodules and attains its high concentration as a result of its fractionation and separation from the principal rock-forming elements in the natural environment during the processes of weathering, transport deposition, diagenesis and subduction. Concentrations of iron and manganese tend to vary inversely to one another (Halbach and Fellerer, 1980), but in general, one of the most important characteristics of polymetallic nodules is their greater enrichment in manganese than in iron relative to the crustal abundances of these two elements (Cronan, 1980). Furthermore, Cronan (2001) stated that manganese nodule exhibit a continuous mixing from diagenetic end members which contain todorokite and rich in Mn, Ni and Cu, to hydrogenous end members which contain ernadite and are enriched with Fe and Co. **Table 1** listed the abundance of elements in polymetallic nodules and other ferromanganese deposits from the world oceans.

Origin

Understanding the origin of polymetallic nodules involves at least three problem. First, the source of the elements in the nodules. Secondly, the mechanisms of transporting

elements in the nodules. Third, the precipitation and growth mechanisms involved in their formation (Cronan, 1980).

The elements in polymetallic nodules could be from any potential source. These potential sources could be submarine volcanoes, continental runoff, as well as cosmic source. Based on its different potential sources of elements, polymetallic nodules were qualitatively classified into hydrogenous, hydrothermal, halmyrolytic and diagenetic (see Cronan (1980) and literatures cited there).

Table 1 Average abundances of elements in polymetallic nodules and other ferro-manganese oxide deposits from the world ocean (wt. %) (From Cronan, 1977)

Elements	World average	Elements	World Average
B	0,0277	Sr	0,0825
Na	1,9409	Y	0,031
Mg	1,8234	Zr	0,0648
Al	3,0981	Mo	0,0412
Si	8,624	Pd	$0{,}553.10^{-6}$
P	0,2244	Ag	0,0006
K	0,6427	Cd	0,00079
Ca	2,5348	Sn	0,00027
Sc	0,00097	Te	0,0050
Ti	0,6424	Ba	0,2012
V	0,0558	La	0,016
Cr	0,0014	Yb	0,0031
Mn	16,174	W	0,006
Fe	15,608	Ir	$0{,}935.10^{-6}$
Co	0,2987	Au	$0{,}248.10^{-6}$
Ni	0,4888	Hg	$0{,}50.10^{-4}$
Cu	0,2561	Tl	0,0129
Zn	0,0710	Pb	0,0867
Ga	0,001	Bi	0,0008

The most obvious mechanism by which manganese and associated elements can be transported to sediment-water interface is by normal process of water oceanic circulation and mixing.

Radiometric dating of deep-sea polymetallic nodules indicates that they grow very slowly. Growth rates between 1 and 100 mm per million years have been reported (Hammond, 1974; Ku, 1977). By comparison, sediment accumulates on the ocean floor at a rate exceeding 1 m per million years even far from sources of continental debris and outside the equatorial zone of high biological productivity (where the rate of accumulation is much higher) (Hammond, 1974).

Diagenetic nodules in an oxic deep-sea sedimentary environment grow from remobilized metals ions as well as re-precipitated Mn-oxide grains, which are supplied to the nodules episodically during the stirring of bottom sediments by benthic fauna and intermittent strong bottom current flow (Jung and Lee, 1999)

Worldwide distribution

Polymetallic nodules are distributed in the deep-sea floor of the world oceans and its distribution is variable on an ocean-wide basis as well as on a scale of kilometers (Cronan, 2001). The distribution of polymetallic nodules is a function of a variety of factors which include the degree of oxidation of the depositional environment, the presence of nucleating agents and/or the nature and age of the substrate, the proximity of sources of elements, sedimentation rates which is largely influenced by the proximity to sources of sediment supply or bottom current activity and the influence of organisms (Cronan, 1980).

Considering the different factors controlling the distribution of nodules the rate of sedimentation seem to be a very important factor (Halbach and Fellerer, 1980). Low sedimentation rates lead to high concentration of nodules at the sediment surface, thus the highest nodules concentration usually found in a red clay or siliceous areas where the sedimentation rates were very slow.

The most important occurrences of polymetallic nodules are concentrated in the northeast Pacific Ocean, more specifically in equatorial North Pacific which is called Clarion-Clipperton Fracture Zone (CCFZ) (**Figure 3**), extending between 6° N and 20° N and 120° W and 160° W (Cronan, 2001) covering depths of 3.200 to 5.900 m. The limits of the area seem to be determined by increases in the rate of sedimentation towards the margin of the Pacific and toward the Equator. To the north, nodule's growth is inhibited by increases in terrigenous and biogenic sedimentation, to the east by turbidite and hemipelagic deposition and to the south by the equatorial zone of rapid carbonate accumulation (Cronan, 1977).

Available data reveals that the South Pacific is not as attractive as the North Pacific although polymetallic nodules deposits are also very common here. In the South Pacific the

occurrence of polymetallic nodule is more irregular than in the North Pacific and also the metals concentrations in the North Pacific nodule belt are higher than in the South Pacific deposits (Halbach and Fellerer, 1980).

Sediments in the northern part of the areas of abundant nodules in the North Pacific are red clays with accumulation rates of around 1 mm per thousand years whereas in the South they are siliceous ooze with accumulation rates of 3 mm per thousand years, or more (Cronan, 2001).

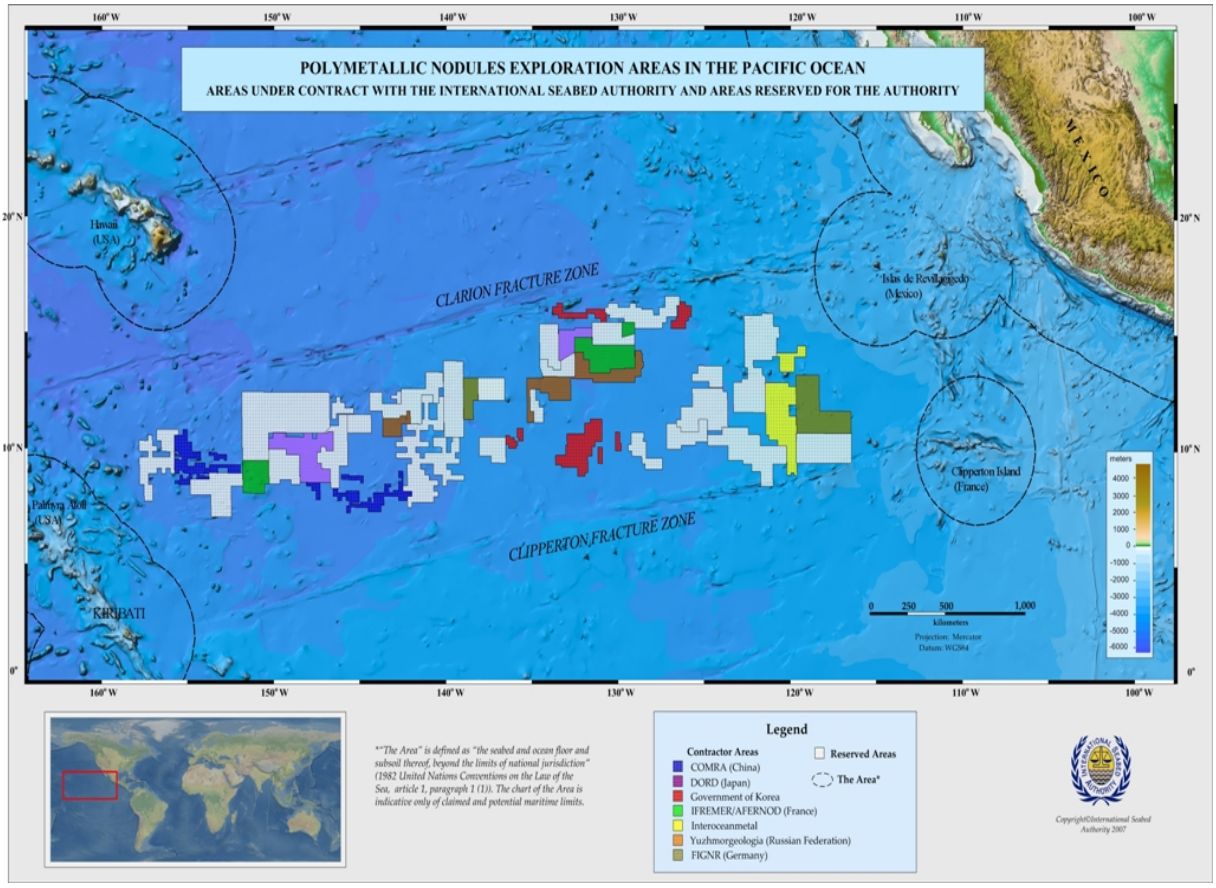


Figure 3 Polymetallic nodule province between Clarion-Clipperton Fracture Zone of Pacific Ocean

There are four types of polymetallic nodules found in the Pacific: iron-rich nodules found in parts of the South and West Pacific and near central America; manganese-rich nodules found in parts of the eastern of Pacific; copper and nickel-rich nodules found in the central and eastern Pacific and cobalt-rich nodules centered on topographic highs in the central, southern and western Pacific (Cronan,1980).

The most extensive areas of nodules coverage in Indian ocean are to the South of the equator. Few nodules have been recorded in the Arabian Sea or the Bay of Bengal most

probably because of the high rates of terrigenous sediment input from this region from the South Asian rivers (Cronan, 2001).

Nodule stocks in terms of kilograms per square meter (abundance) vary according to the topography of the area. The highest abundance of nodules is generally associated with the high relief area, such as valleys (average 6,94 kg/m^2), followed by hilltops (average 5,81 kg/m^2) and slopes (average 4,30 kg/m^2). The plain areas have the least abundance (average 2,72 kg/m^2). However, nodules from the plains have the highest content of Mn, Ni, Cu and Zn, while those from the valleys have the lowest (Jauhari and Pattan, 2000).

Manganese is the highest content in polymetallic nodules from the Central Indian Basin and somewhat lower in the Wharton Basin and to the southwest of Australia. It is intermediate to low in the basins of southern and western Indian Ocean, and lowest of all on the mid-ocean ridge system (Cronan, 1980). Nodules with high content of Ni and Cu is found in south-central part of the Central Indian Basin (Ahmad and Husain, 1987).

Polymetallic nodule abundance in the Atlantic ocean is more limited than in the Pacific or Indian oceans due to its relatively high sedimentation rates. The areas of the Atlantic where polymetallic nodules occur in an appreciable amounts are those where sedimentation is inhibited (Cronan, 2001).

Manganese is highest in deep water areas on either side of Mid-Atlantic Ridge and in deposits from the Blake Plateau and Walvis Ridge. In contrast, iron is highest in samples from the Drake Passage and Scotia Sea area. Nickel is highest in the Cape Basin where it ranges to 1,5% and is somewhat lower over the remainder of the South Atlantic. The distribution of copper and zinc is similar to nickel, both are generally highest in the basins and low in elevated areas of the ocean (Cronan, 1980).

Economic Value

Although deep-sea polymetallic nodules were discovered over a century ago, it was only in early 1950's when the deep-sea polymetallic nodules deposits were considered as a possible resource of manganese (Mero, 1977).

Since the beginning of 1960s a large extent of polymetallic nodule deposits have been examined in some detail by many international consortia with aims at commercial exploitation (Morgan, 2000) and in 1970s industrial nations that conducted exploration cruises claimed potential mining areas and developed mining techniques (Thiel *et al.*, 2001).

The claims for the study and exploitation of nodules are coordinated and contracted by the International Seabed Authority (ISA), an autonomous international organization created

under auspices of the United Nations (http://www.isa.org.jm/en/home). The ISA has its headquarters in Kingston, Jamaica and attends any claim for the exploitation of non-living resources in international waters, were the Law of the Sea constitutes the only vinculant regulatory framework (see below).

Polymetallic nodules are considered an important sources of raw material for industry, mainly because of the relatively high content of nickel, copper and cobalt and because of their potentially large supply (Halbach *et al.*, 1975; Morgan, 2000). The primary use of Mn, Co and Ni are in steel manufactures. Cobalt is also used in electrical, communications, aerospace and engine and tool manufacturing industries. Nickel is used in chemical plants, petroleum refineries, electrical appliances and motor vehicles (Hein *et al*., 2000).

Most probable area for nodule mining

Though extensive deposits of polymetallic nodules have been found in all of the world ocean, e.g.: the Pacific, Indian and Atlantic Oceans but, only few areas in which polymetallic nodules mining will be economically feasible to be conducted (Hammond, 1974; Mero, 1977).

Mero (1977) mentioned several considerations in selecting polymetallic nodules exploitation sites, e.g.: metal contents, areal extent of the deposits, density and coverage of the nodules per unit area of seafloor, continuity of the deposits with respect to metal content and size, size distribution of the nodules within the deposit, water depth, distance to port or process facility, topography of the ocean floor in the deposit area, current velocities throughout the water column, physical characteristics of the associated sediments, frequency and distribution of obstructions to mining systems within the deposit, ease with which the nodules can be processed and weather.

Considering all factors, it would appears that the high grade zone situated between Clarion and the Clipperton Fracture Zone in the northeast Pacific at a depths of 4000–5000 m would be the most likely area of commercial mining in future (Halbach *et al.*, 1975; Mero 1977). Some countries have already claimed certain areas within CCFZ for nodule mining and have been registered as a pioneer investor by ISA to conduct polymetallic nodule mining.

Assuming an average of concentration of 9 kg/m^2 nodule from over 6 million km^2 high-grade area within the North Pacific, Mero (1997) calculated about 38 billion tons of a dry nodules, averaging 29% Mn, 0,3% Co, 1,7% Ni, 1,7% Cu. Such amount of nodule deposit would contain 11 billion tons of manganese, 115 million tons of cobalt, 650 million tons of

nickel and 520 million tons of copper. These nodules also contain an average of about 0,14% Zn and 0,006% Mo (Mero, 1977).

There is no information about total estimation of polymetallic nodules from South Pacific.

Out over 4 million km^2 surveyed in Central Indian Ocean Basin, an area of 300.000 km^2 containing nodules of commercial value was identified. This area contains 1.335 million tons of nodules with average abundance 4,51 kg/m^2 and combined metal values (Ni + Cu + Co) of 21,84 million tons.

1.3. Fauna of Nodules

Meiofauna in polymetallic nodule areas

The deep-sea is a gigantic environment covering more than 50% of the earth's surface (Gage and Tyler, 1991). Most of the deep seafloor is covered by sediment. Hard substrate are limited in regions with recent volcanic activity and areas of very low sedimentation (Hannides and Smith, 2003). Despite increasing knowledge on deep-sea meiofauna in recent decades, little information is available about meiofauna communities from deep-sea floor containing hard substrate of polymetallic nodules (Bussau *et al.*, 1995).

Bussau *et al.* (1995) suggested that the biotope polymetallic nodule constituted of two sub-biotopes: the manganese nodules and the sediment around them. The metazoan meiofauna inhabits the nodule surface (nodule epifauna), the sediment-filled crevices systems of the manganese nodules (nodule endofauna), and the sediment (sediment fauna). The sediment-filled crevices system harbours a different meiofauna community than the sediment surrounds (Thiel *et al*., 1993). Smith (1998) suggested that the nodule assemblages are dominated by suspension feeders, animal that feed on food particles from the water column, while the sediment surround is dominated by deposit feeders, animals that ingest the sediment and digest food particles in it.

Benthic meiofauna from polymetallic nodule areas worldwide are known from some studies only, e.g.: Hessler and Jumars (1974), Snider *et al.* (1984), Mullineaux (1987), Renaud-Mornant and Gourbault (1990), Bussau *et al.* (1995), Ahnert and Schriever (2001), Radziejewska and Modlitba (1999), Radziejewska *et al*. (2001a), Radziejewska et al. (2001b), Radziejewska (2002) and Lambshead *et al.* (2003) from the Pacific Ocean; Parulekar *et al.* (1982), Ansari (2000), Ingole *et al.* (2000) and Ingole *et al.* (2005a) from the Indian Ocean.

Meiofauna composition in polymetallic nodule areas shows a dominance of nematodes, as in other deep-sea regions, followed by harpacticoid copepods (Hessler and

Jumars, 1974; Parulekar *et al.*, 1982; Renaud-Mornant and Gourbault, 1990; Snider *et al.*, 1984; Bussau *et al.*, 1995; Ansari, 2000; Radziejewska, 2002; and Ingole *et al.*, 2005a).

Abundance of deep-sea meiofauna is related to the food availability in the sediment surface which is mainly coming from surface water primary production (Vincx *et al*., 1994). Beside, food availability in the sediment surface also influences meiofaunal sediment penetration. This condition explains the abundance of meiofaunal occurrence at the upper 4–5 cm of the sediment (Thiel, 1983; Shirayama, 1984). In the polymetallic nodule area benthic meiofauna is reported mainly to occur in 0–2 cm top sediment (Bussau *et al.*, 1995; Ansari, 2000; Ingole *et al.*, 2000; Ingole *et al.*, 2005a). Snider *et al.* (1984) reported the relationship between meiofaunal abundance and water content of sediment in the top 2,5 cm.

Harpacticoid copepods in polymetallic nodule areas

Biological data on harpacticoid copepods from polymetallic nodule areas are known from few studies only (Hessler and Jumars, 1974; Snider *et al*., 1984; Bussau *et al*., 1995; Ansari, 2000; Ingole *et al*., 2000; Ahnert and Schrievert, 2001; Radziejewska *et al*., 2001a; Radziejewska *et al*., 2001b; Radziejewska, 2002; Ingole *et al*., 2005a).

Similar to other deep-sea regions, the abundance of harpacticoid copepods in polymetallic nodule areas ranks second after the nematodes (Ahnert and Schrievert, 2001; Ansari, 2000; Ingole *et al*., 2000; Radziejewska, 2002). Most harpacticoid copepods were found in the top 2-3 cm of sediment (Bussau *et al*., 1995; Ahnert and Schrievert, 2001; Radziejewska, 2002).

Taxonomy of deep-sea harpacticoid copepods is poorly known (Thistle, 1983: Seifried, 2004) and most of the harpacticoid copepods (54 to 62%) found in polymetalic nodules areas are new to science (Radziejewska, 2001b). Hessler and Jumars (1974) reported that copepods populations in polymetallic nodule areas of the North Pacific display higher diversity than copepod populations from Gay Head-Bermuda transect.

Harpacticoid copepods have proof to be useful for the study of environmental pollution (Heip *et al*., 1988). Radziejewska (2001b) showed that the response of harpacticoid copepods to disturbance caused by simulated polymetallic nodule mining is stronger than that of nematodes. Among families within Harpacticoida, Ameiridae, Argestidae and Thalestridae are the most appropriate for monitoring the effects of deep-sea mining on benthic communites (Ahnert and Schrievert, 2001).

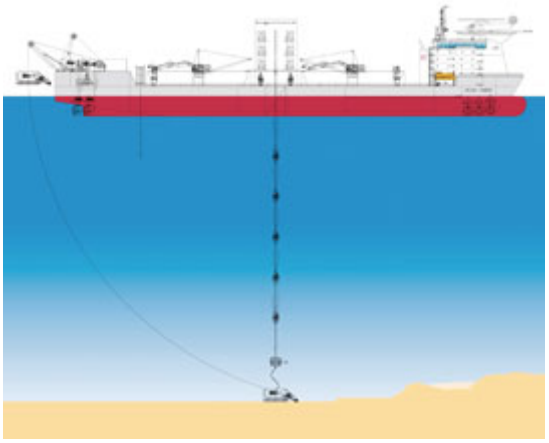


Figure 4 Nodule's collector connected to the mining vessel

1.4. Exploration and Mining of Polymetallic Nodule

Potential Impacts

Independent of its extent, all impacts related to polymetallic nodule mining will disturb species, habitats and communities. The nodule is a habitat for some organisms which is inhabit the surface and the interstitial space between sub-nodule (Thiel *et al*., 1993). Therefore, as the nodule collected, the place to live and to find the food may be altered and specimens may be killed. This condition will happens permanently and on rather large scale (Thiel *et al*., 2005). Deep-sea mining can be divided into three distinct operations, which consists of: 1.) harvesting the nodule being scattered over large areas in a mechanical or electro-hydraulic collector, transport to the pipe assembly, 2.) vertical transport from the sea floor up to the mining unit at the surface through the pipe assembly and 3.) transfer to the ore carriers from the mining vessel which has to stay over the nodule deposits and is capable only to store one days production (**Figure 4**). The special freighters maintain the shuttle service between port and mine site (Halbach and Fellerer, 1980).

On the ocean floor, mining collector will scour superficial layers of sediment along the track. Fine bottom sediments will be suspended and a benthic plume will be is created. At the surface, the discharge mixture will create both a dissolved and a particulate plume and will affect the biota (Ozturgut *et al*., 1981). Possible impacts on the deep-sea fauna include the removal of settling hard substrate, the mechanical stress exerted on soft bottom communities, the effects of sediment plumes, toxic materials and degradable organic matter (Ahnert and Borowski, 2000). Chung *et al*. (1998) summarized some of the potential impacts to benthic fauna, as follow: 1.) direct impact along the track of nodule collector, where the sediment and associated fauna will be crushed or dispersed in a plume and the nodules removed, 2.)

smothering or entombment of the benthic fauna away from the site of nodule removal, where the sediment plume settles, and 3.) clogging of suspension feeders' and dilution of deposit feeders' food resources.

Commercial deep-sea mining of polymetallic nodules was predicted to have significant impact to a huge area since the area containing economic value of polymetallic nodules is vast (9 million km^2 in the Pacific Ocean and 300.000 km^2 in the Indian Ocean) (Morgan, 2000). Thiel (1992) and literature cited there stated that " For the disturbance created by manganese nodule mining, we must assume a large scale severe and disastrous impact on the seabed and benthic community. The areas can be mined in continuous meandering tracks measuring 20 to 50 km^2. Such mining task could be carried out within a period of 3–7 weeks and afterwards mining could progress in another similar field some tens kilometer away".

Disturbance Experiment

As already describe in paragraphs above, mining the deep-sea for manganese nodules will inevitably disturb the seabed and its communities. Therefore, environmental assessment are prerequisites for risk evaluations. Although mining is predicted to begin in two or more decades, considerations and research should be conducted well in advance to evaluate predictable environmental changes, and to give advice to engineers and decision makers (Thiel, 1992), because, without better knowledge of the mining equipment to be employed ultimately and without having monitored the effects that such heavy machinery exerts on the seafloor, impact evaluation did not seem possible (Thiel *et al*., 2005). However, most considerations of the presumed environmental impacts of deep-sea mining have to remain somewhat speculative, since full scale deep-sea industrial mining has not as yet been performed, and in part, the decisions on the operational mode and technical design of the mining equipment to be employed have not been met to date. Therefore, the spatial and temporal dimensions of the resultant impacts on the deep-sea biota are hard to predict (Ahnert and Borowski, 2000).

Major environmental studies related to the deep-sea mining of polymetallic nodule included the US Deep Ocean Mining Environmental Study (DOMES) in the East Pacific (Ozturgut *et al*., 1981), the German *Dis*turbance and Re-*col*onization Experiment (DISCOL) in the South Pacific (Thiel *et al*., 2001), Inter Ocean Metal Benthic Impact Experiment (IOM-BIE) in the eastern area of Clarion-Clipperton Fracture Zone (CCFZ) in North Pacific (Radziejewska et al., 2003), Indian Deep-sea Environment Experiment (INDEX) in the

Central Indian Basin (Sharma, 2001) and the Japan's Deep-sea Impact Experiment (JET) in the Clarion-Clipperton Fracture Zone (CCFZ) of Pacific Ocean (Chung *et al.*, 2002).

- *Deep Ocean Mining Environmental Study (DOMES)*, the Deep Ocean Mining Environmental Study (DOMES) was initiated in 1975 to address environmental impact question on deep-sea polymetallic nodules mining so that environmental guidelines for mining could be developed before full-scale mining began. During DOMES project mining tests were conducted by Ocean Management, Inc. (O.M.I.) and Ocean Mining Associates (O.M.A.) in 1978, near 9ºN and 150ºW; and 15ºN and 126ºW respectively (Ozturgut *et al*., 1981).

- *Disturbance and Re-colonization Experiment (DISCOL)*, the DISCOL project (*Dis*turbance and re-*col*onisation experiment in a manganese nodule area of the deep South Pacific Ocean) had been initiated by the German Ministry of Science and Technology in 1985. The aim had been to create an impact that could be compared to what a manganese nodule miner would create on the sediment surface in the deep-sea (Schriever, 1998).

DISCOL experiment was conducted within a circular area, 2 nautical miles in diameter, of the DISCOL Experimental Area (DEA) in Southeast Pacific in 1989 using specially constructed disturber which is called the plough-harrow (Thiel *et al*., 2001). During the DISCOL experiment DEA was sampled five times: during pre-impact study, directly after the disturbance, six months after disturbance, three years after disturbance, and seven years after disturbance (Bluhm, 2001). The result implies that complete re-colonization is a slow process and some of the benthic organisms may need more than 7 years to re-establish themselves in the disturbed areas in terms of density and diversity (Chung *et al*., 1998).

- *Interoceanmetal Benthic Impact Experiment (IOM-BIE)*, the Interoceanmetal Joint Organization (IOM), an intergovernmental consortium consisting at present of the governments of Bulgaria, Cuba, Czech Republic, Poland, Russia Federation and Slovakia, was set up in 1987 to survey and explore polymetallic nodule deposits in the eastern part of Clarion-Clipperton Fracture Zone (CCFZ) and to prepare their commercial development (Radziejewska *et al*., 2003). In July 1995, IOM carried out Benthic Impact Experiment in the Pacific's CCFZ using Deep-sea Sediment Re-suspension System (DSSRS) within 2 x 1,5 km test site. The experiment was address to study the effects of disturbance produced by DSSRS on benthic community and their habitats (Tkatchenko and Radziejewska, 1998).

Result from three series of sampling the abyssal meiobenthos (1995, 1997 and 2000) showed reestablishment of meiobenthos assemblages, which were moderately disturbed

immediately after disturbance, within impacted and re-sedimentation areas (Radziejewska and Rokicka-Praxmajer, 2001).

- *Indian Deep-sea Environment Experiment (INDEX)*, Indian Deep-sea Environment Experiment (INDEX) is a multi-disciplinary study to establish baseline conditions and evaluate the possible impact of deep-seabed mining in Central Indian Basin (Sharma, 2001). INDEX was conducted by the National Institute of Oceanography (Goa, India) funded by the Department of Ocean Development (Government of India) in 1997 using DSSRS in Central Indian Ocean Basin (Sharma *et al*., 2001).

Post-disturbance assessment indicated different effect of disturbance on macro- and meiobenthic from inside and outside disturbance track immediately after disturbance (Ingole *et al*., 1999). Long term assessment, 44 months after disturbance, indicate different potential recovery both within macro- and meiobenthic fauna (Ingole *et al*., 2005a; Ingole *et al*., 2005b).

1.5. International Seabed Authorities (ISA)

Definition and Description

The International Seabed Authority (ISA) is an autonomous international organization established under the 1982 United Nations Convention on the Law of the Sea (UNCLOS) and the 1994 Agreement relating to the Implementation of Part XI of the United Nations Convention on the Law of the Sea. The Authority is the organization through which States Parties to the Convention shall organize and control their activities, in accordance with the seabed and ocean floor and subsoil thereof beyond the limits of national jurisdiction established in Part XI and the Agreement, particularly to administer the resources of the area.

The Authority, which has its headquarters in Kingston, Jamaica, was established in 16 November 1994, upon the entry into force of the 1982 Convention.

Main Task

Since established in 1994 ISA actively involved in administration and regulation of seabed mineral resources exploration. Specifically for polymetallic nodule the authority has dealt with aspects of environmental protection related with nodule exploration and the prospecting future exploitation which are likely to have environmental impact, by establishing the rules, regulation and procedures for nodule exploration.

Those work involves activities e.g.: determining the baseline should be used to measure the state of environment prior to human activity and how should the environmental

changes be monitored, and what research should be conducted to minimize the possible impact of the future nodule mining.

1.6 Outline and objectives

During past decades there has been substantial advances in our understanding about deep-sea ecosystems, promoted by the development of sampling devices and techniques. The view that deep-sea was a uniform environment which could only support limited number of species has change. Quantitative sampling of the deep-sea bottom has revealed that the deep-sea harbours a much divers communities than previously thought. Samples obtained with epibenthic sledge, box corer, spade corer and multi corer contain high number of species, most of them are new to science.

Compared with the megafauna and macrofauna, deep-sea meiofauna is poorly known, however, their high abundance and diversity suggest their important role in the deep-sea ecosystem.

The ecology of meiofauna communities has been studied from many different habitats, ie.: soft-bottom sediment, hard substrate of polymetallic nodule. Studies of meiofauna from polymetallic nodule areas mostly correlated with disturbance experiment which were conducted by pioneer investors as pilot studies.

Though the commercial mining for deep-sea polymetallic nodule will be conducted in the future decades, the severity of disturbance which was caused by polymetallic nodule mining combine with slow re-colonization in the deep-sea have increase the concerns about the sustainable use of deep-sea ecosystem and non-living resources. Therefore, a complete knowledge of the area which seem to be affected is a prerequisite before the mining can take place in the future to avoid any adverse consequence. Or, as Ahnert and Borowski (2000) stated “nevertheless, in the case of deep-sea mining there is still chance to assess environmental risks before the industrial mining operations begin”.

In this study we compared meiofauna communities, in term of abundance and diversity, from polymetallic nodule area and outside nodule area of the polymetallic nodule province at CCFZ. Specifically, we also compared harpacticoid communities from polymetallic nodule areas and outside nodule area.

Objectives of this study are: 1.) to study the meiofauna communities within polymetallic nodule province in terms of abundance, diversity, endemism and structure community by compare the nodule area and to nearby areas without nodules as a baseline

knowledge in predicting impact of nodule mining, 2.) to study the recovery of meiofauna communities in 26 years old track from the pilot-mining test.

CHAPTER 2
Material and Methods

2.1. Study area

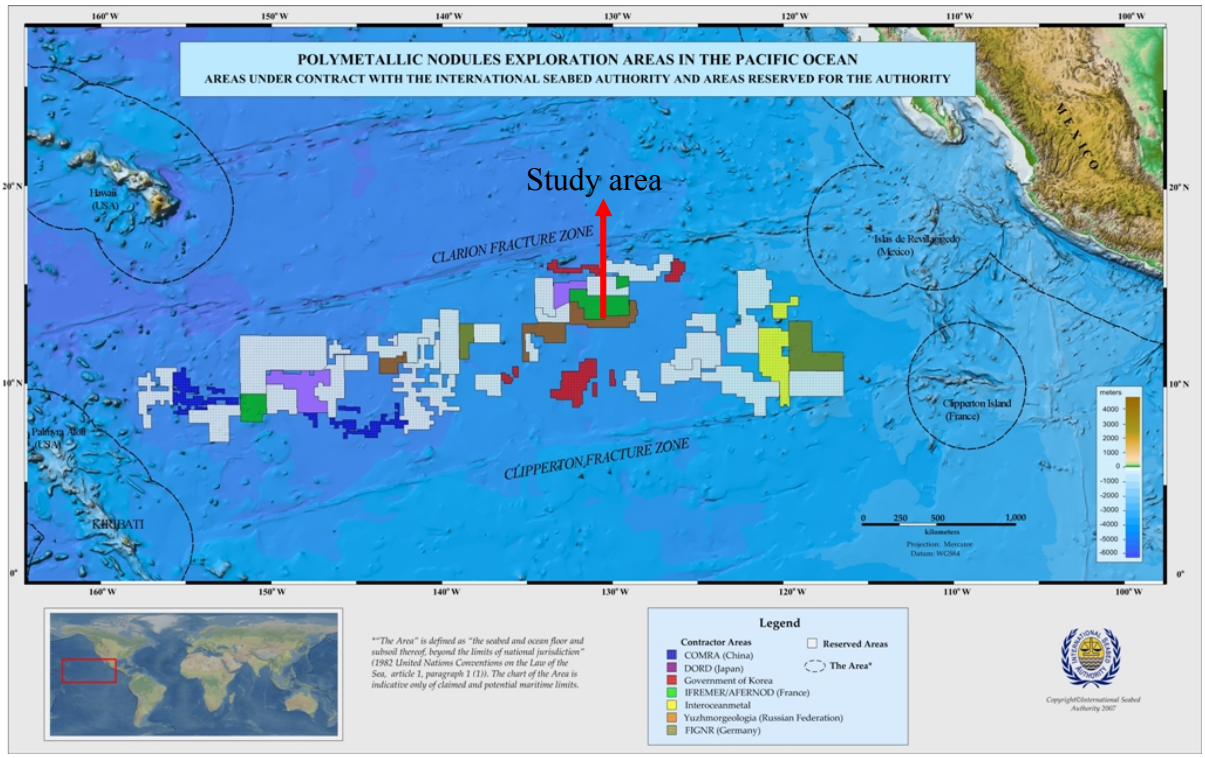


Figure 5 Polymetallic nodule exploration areas in the Pacific Ocean (From www.isa.org)

The study area is located in the eastern zone of the French mining claim area of the Pacific Nodule Province (**Figure 5**) (Galeron and Fabri, 2004). In this study, the Pacific Nodule Province (PNP) is defined as a region located between the Clarion and the Clipperton Fracture Zone (CCFZ) in the Northeastern Pacific, extending from about 110º W to 180º W between approximately 6º 30´ N and 20º N, where there is a great commercial interest in polymetallic nodule mining (Halbach, 1983). The PNP shares several characteristic of the abyssal environment with other deep-sea environment, they are: 1.) low productivity, 2.) relatively constant environmental conditions, 3.) extraordinarily high species diversity, and 4.) large and continuous habitat (Smith, 1998; Grassle, 1989).

Topography and Sedimentology

The PNP, which was bordered with the Clarion Fracture Zone in the north and the Clipperton Fracture Zone in the South is characterized by the presence of abyssal hills. Nodules are found in depths of 3200 to 5900 m. Less nodules are found in the western part of this zone because of increasing seamount density and other topographic features (Halbach,

Table 2 List of sampling stations, coordinate, depth, date and sites category (number of corer in parentheses)

Stations	Latitude	Longitude	Depth (m)	Date	Sites
MTB 6 (2)	N 14 2.862	W 130 5.347	5040	30/05/04	Outside nodules
MTB 7 (2)	N 14 2.8839	W 130 4.9702	5042	30/05/04	Outside nodules
MTB 8 (2)	N 14 2.5510	W 130 5.3506	5035	31/05/04	Outside nodules
MTB 10 (1)	N 14 2.8003	W 130 4.9987	5035	01/06/04	Outside nodules
MTB 11 (1)	N 14 2.9352	W 130 4.7287	5035	01/06/04	Outside nodules
MTB 14 (1)	N 14 3.0838	W 130 8.5499	4877	03/06/04	Nodules area
MTB 15 (2)	N 14 2.6852	W 130 7.8358	4947	03/06/04	Nodules area
MTB 16 (1)	N 14 2.7015	W 130 7.7325	4950	03/06/04	Nodules area
MTB 17 (1)	N 14 2.1982	W 130 6.5987	5000	07/06/04	Nodules area
MTB 18 (3)	N 14 2.5157	W 130 7.9834	4950	07/06/04	Nodules area

1983). Fundamentally, the typical deep-sea landscape exhibit elongated abyssal hills bounding a relatively flat area. Exploitable mining zones were found within the flat areas. (Cochonat *et al*., 1992)

Sediment at this oligotrophic site is red clays of very low organic carbon content. Net sedimentation rate is very low, 1 mm per thousand years (see chapter I) (Cronan, 2001). The sediment surface in this area is covered by abundant polymetallic nodules (Hessler and Jumars, 1974; Smith and Demopoulos, 2003). These nodules were classified based on their shape, size, texture and their presence in the seabed as three different nodule facies: A, B and C. (Veillette *et al*., 2006, *in press*).

Nodule facies A consists of small, round nodules which have smooth surface. This type of nodule is sometimes placed side by side, or coalescent and linked to the rocky outcrops which are found on the slopes of the hills situated to the West.

Nodule facies B consists of nodules with a size between 5 and 10 cm. They are smooth and regularly flattened and show numerous fractures. This facies is situated on the hills and on the foot of the slope to the West of the zone.

Nodule facies C consists of nodules with a bigger size than facies B, able to attain an important size (20 cm). They are covered with mammilated smoother protrusions on the upper surface and phaneritic on the lower surface and have a crenulated equatorial edge. They were found on the plateau to the West (Saget, 2004)

2.2 Sediment sampling for meiofauna communities analysis

Samples were collected during the Nodinaut campaign on board of L'Atalante, May 17th – June 28th , 2004. Ten stations were sampled from two sites, 5 from nodules area (facies B) and 5 from a nearby area without nodules (**Figure 6**) using a multicorer (9,5 cm in diameter) down to 5 cm depth. Detail of sampling sites, stations and the number of corer which were collected are presented in **Table 2**. On board, immediately after collection,

samples were fixed with 4% formaldehyde seawater solution. In the laboratory meiofauna were extracted from the sediment using a centrifugation technique with Ludox and stained with Bengal Rose. Subsequently, they were counted and sorted into major taxa using stereoscopic microscope. The copepods were transferred to glycerin for further identification. All harpacticoid copepods were identified to the species level, however, due to the fact that most of the species where new to science, for this study, they were identified as a working species.

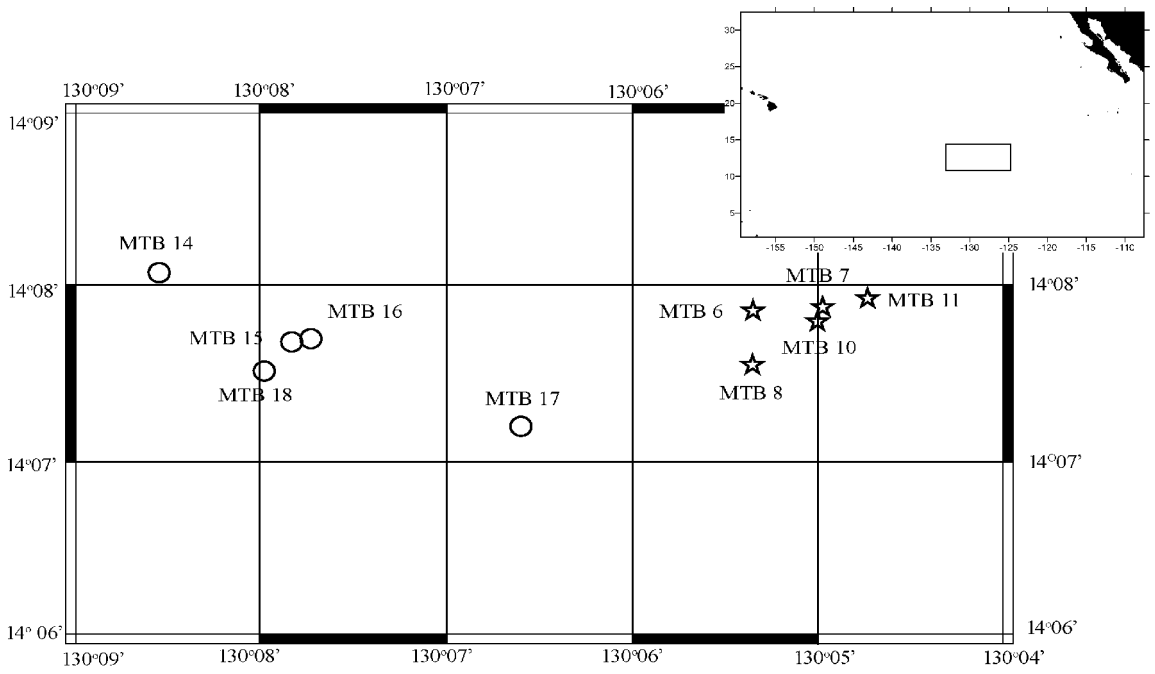


Figure 6 Map of sampling area for the analysis of meiofauna communities from outside the nodule area and nodule area

2.3. Sediment sampling for the study of meiofauna recovery in 26 years old track

These samples were taken during Nodinaut cruise together with multicorer samples, on board of the RV *l'Atalante* in May 17th – June 28th 2004 using blade corer (20 x 9 cm; Menot, pers. comm.) operated from submersible "Nautile" within a 26 years old track where the nodule had been removed during a pilot survey at the Eastern area of French mining claim (**Figure 7**). Details of the sampling are given in **Table 3**. On board the ship, the sediment samples were fixed in 4% formaldehyde solution. In laboratory, the samples were washed through a 0,25 mm mesh sieve for the macrofauna, while meiofauna were isolated from the

sediment using centrifugation method with Levasil®. Subsequently, the meiofauna was stained with Bengal Rose, sorted out and counted to the higher taxonomic groups using a stereoscopic microscope. As the multicorer samples copepods were transferred to glycerine for further identification and all harpacticoid copepods were identified to the species level or to working species.

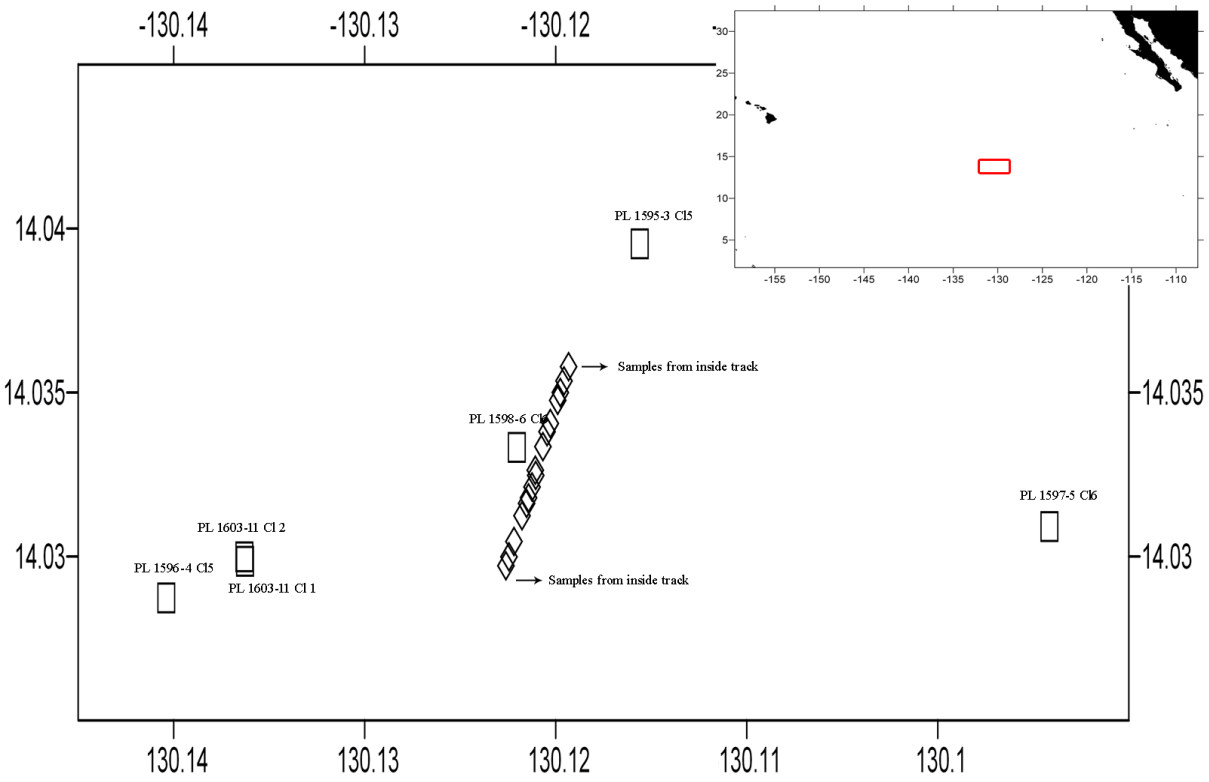


Figure 7 Map of sampling area for the study of meiofauna recovery in 26 years old track

2.4. Data analysis

2.4.1. Multivariate analysis

Multivariate analysis for the comparison of species assemblages at different sites is conducted by computing similarities between any pair of samples (Warwick and Clarke, 1991). Triangular matrices of (dis-)similarities can be produced using a variety of indices (Gray et al., 1988; George, 1999). In this study the Bray-Curtis similarity coefficient was used

$$S_{jk} = 100\left\{1 - \frac{\sum_{i=1}^{p} |y_{ij} - y_{ik}|}{\sum_{i=1}^{p} (y_{ij} + y_{ik})}\right\}$$

Where S_{jk}, is the similarity between the j^{th} and k^{th} samples; y_{ij} is the entry in the i^{th} row and j^{th} column of the data matrix for the i^{th} species in the j^{th} sample; y_{ik} is the entry for the i^{th} species in the k^{th} sample (Clarke and Warwick, 2001).

Table 3 List of sampling stations, coordinate, depth and date

Corer	Latitude	Longitude	Depth (m)	Date	Stations Categories
PL 1595-3CL5	N 14 02.3717	W 130 06.9362	4978	26/05/2004	Outside track
PL 1596-4CL5	N 14 01.7244	W 130 08.4231	4966	27/05/2004	Outside track
PL 1597-5CL6	N 14 01.8549	W 130 05.6493	5027	28/05/2004	Outside track
PL 1598-6CL6	N 14 01.9998	W 130 07.3221	4971	29/05/2004	Outside track
PL 1603-11CL1	N 14 01.7913	W 130 08.1755	4986	05/06/2004	Outside track
PL 1603-11CL2	N 14 01.7990	W 130 08.1777	4986	05/06/2004	Outside track
PL 1599-7CL1	N 14 01.9576	W 130 07.2641	4979	31/05/2004	Inside track
PL 1599-7CL2	N 14 02.0007	W 130 07.2401	4978	31/05/2004	Inside track
PL 1599-7CL3	N 14 02.0281	W 130 07.2275	4978	31/05/2004	Inside track
PL 1599-7CL4	N 14 02.0434	W 130 07.2174	4977	31/05/2004	Inside track
PL 1599-7CL5	N 14 02.1469	W 130 07.1598	4980	31/05/2004	Inside track
PL 1599-7CL6	N 14 02.1210	W 130 07.1740	4980	31/05/2004	Inside track
PL 1599-7CL7	N 14 02.1002	W 130 07.1854	4978	31/05/2004	Inside track
PL 1599-7CL8	N 14 02.0854	W 130 07.1938	4978	31/05/2004	Inside track
PL 1602-10CL1	N 14 01.8969	W 130 07.2917	4980	04/06/2004	Inside track
PL 1602-10CL2	N 14 01.9073	W 130 07.2857	4980	04/06/2004	Inside track
PL 1602-10CL3	N 14 01.9273	W 130 07.2744	4979	04/06/2004	Inside track
PL 1602-10CL4	N 14 01.9484	W 130 07.2632	4979	04/06/2004	Inside track
PL 1602-10CL5	N 14 01.8742	W 130 07.3056	4980	04/06/2004	Inside track
PL 1602-10CL6	N 14 01.8271	W 130 07.3314	4981	04/06/2004	Inside track
PL 1602-10CL7	N 14 01.7994	W 130 07.3466	4981	04/06/2004	Inside track
PL 1602-10CL8	N 14 01.7831	W 130 07.3566	4982	04/06/2004	Inside track

These similarity matrices were then subjected to an ordination methods, e.g.: non-metric multidimensional scaling (MDS), to construct a map of the sites for the graphical visualization of its similarity to each other in 2-dimensions. The more similar 2 samples are in the similarity matrix, the nearer they are to each other on the map. The relative goodness of the ordination is expressed by the stress value, which sums the scatter around the regression line in a Shepard diagram as calculated using equation:

$$Stress = \sqrt{\frac{\sum\sum\left(d_{jk} - \hat{d}_{jk}\right)^2}{\sum\sum d_{jk}^2}}$$

where $\hat{d}_{jk}$ is the distance predicted from the fitted regression line corresponding to dissimilarity δ_{jk}. If $d_{jk} = \hat{d}_{jk}$ for all the $n(n-1)/2$ distances in this summation, the stress is zero.

If the stress values is low (<0,1), an MDS ordination is more useful representation than a cluster analysis (Clarke and Warwick, 2001).

2.4.1.1. ANOSIM

ANOSIM significance test was performed in order to provide a test for significant differences between groups. The null hypothesis (H_0) is that there are no differences in community composition. In order to test H_0, 3 steps were performed:
1. Compute a test statistic (*R*) which reflects the observed differences between sites contrasted with differences within sites. If the method of display was an MDS ordination the suitable test statistic is:

$$R = \frac{\left(\bar{r}_B - \bar{r}_W\right)}{\frac{1}{2}M}$$

$\bar{r}_W$ is defined as the average of all rank similarities among replicates within sites, $\bar{r}_B$ is the average of rank similarities from all pairs of replicates between different sites. Where M = n(n–1)/2, and n is the total number of samples under considerations.

The statistic test is calculated directly from values in the dissimilarity matrix and based on the rank of dissimilarity.

2. Recalculated statistic *R* under permutation of sample labels.

3. Calculate the significance level by referring the observed value of R to its permutation distribution. (Clarke and Warwick, 2001)

2.4.1.2. Minimum Spanning Tree

Due to the complexity of multivariate data analysis, sometime, it is necessary to perform several methods in significance test. As an alternative test for testing the significant difference between sites the minimum spanning tree (MST) is used. This test is based on the dissimilarities between all pairs of subsamples, similar to ANOSIM test. However, it differs to ANOSIM by the construction of statistic test. ANOSIM uses the difference of the rank similarities between and within the samples. The MST uses the number of sub-trees linking subsamples from the same sample as the test statistic (Schleier and van Bernem, 1996). The MST provides a direct representation between point distances but doesn't reduce the dimensionality of the hyperspace, therefore, there is no inherent distortion (Warshauer and Smosna, 1981)

The MST was performed base on (dis-)similarity matrix to create the shortest tree connecting all replicates in a multidimensional space. Then, all connections between points of different station were removed and a certain number of sub-trees was left. The sites were significantly different if the number of sub-trees left lower than expected under null hypothesis (Rose *et al*., 2005).

2.4.1.3. Similarity Percentage

To identify the contribution of variables (individual species) to the separation between two groups of samples we performed the similarity percentage routine (SIMPER). The SIMPER calculates the average Bray-Curtis dissimilarity between all pairs of inter-group samples (i.e. all sites of habitat 1 against all sites of habitat 2). Because Bray-Curtis dissimilarity measure incorporates the contribution of each feature (e.g. each species), the average dissimilarity between sites of habitat 1 and 2 can be expressed in terms of the average contribution from each species. The standard deviation provides a measure of how consistently a given species will contribute to the dissimilarity between habitats 1 and 2. A good discriminating species will contributes heavily to inter habitat dissimilarity and has a small standard deviation (Clarke and Gorley, 2006).

2.4.2. Univariate analysis

2.4.2.1. t-test

Student's t-test was performed to test for significant differences of means of total number of individuals (mean abundance) The null hypothesis is that the population means related to two independent, random samples from an approximately normal distribution are equal. Saphiro-Wilks test is used to determine whether the mean abundance are normally distributed.

Assuming that the variances are equal, the test statistic is calculated as:

$$t = \frac{\bar{x}_1 - \bar{x}_2}{\sigma d}$$

Where $\bar{x}_1$ *and* $\bar{x}_2$ *are* the sample means, σd is the variance of the difference between means and t is the observed t-values. The Student's t-test should not be used if there is significant difference between the variance of the two samples. For this case the statistic test which is used is Welch t-test.

2.4.2.2. Diversity indices

Diversity not only refers to the number of species, it also has an additional dimension, e.g. evenness and dominance (Magurran, 2006). Diversity aspect of communities could be measured by reducing complexity data into a single indices which can be handled with univariate methods (Clarke and Warwick, 2001). These indices are e.g.: Shannon index (H`) for diversity, Pielou's for evenness (J) , and Simpson index (1-λ) for dominance.

Shannon diversity index

The organization of a community can be represented by the number of species and the number of individuals per species. One of the most widely used diversity measures to describe community is Shannon index. Shannon index is calculated by the equation (Shannon, 1949):

$$H' = -\sum_{i=1}^{S} p_i \log (p_i)$$

where $p_i = n_i / N$ (n_i being the number of individuals found in the i^{th} species and N the total number of individuals) and S is the total number of species.

Pielou's evenness

As a heterogeneity measure of the Shannon index which takes into account the degree of evenness in species abundance, because evenness expresses the distribution of individuals among species. The maximum diversity, that could possibly occur at a given number of species is found when all species have equal abundances (maximum Evenness), or in other word $H' = H_{max} = \log S$ (Magurran, 2006).

Therefore, the ratio of observed diversity to maximum diversity from Pielou (1969, 1975) can be used to measure evenness (J') as followed, from Magurran, 2006:

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

Simpson index

The Simpson index is a dominance index in the sense that its largest values corresponds to assemblages whose total abundance is dominated by one or very few of the species present. Simpson index has a number of forms:

$$\lambda = \Sigma p_i^2$$

$$1-\lambda = 1-(\Sigma p_i^2)$$

$$\lambda' = \{\Sigma_i N_i(N_i-1)\}/\{N(N-1)\}$$

$$1-\lambda' = 1-\{\Sigma_i N_i(N_i-1)\}/\{N(N-1)\}$$

where p_i = the proportion of individuals in the ith species, n_i the number of individuals in the i^{th} species and N total number of individuals.

The index λ is the probability that any two individuals from the sample, chosen at random, belong to the same species (λ is always ≤ 1). As the λ increase, diversity decrease. Additionally, to discriminate whether an assemblages is more or less diverse than the other, diversity indices could be presented graphically as means and confidence interval for each site or it is also possible to be tested with standard parametric tests such as the t-test (Gray *et al*., 1988; Clarke and Warwick, 2001; Magurran, 2006).

2.4.2.3. Rarefaction

Another method for comparing diversity patterns between samples of different size (abundance) which has been widely used to describe the highly diverse deep-sea benthic fauna is the rarefaction method of Sanders (1968). Rarefaction curves were constructed under assumption that the counts of total individuals (N) and species (S) from the sample that were collected can be used to estimate the expected number of species (Es_n) which would have been observed with samples with a smaller number (n) of individuals.

Sanders (1968) original rarefaction formula was subsequently modified by Hurlbert (1971) as follows:

$$E(Sn) = \sum_{i=1}^{S}\left[1-\frac{\binom{N-N_i}{n}}{\binom{N}{n}}\right]$$

2.4.2.4. k-Dominance

Comparative studies of diversity include the using of various methods to display species abundance data, for instance, k-dominance curves (Lambshead *et al*., 1983). The k-dominance curve present the cumulative abundance (y axis) in relation to species rank (x axis). The more steep the curve the less diverse the assemblage (Magurran, 2006).

2.5. Statistical Software

All univariate statistics were performed with PAST (Palaentological Statistic) version 1.34 (Hammer *et al*., 2005). Rarefaction and k-dominance methods were performed with BioDiversityPro (McAleece *et al*. (1997). Multivariate statistic procedures e.g. ANOSIM and SIMPER routine were conducted using the PRIMER v6 software (Clarke and Gorley, 2006) and the minimum spanning tree was performed using SPANTREE 1.0 (AG Angewandte Statistik in der Ökosystemforschung Niedersächisches Wattenmeer and C v O Universität Oldenburg).

CHAPTER 3
Result

3.1 Meiofauna communities of Pacific Nodule Provinces

3.1.1 The abundance and composition of meiofauna

A total of 13 taxa were identified from outside the nodule area **(Table 4)**. The number of taxa per core ranges from 7–12. The average values of meiofaunal density from outside the nodule area is 181,66 ind./10 cm^2 (range between 139,69 to 229,66 ind./10 cm^2) with the main groups Nematoda (average 152 ind./10 cm^2; range between 115,11 to 194,21 ind./10 cm^2), Copepoda + nauplii (average 23,36 ind./10 cm^2; range between 17,09 to 32,06 ind./10 cm^2). The other meiofaunal taxa (Tardigrada, Polychaeta, Halacaroida, Ostracoda, Kinorhyncha, Bivalvia, Tantulocarida, Rotifera, Isopoda, Loricifera and Tanaidacea) are very rare. Together, they have an average of 6,18 ind./10 cm^2; range between 3,81 to 8,47 ind./10 cm^2 **(Table 5)**. Arithmetic mean for the densities of total meiofauna, Nematoda, Copepoda + nauplii and other meiofauna taxa from outside the nodule area and nodule area are presented in **Figure 8**.

Nematoda is the most dominant taxon from outside the nodule area, it averages 84% (range between 79,51% to 85,56%) of total meiofauna from outside the nodule area. The next dominant taxon is Copepoda + nauplii which is average 13% (range between 10,02% to 17,85%). Category Copepoda (adult) consist primarily copepods from harpacticoid families, but also include small number of others copepod orders (Calanoida, Siphonostomatoida and Cyclopoida). The other meiofauna taxa contribute only 3% (range between 1,93% to 4,63%) of total meiofaunal abundance **(Figure 9A)**.

Table 4. Meiofaunal taxa identified from study area (+ = present ; - = absent)

Meiofaunal taxa	Outside the nodule area	Nodule area
Nematoda	+	+
Copepoda + nauplii	+	+
Tardigrada	+	+
Polychaeta	+	+
Halacaroida	+	+
Ostracoda	+	+
Kinorhyncha	+	+
Bivalvia	+	+
Gastrotricha	-	+
Tantulocarida	+	+
Rotifera	+	+
Isopoda	+	+
Loricifera	+	+
Tanaidacea	+	+
Priapulida	-	+

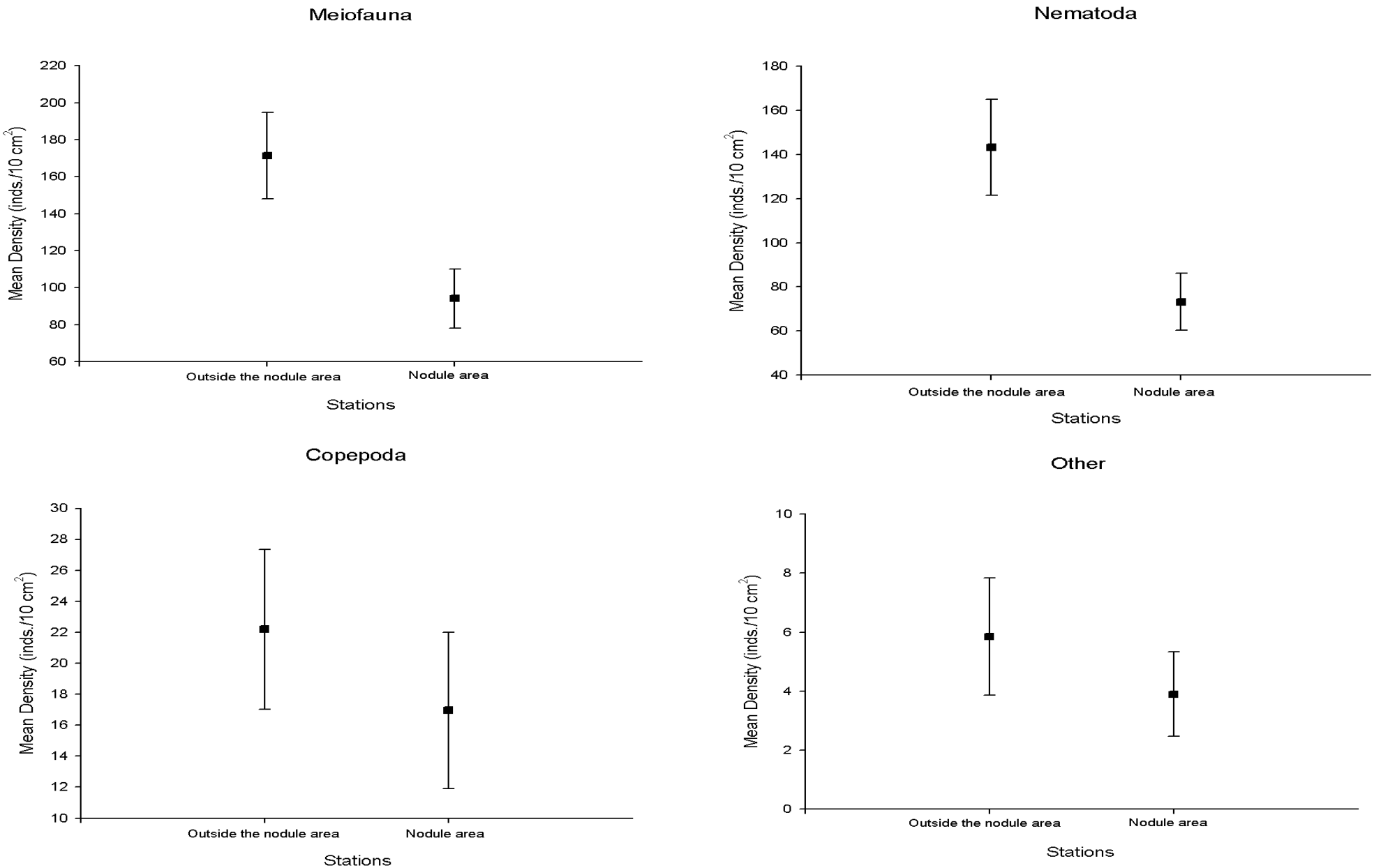


Figure 8. Mean densities of total meiofauna and several dominant taxa

Table 5. Total abundance of meiofaunal taxa, n=8

Stations	Outside the nodule area				Nodule area			
Taxa	RAW		Ind./10cm^2		RAW		Ind./10cm^2	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Nematoda	1077	218,47	152,00	30,86	544,88	139,77	76,96	19,74
Copepoda + nauplii	165,38	40,72	23,36	5,75	107,25	36,73	15,15	5,19
Tardigrada	14,25	7,80	2,01	1,10	3,75	5,18	0,53	0,73
Polychaeta	13,5	3,07	1,91	0,43	8,13	6,96	1,15	0,98
Halacaroida	6,25	8,26	0,88	1,17	6,88	3,31	0,97	0,47
Ostracoda	3,88	1,25	0,55	0,18	5,63	2,45	0,79	0,35
Kinorhyncha	1,75	1,49	0,25	0,21	0,13	0,35	0,02	0,05
Unknown	1,5	3,85	0,21	0,54	0,25	0,46	0,04	0,07
Bivalvia	1	1,51	0,14	0,21	0,25	0,46	0,04	0,07
Gastrotricha	0,00	0,00	0,00	0,00	0,13	0,35	0,02	0,05
Tantulocarida	0,63	0,92	0,09	0,13	0,38	0,52	0,05	0,07
Rotifera	0,38	0,74	0,05	0,11	0,38	0,74	0,05	0,11
Isopoda	0,25	0,46	0,04	0,07	0,88	1,13	0,12	0,16
Loricifera	0,25	0,46	0,04	0,07	0,38	0,52	0,05	0,07
Tanaidacea	0,13	0,35	0,02	0,05	0,13	0,35	0,02	0,05
Priapulida	0,00	0,00	0,00	0,00	0,13	0,35	0,02	0,05
Total meiofauna	1286,13	251,80	181,66	35,56	679,5	165,91	95,97	23,43

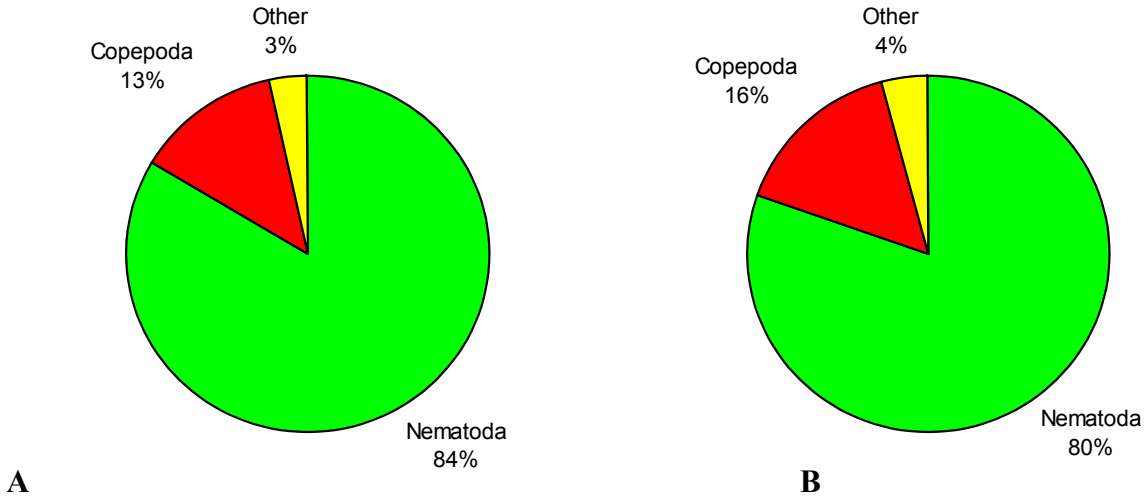


Figure 9. Relative abundance of meiofauna taxa from outside the nodule area (**A**.) versus relative abundance of meiofauna taxa from nodule area (**B**.)

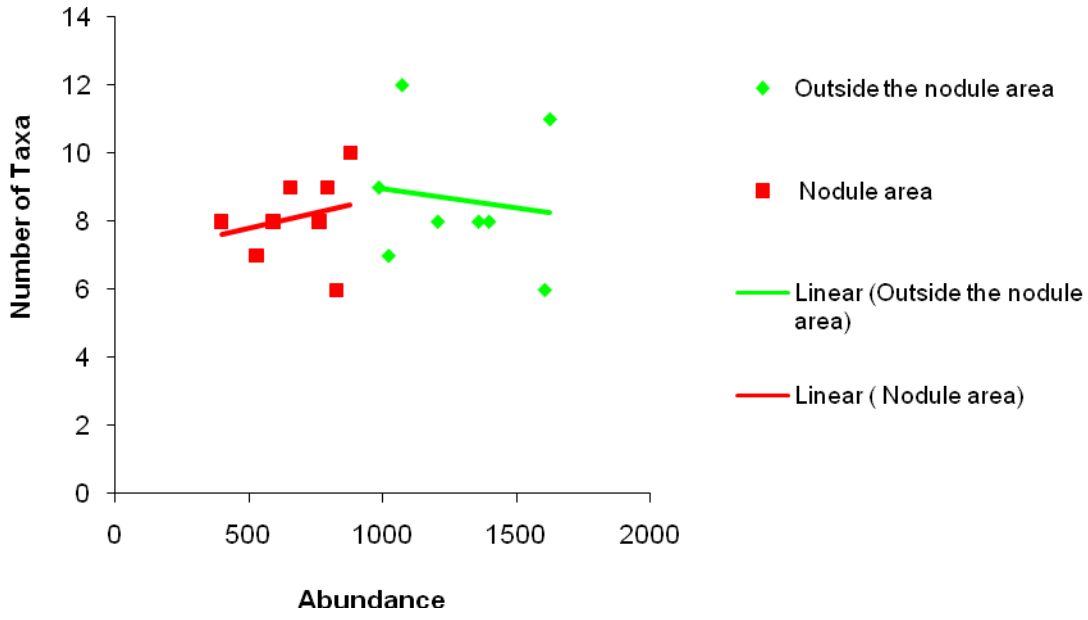


Figure 10. Relationship between abundance and the number of meiofaunal taxa from outside the nodule area and nodule area

A total of 15 taxa were identified from nodule area **(Table 4)**. The number of taxa per core range between 6 to 10. The average values of meiofaunal density from nodule area is 95,97 ind./10 cm^2 (range between 56,21 to 124,15 ind./10 cm^2). The main groups in this area were Nematoda with an average of 76,96 ind./10 cm^2 (range between 47,88 to 102,97 ind./10cm^2) and Copepoda + nauplii with an average of 15,15 ind./10 cm^2 (range between

6,78 to 25,42 ind./10 cm^2). The remainder meiofaunal taxa (Tardigrada, Polychaeta, Halacaroida, Ostracoda, Kinorhyncha, Gastrotricha, Bivalvia, Tantulocarida, Rotifera, Isopoda, Loricifera, Tanaidacea, Priapulida and some unidentified meiofaunal taxa) are rare. Together they have an average of 3,87 ind./10 cm^2 (range between 1,55 to 6,21 ind./10 cm^2) **(Table 5)**.

The dominant taxa from nodule area are Nematoda, which is average 80% (range 73,93% to 85,18%), and Copepoda + nauplii with average 16% (range 12,06% to 22,67%). As copepods from outside nodule area, here, category Copepoda (adult) also consist primarily of copepods from harpacticoid families and small number of other copepod orders. In this area, the rest of meiofaunal taxa are also very rare. Together they have an average of 4% (ranging between 2,76% to 6,7%) **(Figure 9B)**.

Analysis on relationship between abundance and the number of meiofaunal taxa shows that the average number of meiofaunal taxa which were found from outside the nodule area are slightly higher than from the nodule area **(Figure 10)**.

3.1.2. The abundance and composition of harpacticoid copepod

A total of 2181 copepods were quantitatively sampled from the eastern part of French claim area of the Pacific polymetallic nodule province. The vast number of specimens was composed by nauplii (44%) and copepodids (36%), while adult copepods contributed only to 20% of copepod community **(Figure 11)**. Similar relative abundance of developmental stages was present outside the nodule area and in the nodule area, most of copepod consist of juvenile stages **(Figure 12A and 12B)**.

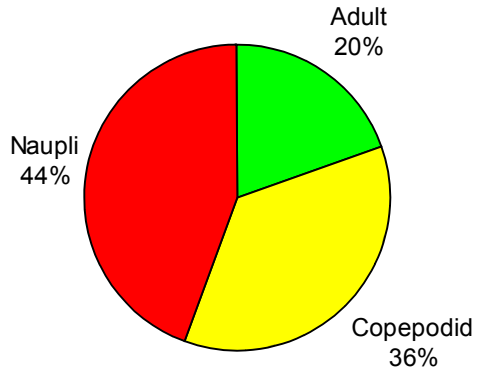
Table 6 presented the summary of copepods found throughout the study area. The adult copepods were dominated by Harpacticoida (99%) and very few Cyclopoida (1%) **(Figure 13)**. In total of 424 adult harpacticoids, 340 species were recorded, however, among those 340 species only 2 species with 3 specimens were recognized as known (described) species while most of them were assigned to working species. The known species were *Selenopsyllus antarcticus* Moura and Pottek (2 specimens), 1998 and *Ceratonotus steiningeri* George, 2006 (1 specimen). A complete list of harpacticoid genera and families found during this study is provided in **Appendix 1**.

The adult copepods belonged to 61 genera and 21 families (18 Harpacticoida and 3 Cyclopoida). Only 6 individuals could not be satisfactorily assigned to any know harpacticoid family. Among the copepod families, the most dominant were: Ameiridae (21,4%), followed by Argestidae (14,65%), Ectinosomatidae (12,09%), Canthocamptidae (11,63%), Zosimidae

(8,84%), Neobradyidae (8,37%), Pseudotachidiidae (8,37%) Diosaccidae (3,02%) and Paramesochridae (1,4%). The other families, e.g.: Cerviniidae, Cyclopinellidae, Ancorabolidae, Cylindropsylidae, Idyanthidae, Canuellidae, Huntemannidae, Leptastaciidae, Rometidae, Tisbidae, Schminkepinellidae and Gisellinidae are very few in number, their abundance is less than 1%.

Subsequently, for harpacticoid copepods Ameiridae (19%) and Canthocamptidae (17%) dominate the samples outside the nodule area, followed by Argestidae (14%), Zosimidae (14%), Ectinosomatidae (12%), Neobradyidae (6%), Pseudotachidiidae (6%) and Diosaccidae (4%). The other taxa occurred in very few numbers, together they contribute to 8% of harpacticoid copepods in samples collected outside of the nodule area **(Figure 14A)**.

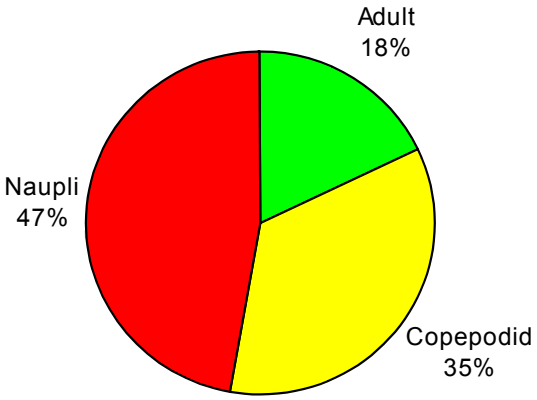
In the nodule area the dominant family is Ameiridae (26%). followed by Argestidae with 15%, Ectinosomatidae (12%), and Neobradyidae and Pseudotachidiidae which share



Outside the nodule area

Figure 11. Relative abundance of total copepod found in study area based on development stadia

Nodule area



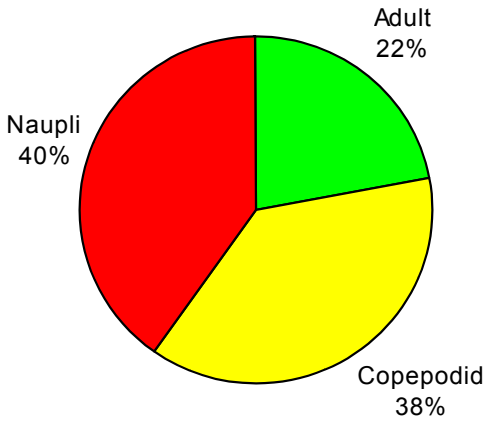


Figure 12. Relative abundance of copepod in each area based on development stadia

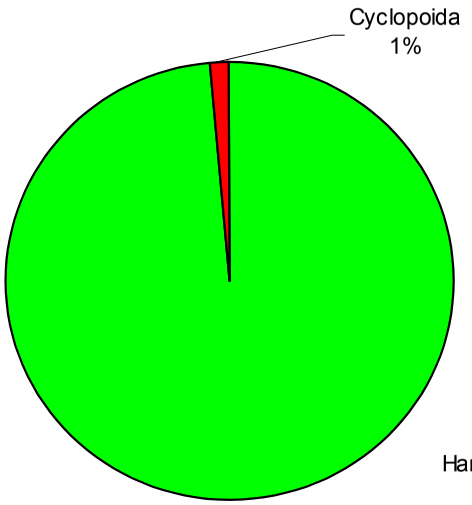


Figure 13. Relative abundance of adult copepod found in study area

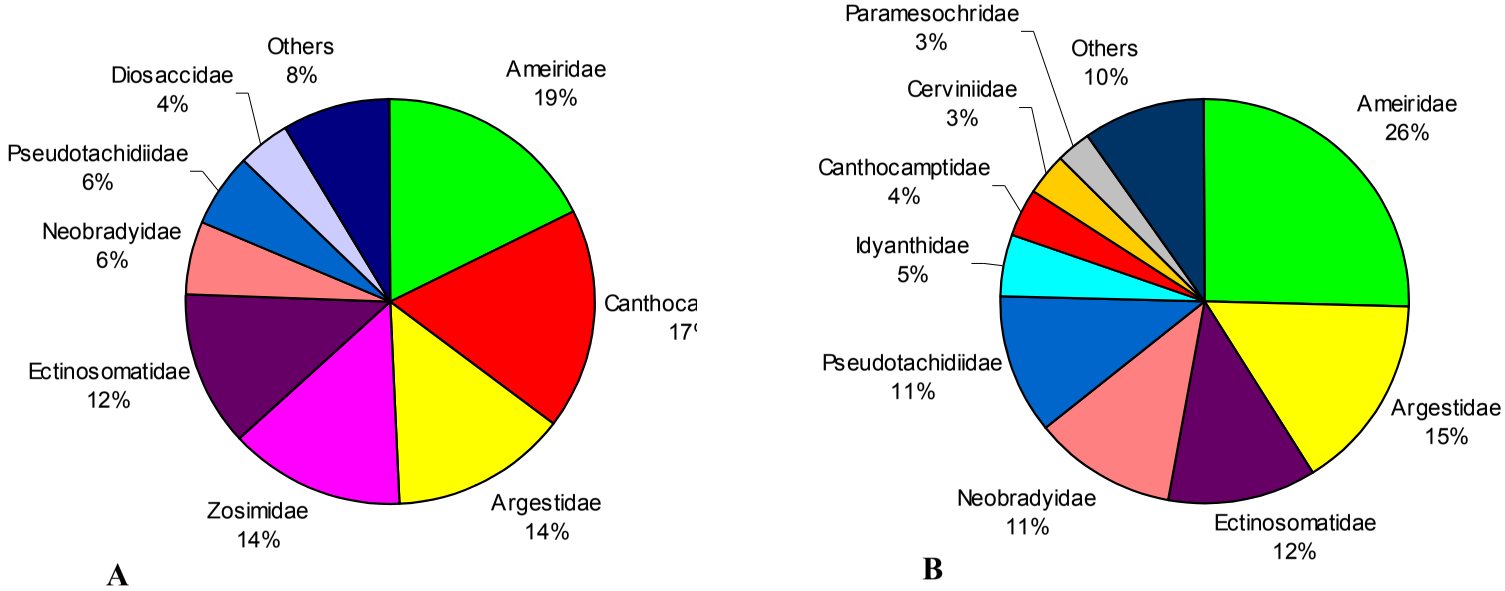


Figure 14. Relative abundance of harpacticoid copepods **A.** Outside the nodule area; **B.** Nodule area

Table 6. Summary of copepods found at the Pacific Nodule Province

Family	Number of genera	Number of species	Total abundance	%
Ameiridae	10	88	92	21,40
Ancorabolidae	2	3	3	0,70
Argestidae	7	58	63	14,65
Canthocamptidae	5	26	50	11,63
Canuellidae	1	1	1	0,23
Cerviniidae	4	4	4	0,93
Cylindropsyllidae	1	2	3	0,70
Diosaccidae	5	10	13	3,02
Ectinosomatidae	7	48	52	12,09
Huntemannidae	2	6	7	1,63
Idyanthidae	3	9	11	2,56
Leptastaciidae	1	1	1	0,23
Neobradyidae	1	31	36	8,37
Paramesochridae	1	5	6	1,40
Pseudotachidiidae	4	24	36	8,37
Rometidae	1	1	1	0,23
Tisbidae	1	1	1	0,23
Zosimidae	2	16	38	8,84
Harpact. incertae sedis	0	6	6	1,40
Schminkepinellidae	2	2	5	1,16
Giselinidae	1	1	1	0,23
Adult Cyclopoida	3	3	6	1,40
Adult Harpacticoida	58	340	424	98,60
Adult Copepoda	61	343	**430**	**100,00**
Copepodid			**783**	
Nauplii			**968**	
Total copepoda			**2181**	

similar relative abundance (11%). Next were Idyanthidae (5%) and Canthocamptidae which is the second dominant in samples outside the nodule area (17%), occurs in the nodule area only in small numbers (4%). The other taxa which occur in small numbers were Cerviniidae and Paramesochridae (3%). Some taxa, e.g.: Ancorabolidae, Canuellidae, Cylindropsyllidae, Diosaccidae, Huntemannidae, Leptastaciidae, Rometidae, Tisbidae, Zosimidae and Harpacticoida incertae sedis were eventually found, together they account for 10% of harpacticoid copepods in the nodule area **(Figure 14B)**.

Abundance and densities among harpacticoid families in samples outside the nodule area and in the nodule area have been presented in **Table 7**. The densities were vary from 2,82 to 5,08 ind./10 cm^2 (average 4,17 ind./10 cm^2) in samples from outside nodule area and

2,68 to 4,66 ind./10 cm^2 (average 3,32 ind./10cm^2) in samples from nodule area. Arithmetic mean of some diversity indices for harpacticoid from outside nodule and nodule area were presented in **Figure 15 A**, **B** and **C**.

3.1.3. Similarity analysis

The result of Shapiro-Wilk test revealed that the samples of total meiofauna, Nematoda, Copepoda and the rest of meiofaunal taxa (Tardigrada, Polychaeta, Halacaroida, Ostracoda, Kinorhyncha, Gastrotricha, Bivalvia, Tantulocarida, Rotifera, Isopoda, Loricifera, Tanaidacea, Priapulida and some unidentified meiofaunal taxa) are unlikely from a not normal distribution **(Appendix 2)**. Parametric F-test showed that the variances of samples of total meiofaunal taxa, Nematoda, Copepoda and the rest of meiofaunal taxa from outside nodule area and from the nodule area are equal **(Table 8)**.

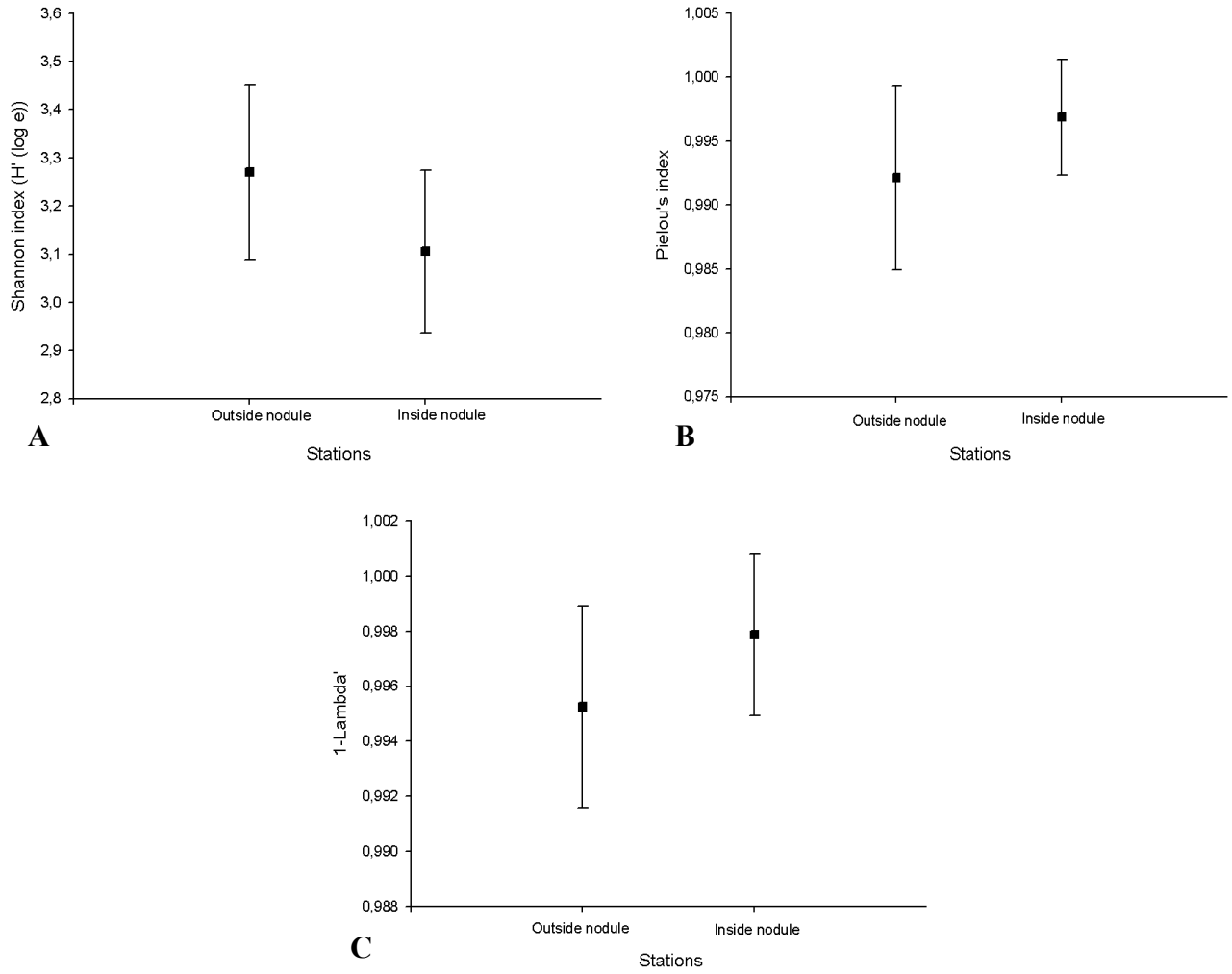


Figure 15. Arithmetic mean of some diversity indices for harpacticoid communities, **A.** Shannon index; **B.** Pielou's evenness; and **C.** Simpson index

Table 7. Harpacticoid families abundance and density (ind./10 cm^{-2})

Taxa	Outside the nodule area				Nodule Area			
	Abundance (Raw)		Density (ind./10cm^2)		Abundance (Raw)		Density (ind./10cm^2)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Ameiridae	5,25	3,06	0,74	0,43	6,25	2,76	0,88	0,39
Ancorabolidae	0,25	0,46	0,04	0,07	0,13	0,35	0,02	0,05
Argestidae	4,13	1,55	0,58	0,22	3,75	2,31	0,53	0,33
Canthocamptidae	5,13	2,42	0,72	0,34	1,13	0,99	0,16	0,14
Canuellidae	0,13	0,35	0,02	0,05	0,00	0,00	0,00	0,00
Cerviniidae	0,00	0,00	0,00	0,00	0,50	0,76	0,07	0,11
Cylindropsyllidae	0,38	0,52	0,05	0,07	0,00	0,00	0,00	0,00
Diosaccidae	1,25	1,16	0,18	0,16	0,38	0,52	0,05	0,07
Ectinosomatidae	3,63	1,19	0,51	0,17	2,88	2,53	0,41	0,36
Huntemannidae	0,63	0,74	0,09	0,11	0,25	0,46	0,04	0,07
Idyanthidae	0,38	0,52	0,05	0,07	1,00	1,20	0,14	0,17
Leptastaciidae	0,13	0,35	0,02	0,05	0,00	0,00	0,00	0,00
Neobradyidae	1,75	1,28	0,25	0,18	2,75	2,66	0,39	0,38
Paramesochridae	0,00	0,00	0,00	0,00	0,75	0,71	0,11	0,10
Pseudotachidiidae	1,75	1,83	0,25	0,26	2,75	1,16	0,39	0,16
Rometidae	0,13	0,35	0,02	0,05	0,00	0,00	0,00	0,00
Tisbidae	0,13	0,35	0,02	0,05	0,00	0,00	0,00	0,00
Zosimidae	4,13	1,89	0,58	0,27	0,63	0,52	0,09	0,07
Harpacticoida Incertae Sedis	0,38	0,52	0,05	0,07	0,38	0,52	0,05	0,07
Total			4,17	0,91			3,32	0,69

Therefore, we can use Student's t-test for testing significant differences of the means between both sites. The result of t-test revealed that mean abundance of total meiofaunal and Nematoda were significantly different at the level of confidence of 95%, while mean abundance of Copepoda and the rest of meiofaunal taxa were not significantly different. Subsequently, several diversity indices of total meiofauna samples e.g.: Shannon index, Pielou's evenness and Simpson index were tested for normal distribution with Shapiro-Wilks test **(Appendix 3)** and then were tested with F and t-test for difference in variance and mean samples, the result showed significant differences between the areas **(Table 8)**.

Table 8. Result of F-test, Student's t-Test and Welch-t Test for differences between mean densities (Ind. /10cm^2) of total meiofauna and some dominant taxa, and some diversity indices of total meiofaunal from outside the nodule area and from nodule area (n = 5; p = 0,05)

Taxa	F-value	Df	t-value	p
Total meiofauna	2,18	4	6,09	0,000291*
Nematoda	2,84	4	6,18	0,00026486*
Copepoda	1,05	4	1,63	0,14
Other	1,91	4	2,78	0,11
H' (log e)	8,37	4	2,61[a]	0,05*
J'	1,81	4	2,61	0,03*
1-λ	3,06	4	2,73	0,03*

* statistically significant (p<0,05); [a] Welch t-test

Table 9. Result of F-test and t-test for harpacticoid density and diversity indices between outside the nodule area and nodule area

Variation	F-value	Df	t-value	p
H'(loge)	1,925	4	0,316	0,760
Pielou's evenness (J')	1,076	4	0,131	0,899
Simpson (1-Lambda')	1,102	4	0	1
Abundance	1,423	4	0,311	0,764

* statistically significant (p<0,05)

Additionally, the different of mean density and some diversity indices e.g.: Shannon index (H'), Pielou's evennes (J') and Simpson index (1-Lambda) of harpacticoid from outside the nodule area and nodule area were tested with F and t-test and the result presented in **Table 9.** The result revealed that there are no significant difference between outside the nodule area and nodule area in term of density, species diversity, evennes and dominance. These result supported the result of F and t-test for copepod density in higher level as presented in **Table 8**.

Non metric 2D-MDS plot (stress = 0,01) for total meiofauna showed that meiofauna communities are separated between outside the nodule area and in nodule area **(Figure 16)**. The ANOSIM test which was based on ranked matrix of Bray-Curtis similarity was

performed to find out the existence significant differences between groups. The result confirmed 2D-MDS plot with global R = 0,707 and significant level=0,1% **(Appendix 4)**. Shepard diagram of 2D MDS presented in **Figure 17**, to show the relative success of non metric 2D MDS in preserving the similarity relationship in the ordination plot. The MST-test result also confirmed the significant difference between both sites with observed number of sub trees = 4 instead of 8 if the H0 is accepted (p = 0,01) **(Appendix 5)**.

A non-metric 2D-MDS plot based on Bray-Curtis similarity of showed the distribution of harpacticoid communities at family, genus and species level from outside the nodule area and from nodule area **(Figure 18A, B, and C)** to be clearly separated between both sites. **Figure 19 A, B,** and **C** shows the Shepard diagrams which shows the goodness-of-fit of the MDS plots in preserving samples relationship in the distance of ordination plot for family, genus and species level. The significant difference between harpacticoid communities from outside and inside nodule areas was tested with the ANOSIM test which was based on ranked matrix of Bray-Curtis similarity. The result showed that H_0 ("no different between sites") was rejected with significant level of sample statistic, p = 0,1% (global R = 0,501) for family level; p = 0,1% (global R = 0,461) for genus level and p = 0,2% (global R = 0,389) for species level **(Appendix 6)**.

The similarity percentages of harpacticoid communities between the sites were computed with the SIMPER routine of the PRIMER package in respect to average similarity within area and average dissimilarity between area. For family level, the average similarity within samples outside and inside nodule area 65,28 and 58,37, respectively. While the average dissimilarity between both area was 46,58. For genera level, the average similarity within samples from outside the nodule area and from nodule area were 41,9 and 37,2, while the average dissimilarity was 67,61. At species level, the average similarity within samples from outside the nodule area and nodule area were 6,78 and 4,04 and the dissimilarity of samples between both area was 97,72 **(Appendix 7)**.

K-dominance and rarefaction curves revealed the high evenness of harpacticoid communities both, outside and in the nodule area and that the evenness between harpacticoid communities from both habitats do not substantially differ **(Figure 20 and 21)**. The rarefaction curve doesn't reach an asymptote, indicating that many more species that the ones collected in the present survey can be expected to live in the area.

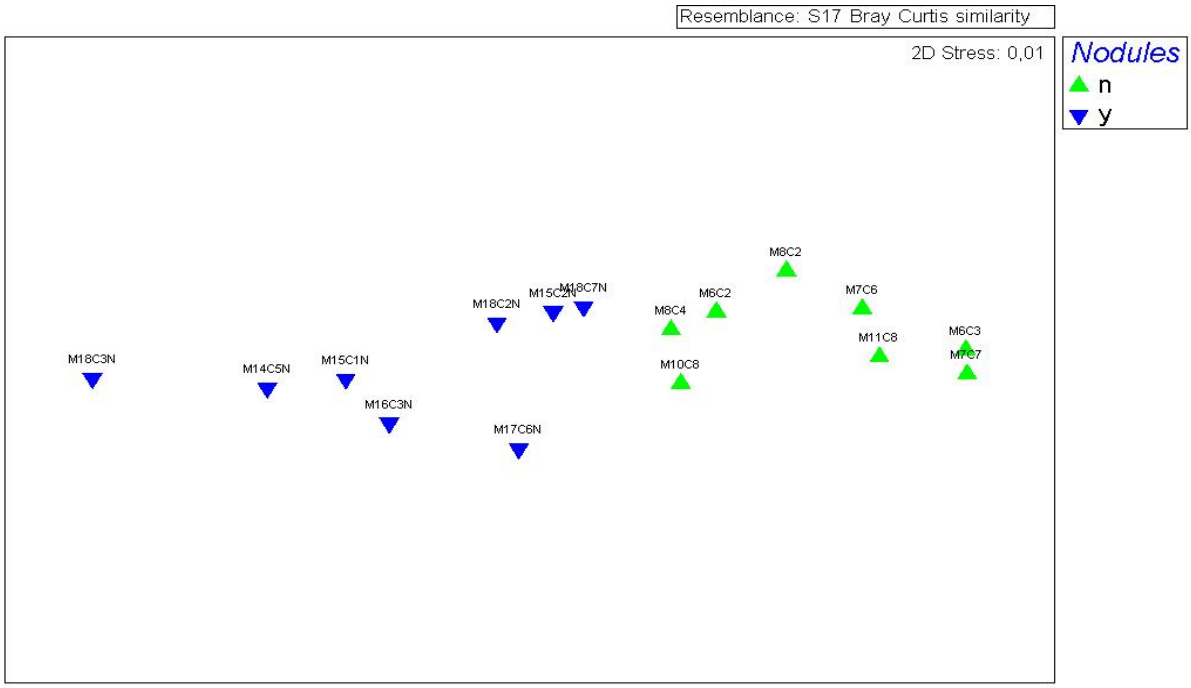


Figure 16. 2D-MDS of meiofauna samples from outside the nodule area and nodule area

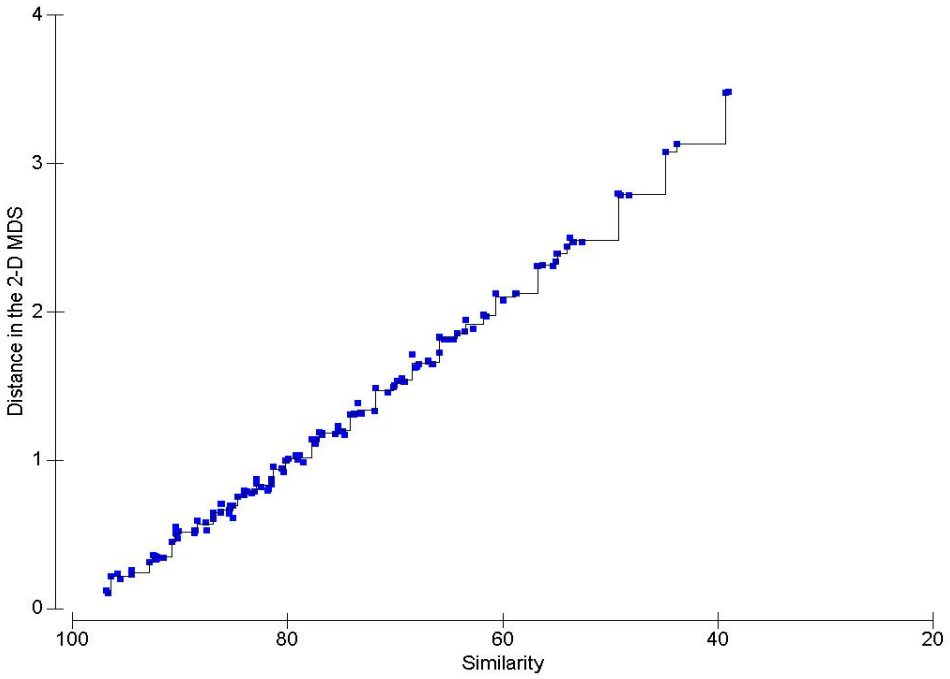


Figure 17. Shepard diagram of 2D-MDS plot of total meiofauna samples from outside the nodule area and nodule area

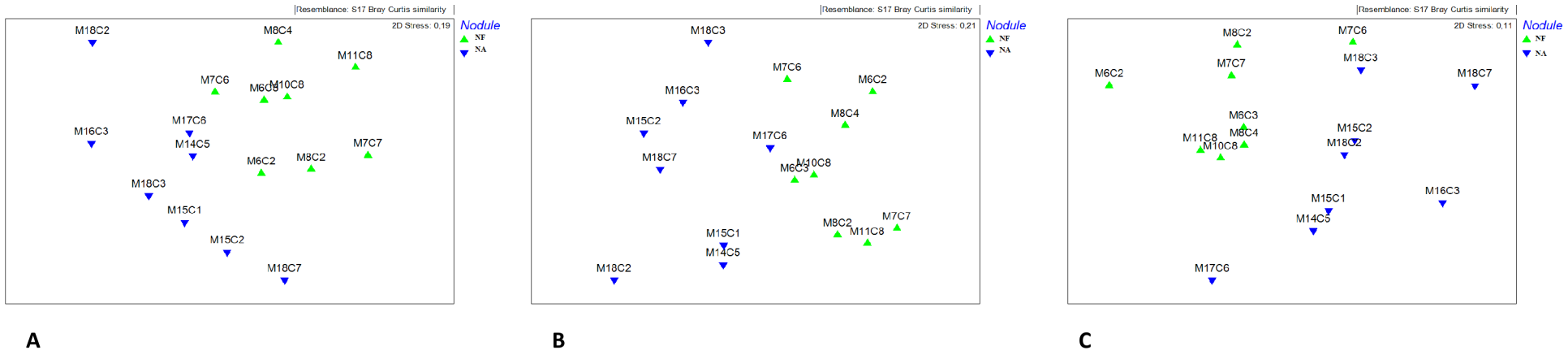


Figure 18. 2D-MDS of harpacticoid samples from outside the nodule area and nodule area **A.** Family level; **B.** Genus level; **C.** Species level

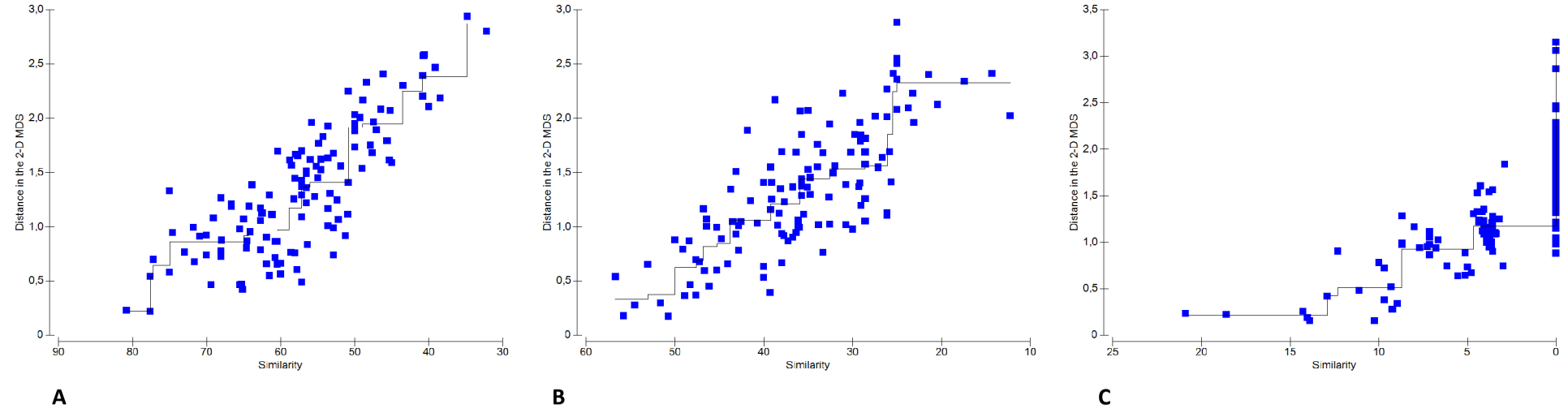


Figure 19. Shepard diagram of 2D-MDS plot of harpacticoid samples from outside the nodule area and nodule area **A.** Family level; **B.** Genus level; **C.** Species level

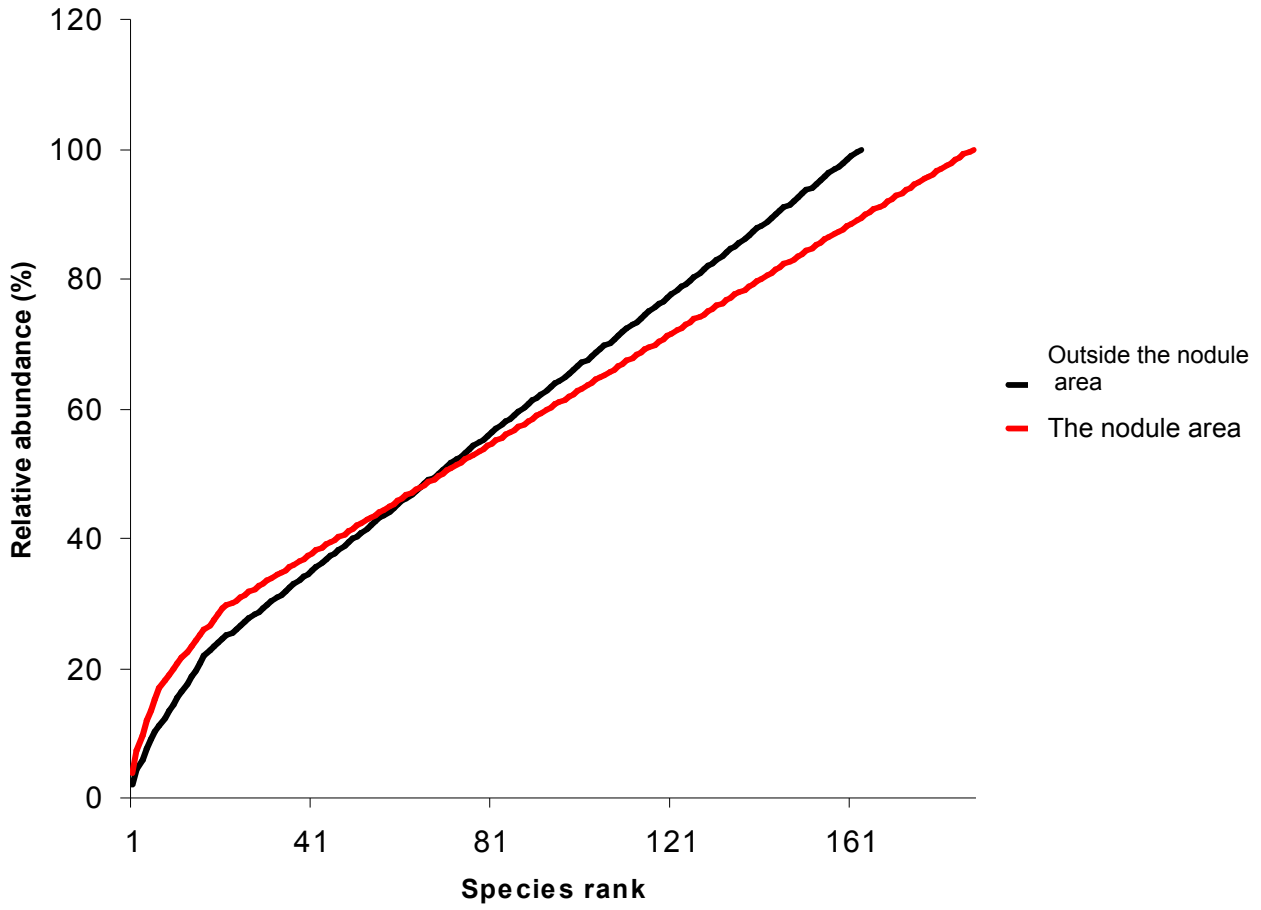


Figure 20. k-Dominance curve of harpacticoid communities

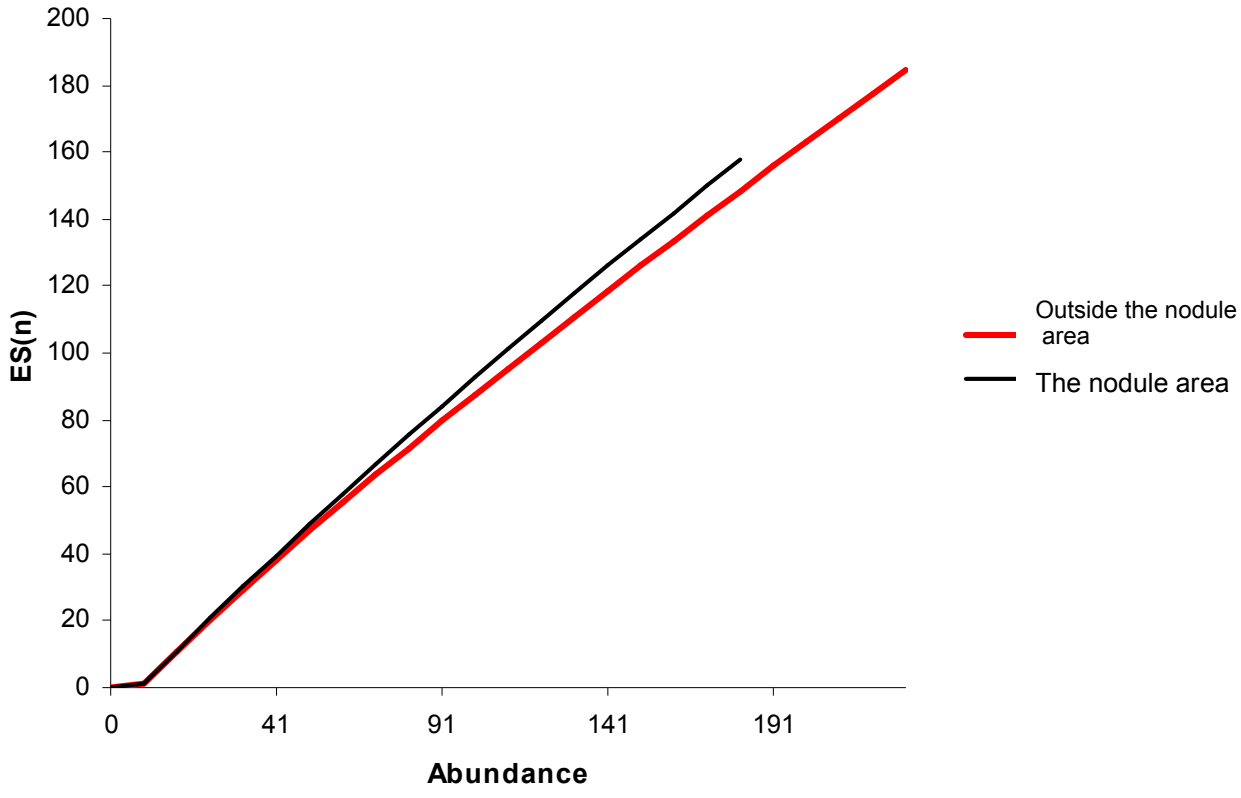


Figure 21. Rarefaction curve of harpacticoid communities

3.2. Recovery of meiofauna communities within a 26 years old track

3.2.1. Meiofauna

A total of 13 metazoan meiofauna taxa were recorded in the samples taken from outside and inside the track depleted from nodules in 1978 during a pilot survey by OMCO in the western part of French claim area at the CCFZ . Their mean densities are presented in **Table 10**. Nematoda was the most dominant taxon found in the samples from both areas (ranged between 80 to 84 % of meiofauna) followed by Copepoda (ranged between 13 to 18%). In samples from outside track these two taxa were followed by Ostracoda (1%) and Halacaroida (1%), while in samples from inside track both taxa were followed by Halacaroida with relative abundance less than 1%. The other taxa, e.g.: Tardigrada, Polychaeta, Kinorhyncha, Bivalvia, Gastrotricha, Tantulocarida, Rotifera, Loricifera and the larvae of Annelidae were rarely found , together they contribute to 1% of total meiofauna abundance in both areas **(Figure 22)**.

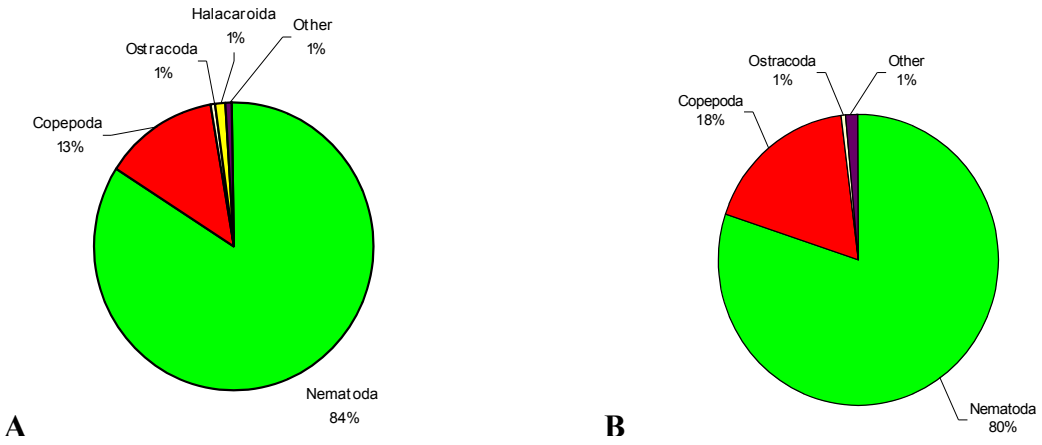


Figure 22. A Relative abundant of meiofauna taxa from outside track; **B** Relative abundant of meiofauna taxa from inside track

Arithmetic mean density of total meiofauna and some major meiofaunal taxa from outside- and inside track is presented in **Figure 23 A, B, C and D**. The graphs showed that mean densities of total meiofauna and some major meiofaunal taxa display a slightly different value inside track than outside track. In order to know whether this

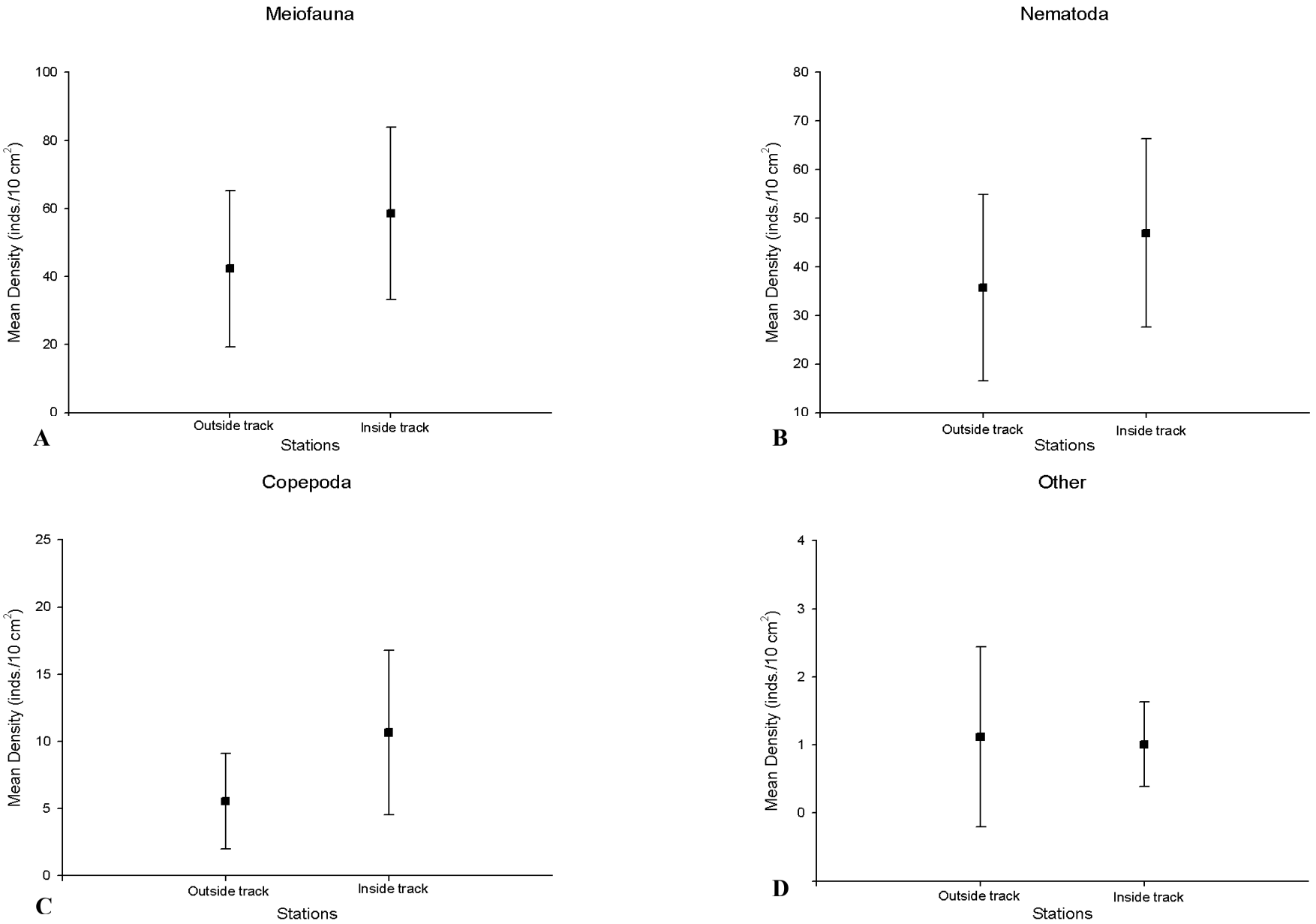


Figure 23. Arithmetic mean density of meiofauna and some dominant taxa

Table 10. Mean densities of meiofauna communities from outside track and inside track

Stations	Outside track				Inside track			
	RAW		ind/10cm^2		RAW		ind/10cm^2	
Taxa	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Nematoda	642	344,77	35,67	17,49	798,13	374,84	44,34	20,82
Copepoda + nauplii	99,67	63,68	5,54	3,23	179,38	92,28	9,97	5,13
Tardigrada	1,67	1,63	0,09	0,08	1,06	1,39	0,06	0,08
Polychaeta	1,17	1,33	0,06	0,07	2,75	3,47	0,15	0,19
Halacaroida	9	19,14	0,5	0,97	2,88	2,99	0,16	0,17
Ostracoda	5,33	3,56	0,3	0,18	5,94	3,55	0,33	0,2
Kinorhyncha	0,17	0,41	0,01	0,02	0,94	1,18	0,05	0,07
Unknown	1,5	2,81	0,08	0,14	0,94	2,38	0,05	0,13
Bivalvia	0	0	0	0	0,81	2,74	0,05	0,15
Gastrotricha	0	0	0	0	0,19	0,75	0,01	0,04
Tantulocarida	0,5	1,22	0,03	0,06	0,25	0,45	0,01	0,02
Rotifera	0,33	0,82	0,02	0,04	0,25	0,68	0,01	0,04
Loricifera	0	0	0	0	0,06	0,25	0	0,01
Annelida (larvae)	0,5	1,22	0,03	0,06	2,75	3,59	0,15	0,2
Total Meiofauna	761,83	413,77	42,32	20,98	798,13	374,84	55,35	25,51

difference is statistically significant, meiofaunal difference between outside and inside track were tested with F test and Student's t-test and the shown in **Table 11**. The results indicate that meiofaunal communities from outside track were not statistically different with meiofaunal communities from inside track in terms of abundance. The results of those univariate analysis were confirmed by 2D MDS plot **(Figure 24)** and one way ANOSIM (Global R = 0,039; p = 27,8%) **(Appendix 8)**. The shepard diagram is also presented to show the adequacy of MDS plot **(Figure 25)**.

Table 11. Result of F-test and t-Test for differences between mean density (ind./10cm$^{2)}$ of meiofauna communities and some major meiofaunal taxa from outside track and inside track (n = 6; p = 0,05)

Taxa	F-value	Df	t-value	p
Total meiofauna	1,2092	10	1,167	0,2703
Nematoda	1,0204	10	1,0147	0,3342
Copepoda	3,0098	10	1,7672	0,1076
Other	4,5352	10	0,1860	0,8562

*difference statistically significant (p<0,05)

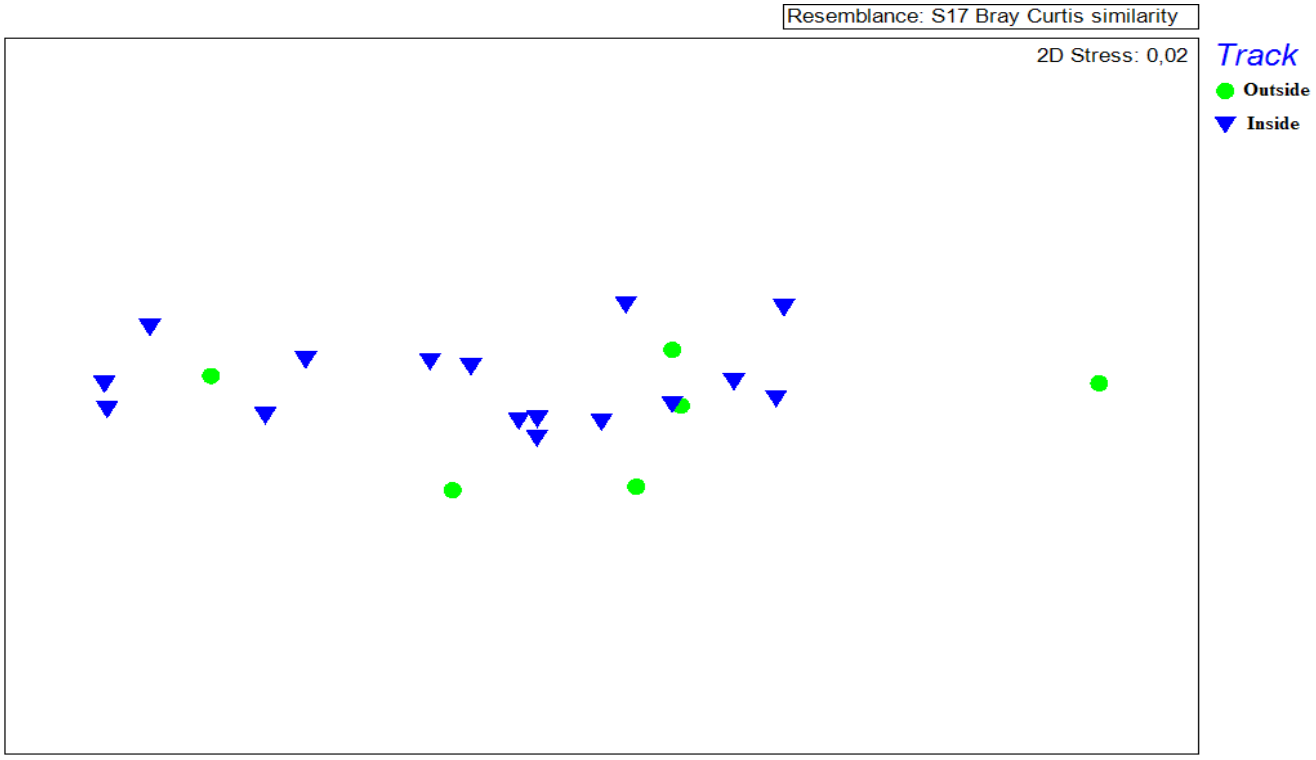


Figure 24. 2D-MDS of meiofaunal taxa from outside track and inside track

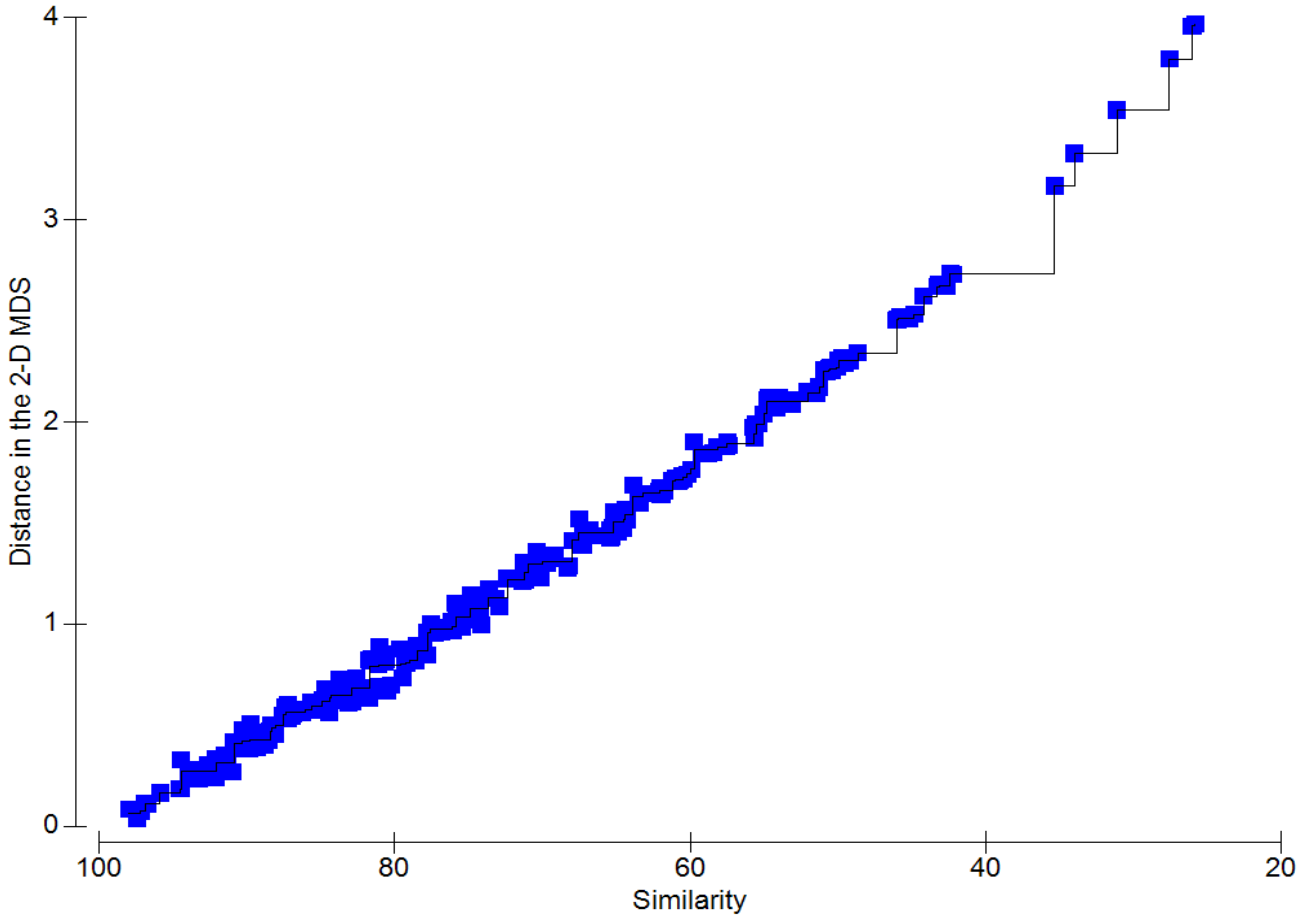


Figure 25. Shepard diagram for 2D-MDS plot of meiofaunal taxa from outside track and inside

3.2.2. Harpacticoid copepod

A total 3458 copepods were collected **(Table 12)**, of which 79 % were juvenile (copepodid and naupli), only 21% were adults **(Figure 26)**. Similar percentage was present outside and inside the track **(Figure 27 A and B)**. Of the 710 adult copepods, 96,76% belonged to the order Harpacticoida . The other orders of copepod found were, Cyclopoida with 2,11 % of adult copepods, and Poecilostomatoida and Siphonostomatoida with 0,28% and 0,85% adult copepods respectively. Together they contribute to 3,24 % of total copepods abundant **(Figure 28)**. Relative abundance of copepod's order within each area are given in **Table 13**.

Table 12 Summary of copepods identified from outside track and inside track

Taxa/Stadium	Nr. of genera	Nr. of species	Abundance
Adult Cyclopoida	4	9	15
Adult Poecilostomatoida	2	2	2
Adult Siphonostomatoida	1	3	6
Adult Harpacticoida	63	420	687
Adult copepoda	70	434	710
Copepodid			1370
Naupli			1378
Total copepoda			3458

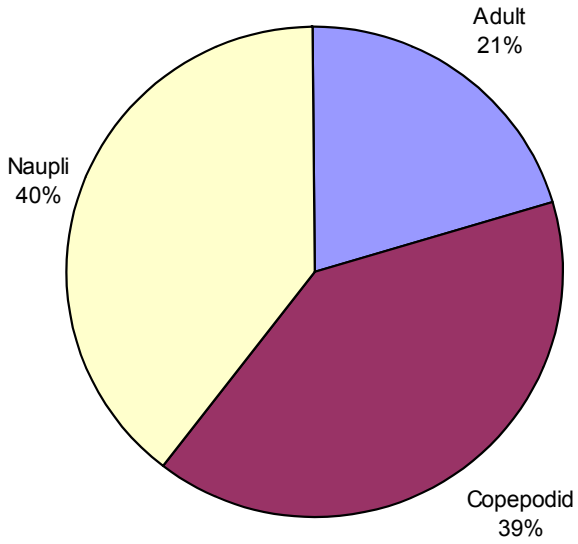


Figure 26. Relative abundance of total copepods from outside track and inside track based on development stadium

Table 13 Relative abundance of copepod's order in each stations

Taxa	Outside track	%	Inside track	%
Cyclopoida	4	2,90	11	1,92
Poecilostomatoida	1	0,72	1	0,17
Siphonostomatoida	5	3,62	1	0,17
Harpacticoida	128	92,75	559	97,73

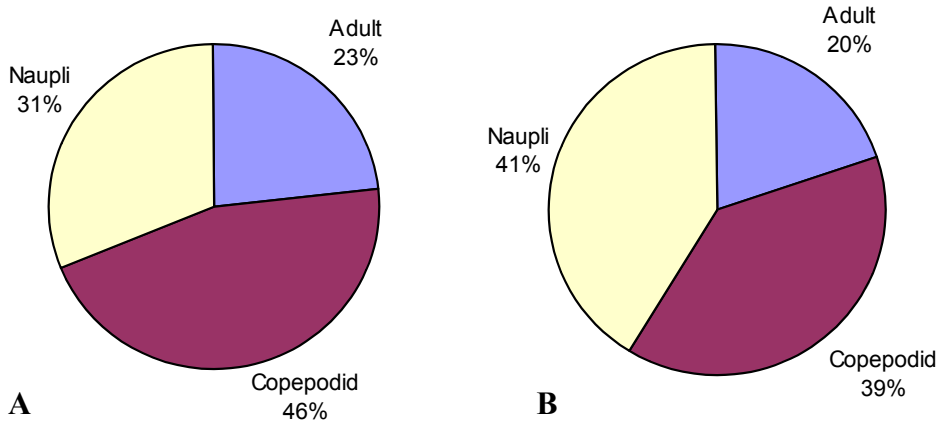


Figure 27. Relative abundance of copepods from **A.** Outside track, and **B.** Inside track based on development stadium

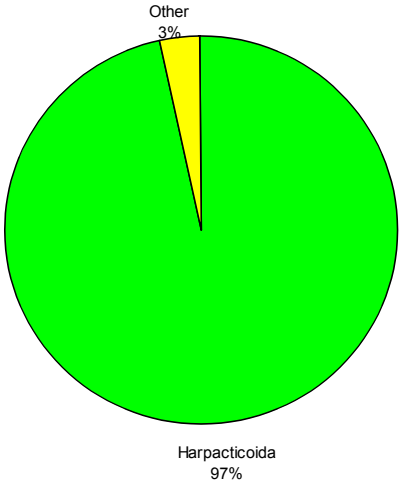


Figure 28. Relative abundance of total copepod based on order

Within Harpacticoida , Neobradyidae (18,2%) is the most dominant taxon followed by Ameiridae (16,16%), Argestidae (14,7%), Ectinosomatidae (12,23%) and Canthocamptidae (10,48%). Pseudotachidiidae and Zosimidae constitute of 8,59% and 8,79% of the total harpacticoid copepods. The presence of the other harpacticoid families in the samples is very low, with relative abundance between 0,15% to 2,04% and together they were consist of 11% of total harpacticoid **(Figure 29)**. Those dominant taxa were distributed in samples from outside- and inside track, in both areas they contribute to 89% to 91% of harpacticoid

copepods while the other taxa contribute to 9% to 11% of harpacticoid. A list of harpacticoid genera found from outside track and inside track is presented in **Appendix 1**.

Tabel 14 Summary of Harpacticoid families identified from outside track and inside track

Family	Number of genera	Number of species	Total abundance	%
Aegisthidae	1	1	1	0,15
Adenopleuridae	1	1	1	0,15
Ameiridae	13	97	111	16,16
Argestidae	7	54	101	14,70
Canuellidae	1	1	1	0,15
Canthocamptidae	4	36	72	10,48
Cerviniidae	2	4	4	0,58
Cyllindropsilllidae	1	3	4	0,58
D'Arcythomsoniidae	1	1	1	0,15
Ectinosomatidae	7	57	84	12,23
Huntemannidae	2	9	13	1,89
Idyanthidae	3	5	9	1,31
Laophontidae	1	1	1	0,15
Miraciidae	4	6	12	1,75
Neobradydae	2	55	125	18,20
Paramesochridae	2	9	12	1,75
Pseudotachidiidae	8	52	59	8,59
Rometidae	1	2	2	0,29
Zosimidae	2	19	60	8,73
Harpacticoida Incertae Sedis	0	7	14	2,04

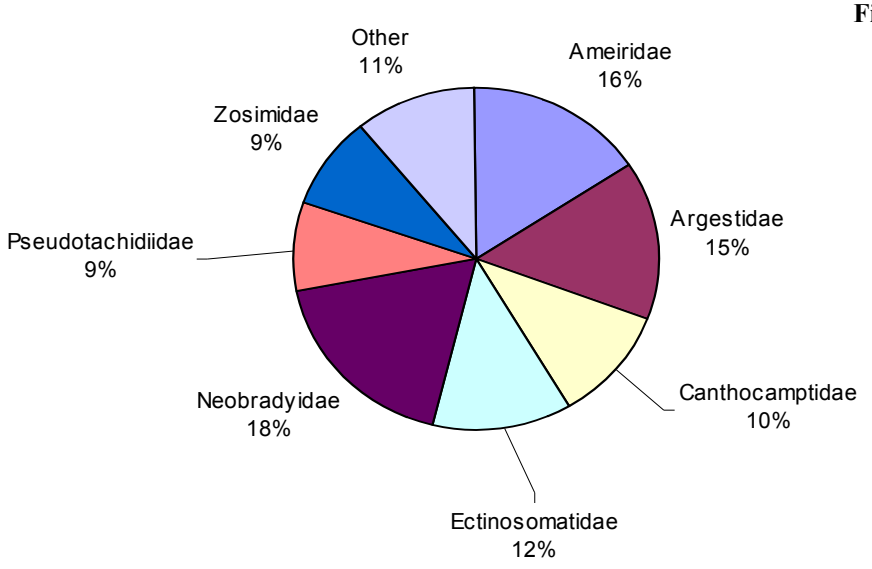


Figure 29. Relative abundance of harpacticoid copepod from outside track and inside track

The most dominant taxon within samples from outside track was Argestidae followed by Neobradyidae and Ameiridae. However, the most dominant taxon within samples from inside track was Neobradyidae followed by Ameiridae and Argestidae **(Figure 30 A and 30 B)**.

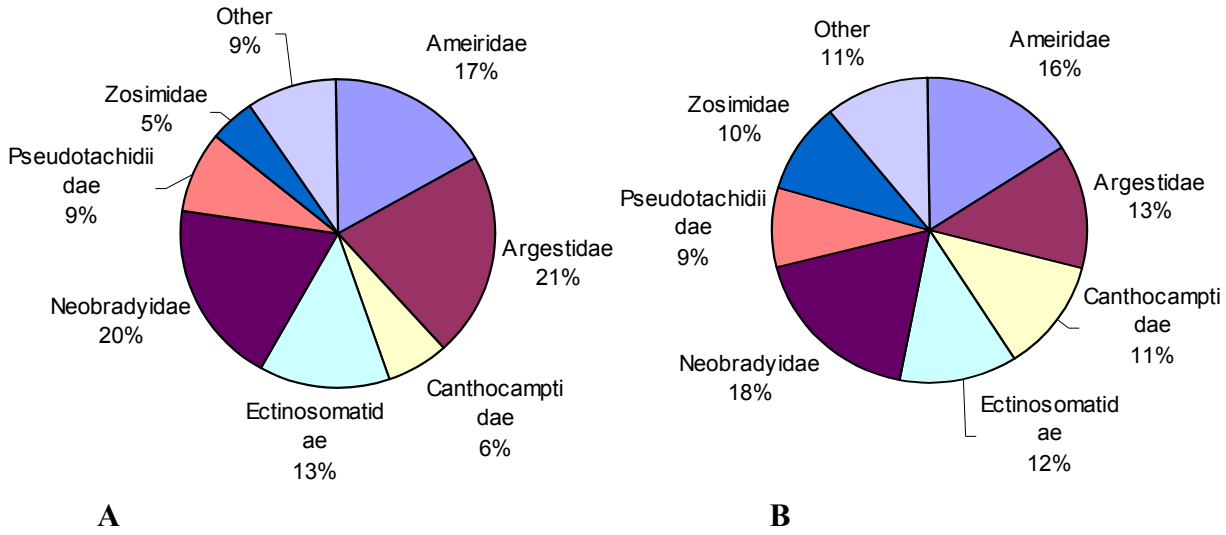


Figure 30. Relative abundance of harpacticoid copepods from **A.)** outside track and, **B.)** inside track

Table 15 Result of F-test and t-Test for differences between diversity indices of copepod species from outside track and inside track (n = 6; p = 0,05)

Indices	F-value	Df	t-value	p
Shannon diversity	3,1666	10	2,0159	0,071468
Pielou's evenness	2,638	10	1,4959	0,16556
Simpson	1,977	10	1,4669	0,17315

*the difference is statistically significant (p<0,05)

Mean value of Shannon diversity index of copepod species in samples from inside track is slightly higher than samples from outside track, but the mean values of Pielou's evenness and Simpson index is slightly higher for samples from outside track than samples from inside track **(Figure 31)**. However, these differences are not significant as we can see that their standard deviation are overlapping. Also, univariate analysis (Student's t-test) on the mean of Shannon diversity index of copepods from outside- and inside track indicated that diversity and species richness of copepods from outside- and inside track are not statistically

different. The same applies to the evenness of copepods from outside- and inside track as shown by the means of Pielou's index and Simpson index **(Table 15)**. For harpacticoid abundance, the similarity between both communities were confirmed by 2-D MDS **(Figure 32)**. This result was supported by one way ANOSIM test (Global R = 0,375; p = 0,2%) **(Appendix 9)** which showed that the groups of samples (outside- and inside track) are not significantly different which regards their copepod species similarity. Shepard diagram showed the adequacy of MDS plot in representing sample's distance within Bray-Curtis similarity matrix **(Figure 33)**. Subsequently, the rarefaction curve which was constructed based on the samples from outside- and inside track also confirmed high diversity of both copepods assemblages in term of expected number of species **(Figure 34)**. Besides, k-Dominance curve showed high evenness of both copepods assemblages **(Figure 35)**.

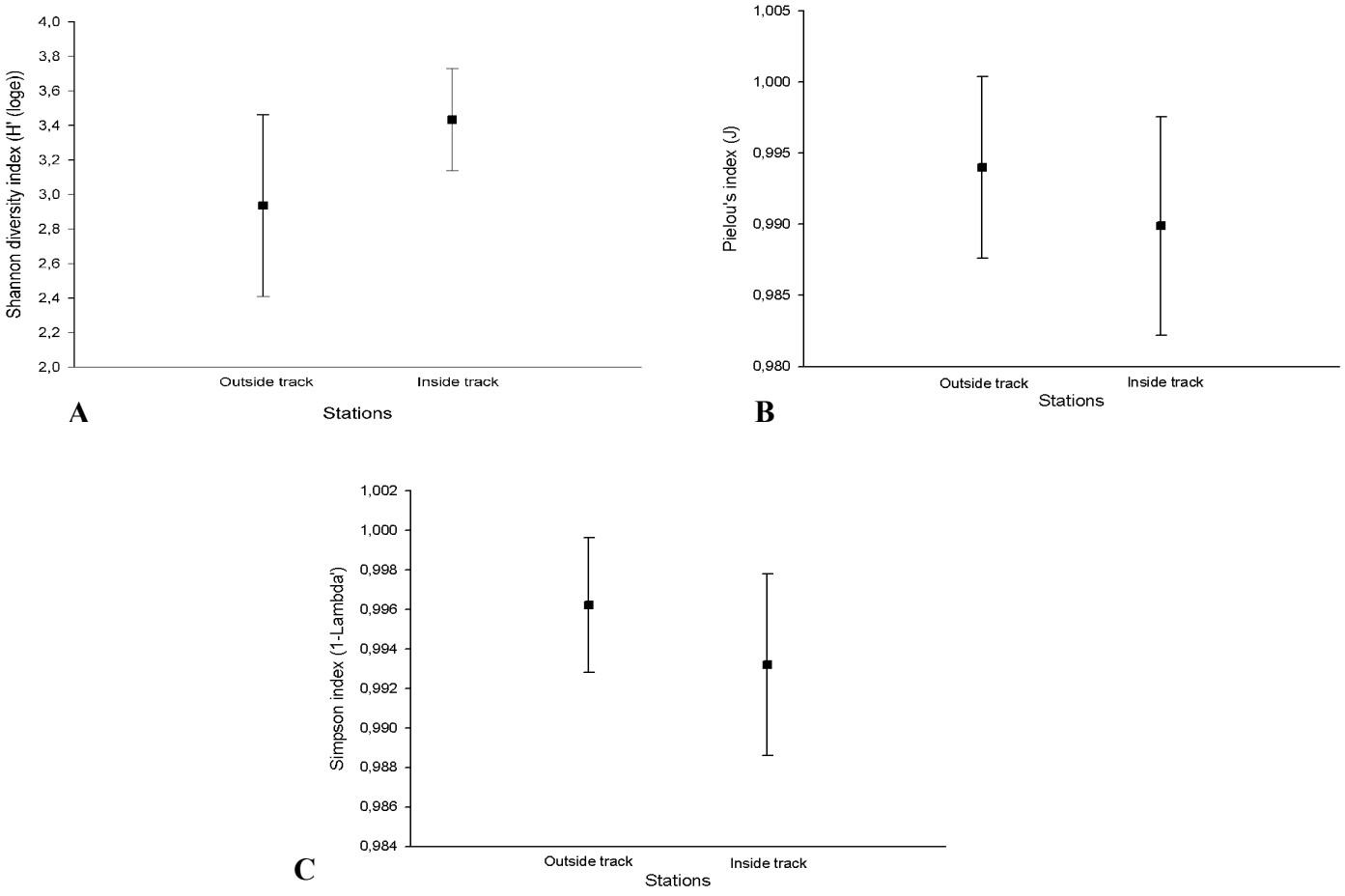


Figure 31. Arithmetic mean of several diversity index for harpacticoid from outside track and inside track **A.** Shannon index; **B.** Pielou's evenness and **C.** Simpson index

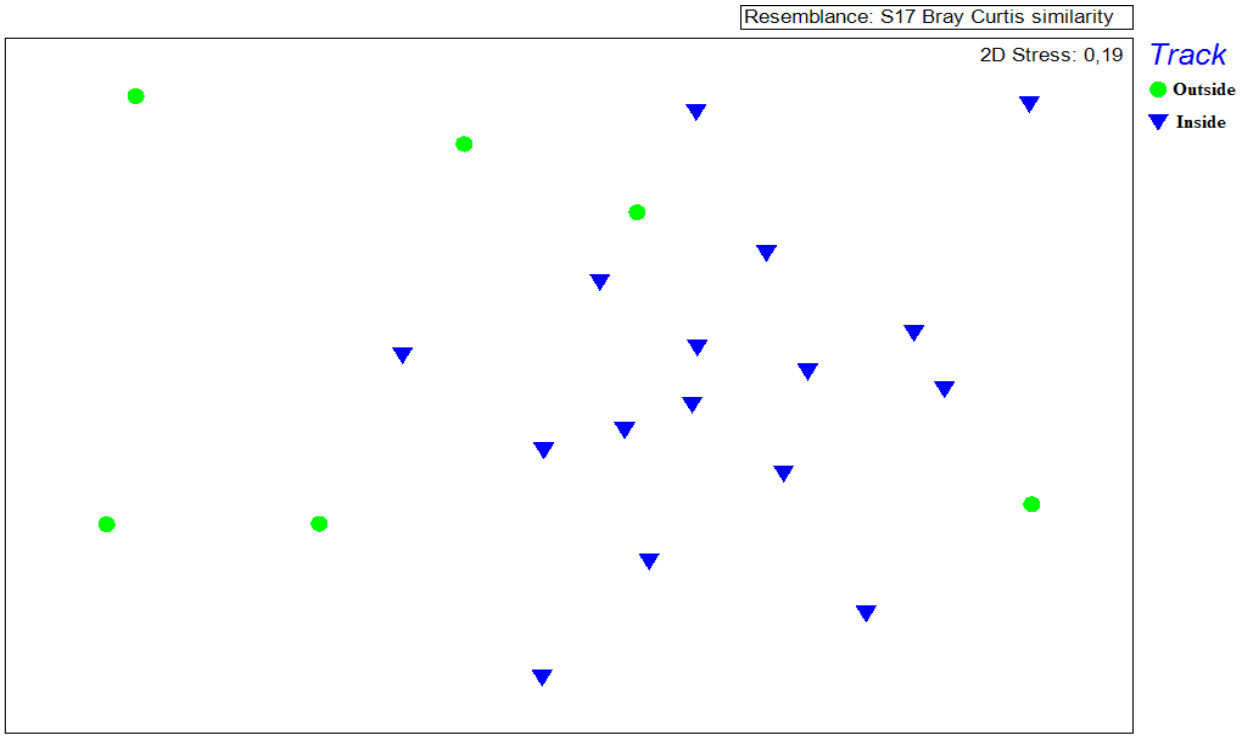


Figure 32. 2D-MDS of copepods from outside track and inside track

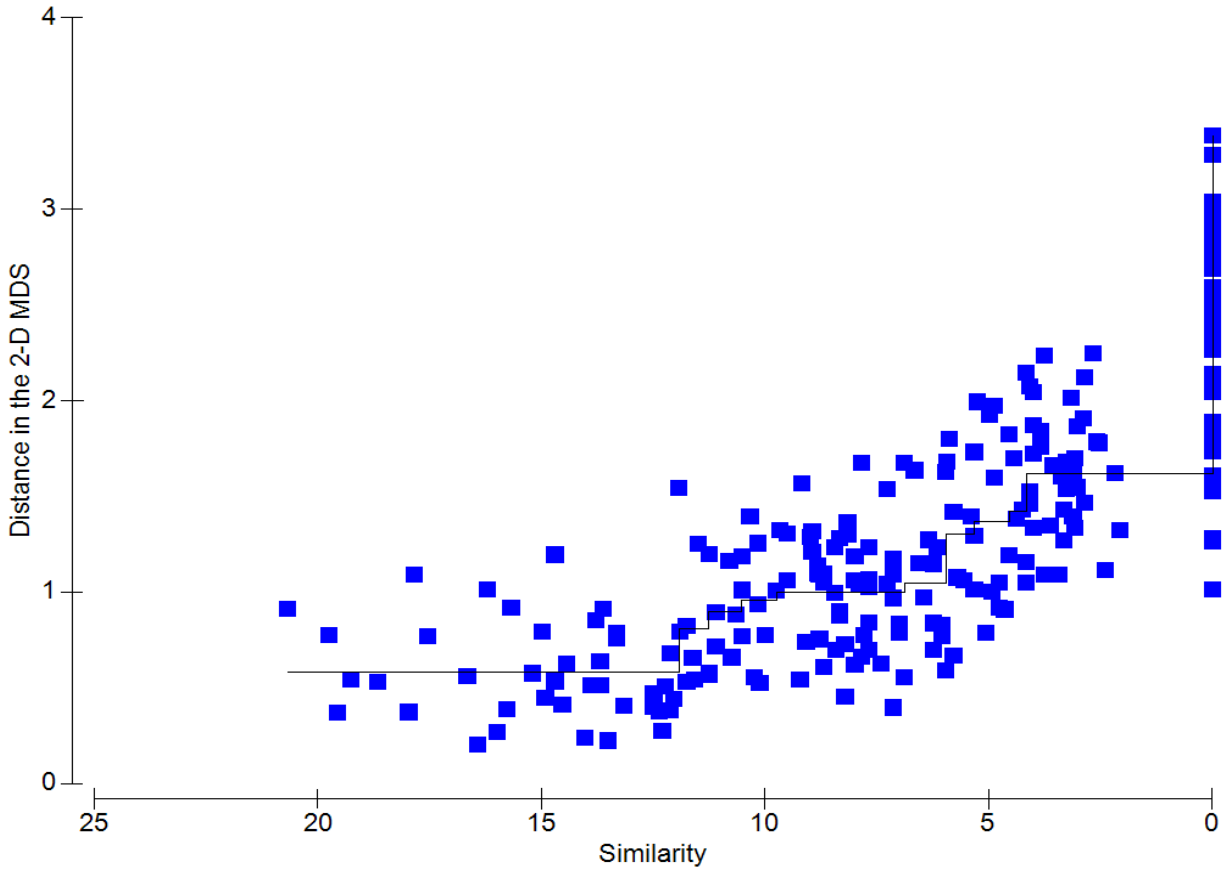


Figure 33. Shepard diagram for 2D-MDS of copepods from outside track and inside track

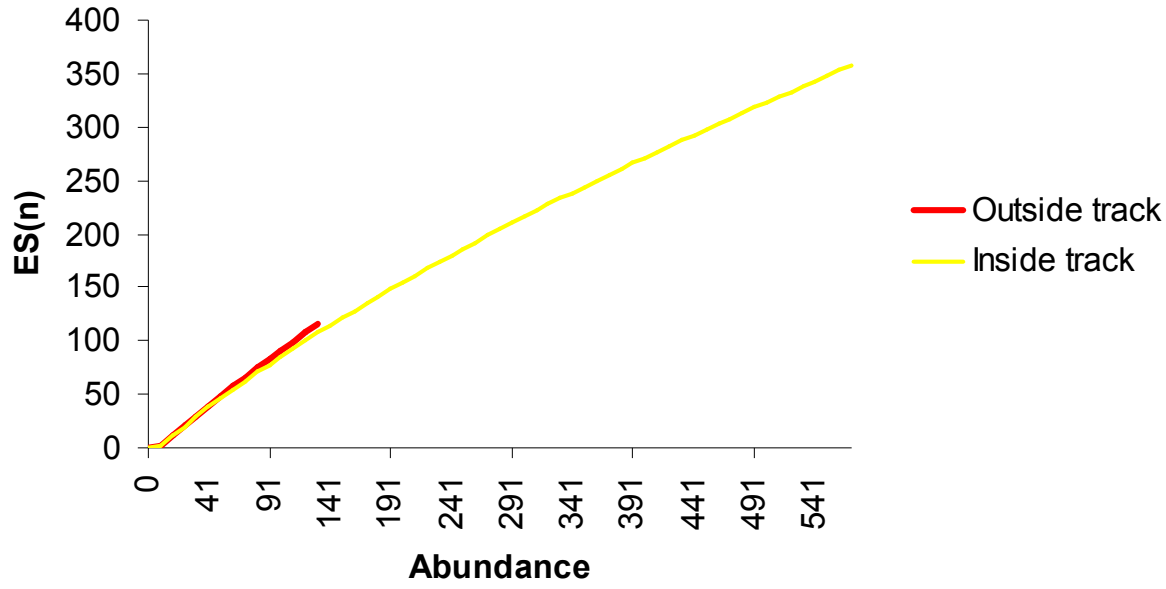


Figure 34. Rarefaction curve of copepods from outside track and inside track

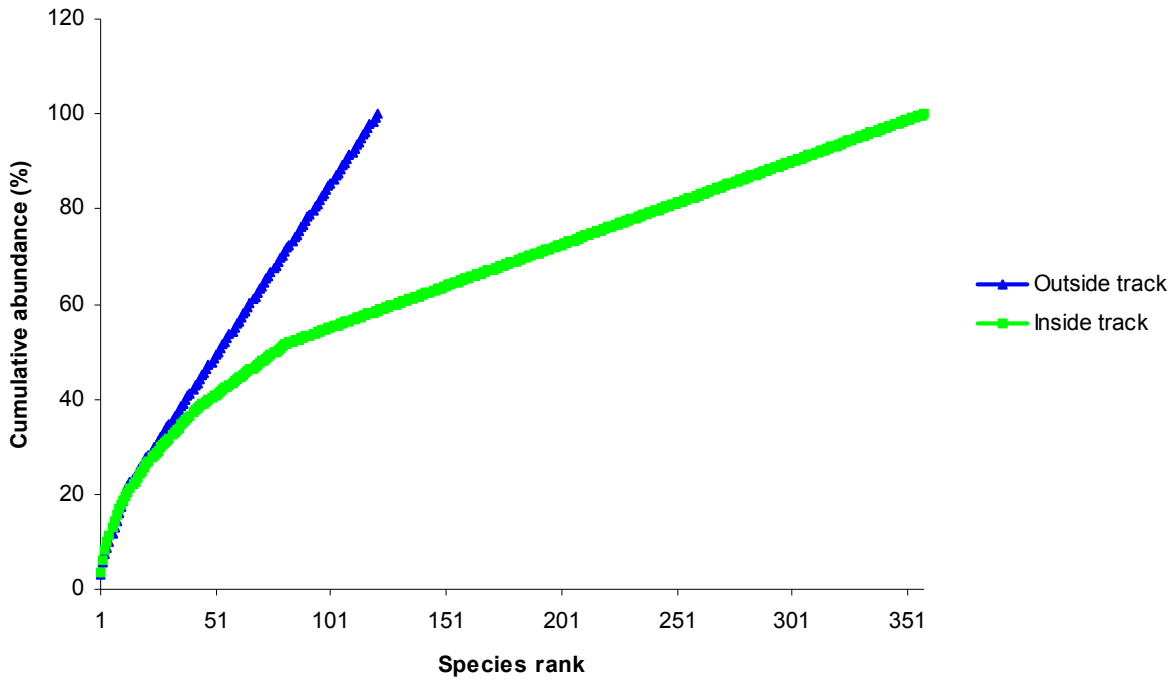


Figure 35. k-Dominance curve of copepods from outside track and inside track

Chapter 4
Discussion and Conclusions

4.1. Meiofauna communities of the Pacific nodule province

4.1.1. Composition and abundance of meiofauna

This study shows the dominance of nematoda in meiofauna composition. They comprise of 84% (range between 79,51 to 85,56%) and 80% (range between 73,93 to 85,18 %) of total meiofauna outside the nodule are and in the nodule area, respectively **(Figure 9 A and B)**. This result is in accordance with the data presented by other authors working on meiofauna communities in polymetallic nodule areas. Renaud-Mornant and Gourbault (1990) sampled meiofauna communities from different part of the Clarion-Clipperton Fracture Zone at water depths of 4905–5140 m. They found nematode dominance of 84 to 100%. Bussau *et al*. (1995), who have worked on meiofauna communities from a manganese nodule area of the eastern South Pacific in water depth of 4100–4200 m (DISCOL Area), found that the average nematode percentages in this area was 82% (range between 77 to 87%). Our result also corresponds with the data reported by other authors from the same depth of other different localities (Snider *et al*., 1984; Vincx *et al*., 1994).

Several data of total meiofauna, nematodes and copepods abundance (ind./10 cm^2) from different localities at similar depth is presented in **Figure 36** for comparison with meiofaunal abundance in our study area. The mean values of meiofauna densities from inside nodule area (95,97 ind./10 cm^2) **(Table 5)** is comparable with the data presented by Renaud-Mornant & Gourbault (1990), 82 ind./10 cm^2, but lower than average meiofaunal densities reported by Bussau *et al*. (1995) from the sediment of manganese nodule area (147 ind./10 cm^2). The nematodes and copepods average densities from inside nodule area in our result (76,96 ind./10 cm^2, and 15,15 ind./10 cm^2, respectively) **(Table 5)** is also lower than the result presented by Bussau *et al*.(1995), 121 ind./10 cm^2 (range 66 to 177 ind./10cm^2) and 22 ind./10 cm^2 (range 8 to 34 ind./10cm^2) respectively, however, it is still fall inside the reported range. Ansari (2000) reported that the density of nematodes and harpacticoids copepod from polymetallic nodule area in Central Indian Basin ranging between 28 to 54 ind./10 cm^2 and 11 to 16 ind./10cm^2, respectively, which is lower than our result. Total meiofauna, nematodes and copepods in our study also showed higher abundance compared to those reported by Parulekar *et al*. (1982) from Central Indian Basin as they reported the density of meiofauna, nematodes and copepods ranging between 2 to 15 ind./10cm^2, 2 to 9 ind./10cm^2 and 2 to 6 ind./10cm^2, respectively.

Total meiofauna and nematodes densities from outside nodule area in our study (181,66 ind./10 cm^2 and 152 ind./10 cm^2, respectively) **(Table 5)** is comparable with the result reported by Radziejewska (2002) prior to the disturbance following IOM-BIE (201,6

ind./10 cm^2 and 177,78 ind./10 cm^2, respectively) in outside nodule area at eastern part of CCFZ (in water depth of 4380–4430 m).

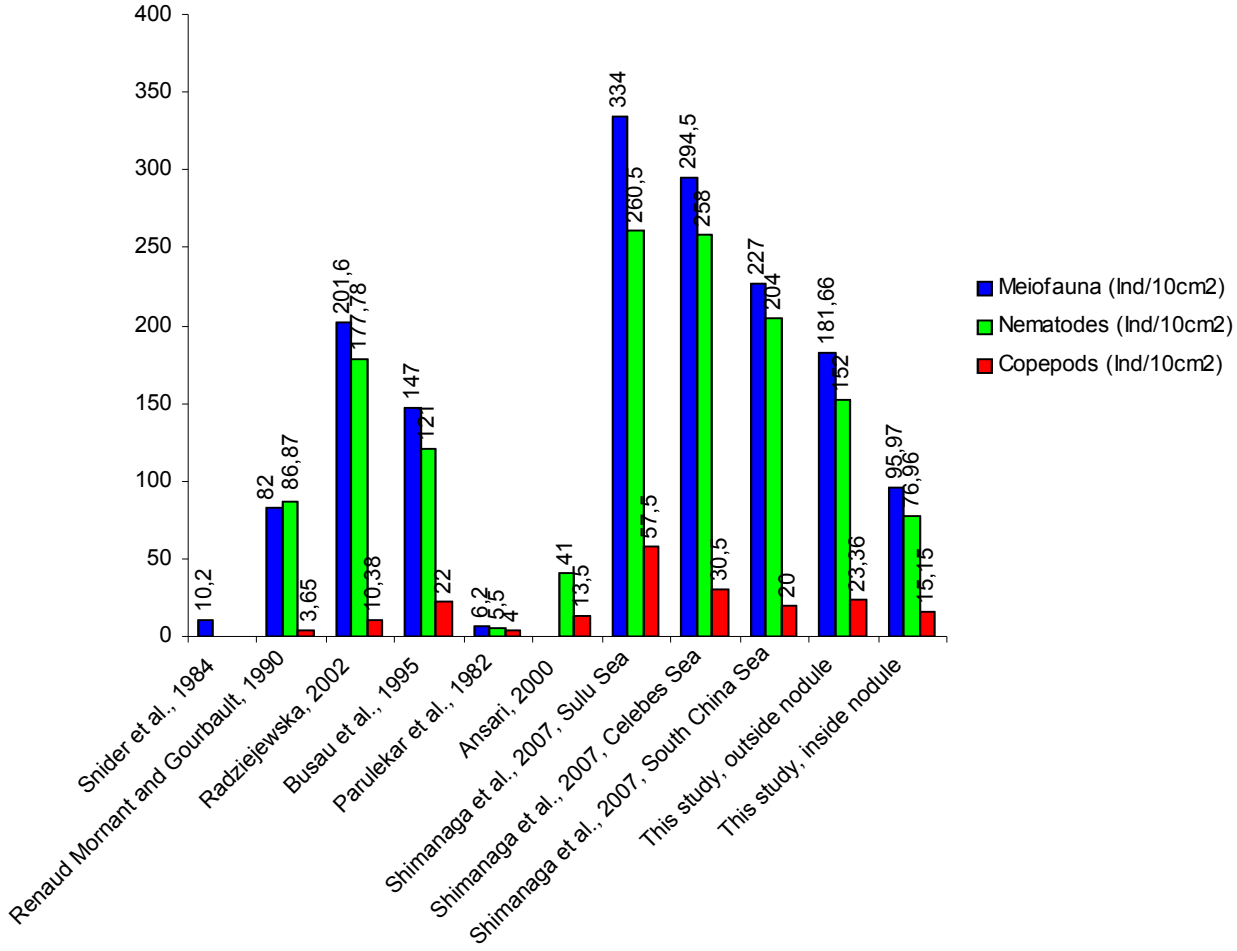


Figure 36. The abundance (ind./10 cm^2) of meiofauna, nematodes and copepods from different localities at similar depth

Copepods + nauplii density from outside nodule area in our study (23,36 ind./10 cm^2) is comparable with copepods + nauplii density from South China Sea (20 ind./10 cm^2) but lower than copepods + nauplii density from Celebes Sea and Sulu Sea (30 – 31 ind./10 cm^2 and 73 – 79 ind./10 cm^2, respectively) as reported by Shimanaga *et al*. (2007).

Generally, meiofaunal composition in our study area show similarity with the result from other studies. However, there are some variations in the abundance of total meiofauna and some dominant taxa, e.g.: Bussau *et al*. (1995), Radziejewska (2002), Ansari (2000) and Shimanaga *et al*. (2007). These variation in meiofaunal abundance may be related to sediment

granulometry, hydrographic condition and food availability (Vincx *et al*., 1994). Besides, different sampling methods used by other authors may caused biased in comparing meiofauna abundance. For example, a bow wave associated with box corer result in displacement of surface sediment and any superficial detritus layer together with their associated fauna will result less metazoan meiobenthic than corresponding multicore samples (Bett *et al*., 1994).

The result of diversity analysis between both sites showed that there is more or less inverse relation between nodule occurrence and meiofaunal abundance. Meiofauna abundance tends to be lower in the nodule area than outside the nodule area). Since diversity is related to abundance at high diverse environments (i.e were evenness is very high), this condition influence the number of taxa which were found in both area, that is, the number of taxa which were found from inside nodule area is less than the number of taxa which were found from outside nodule area **(Figure 10)**. Although it could be explained by the presence of polymetallic nodules on the surface of sediment, we should keep in mind that the low values of meiofaunal abundance inside nodule area can be under influence of other non measured variables.

4.1.2. Composition and abundance of harpacticoid copepod

In the present study we found out that the copepod samples from the north eastern of Pacific nodule province were dominated by nauplii and copepodid, they contributed to 80% of copepod which were found from outside and inside nodule while adult copepod contributed to 20%.

Among the adult copepods, Harpacticoida is the most abundant. Harpacticoida is highly successful group of Copepoda in terms of species richness and adaptive radiation. It has diversified in marine but also in freshwater benthic habitat (Seifried and Schminke, 2003). However, knowledge of deep-sea harpacticoid is poor, beside, its taxonomy is still in immature condition, the number of species which has been described is very low if we compared with the deep-sea coverage. Seifried and Schminke (2003) noted that the proportion of new species found for this group from a deep-sea site in the Angola Basin is almost 100 percent.

Throughout the study area we found out that harpacticoid communities was dominated by Ameiridae (22,22%). This result is similar to those reported by Ahnert and Schriever (2001) from southeastern Pacific where Ameiridae dominated harpacticoid samples with 16,74% of total abundance. However, the next dominant taxa which we found in our study area is slightly different in composition with the report of Ahnert and Schriever (2001), this

may be because some genera have mean meanwhile re-alocated to other families. This difficult the analysis at family level. For example the great number of Tisbidae, Diosaccidae and Paranannopidae in Ahnert and Schriever's samples can be explained the great number of Zosimidae *sensu* Seifried (Seifried, 2003) and Pseudotachidiidae *sensu* Willen (Willen 2000) in our samples, which were formaly considered to belong to the Tisbidae and Diossaccidae (Pseudomesochra) and Paranannopidae respectively. Besides, the dominant family was Cletodidae in by Bussau (1995), but this species are assigned today to the Argestidae and Huntemannidae which belong to the dominant taxa in our study. Though slightly different in proportion, generally our findings confirm the results from Ahnert and Schriever (2001)

We also confirm the abundance of genera, which dominate deep-sea harpacticoid assemblages as reported by Hicks and Coull (1983), within its respective families e.g. Bradya (Ectinosomatidae), Zosime (Zosimidae *sensu* Seifried), Pseudomesochra (Pseudotachidiidae *sensu* Willen), and Mesocletodes (Argestidae *sensu* Por).

One specimen of *Ceratonotus steiningeri* and two specimens of *Selenopsyllus antarticus* are the only harpacticoid species which could be identified to species from the samples. *Ceratonotus steiningeri* was described by George (2006) based on the specimen from the abyssal Angola basin, while *Selenopsyllus antarcticus* was described by Moura and Pottek (1998) based on the specimens from the Antarctic Weddel Sea at the depth of 3480 m. This fact is surprising because both areas are separated thousands of kilometres from our sampling area.

The density of harpacticoids in our study area (average 3,32 ind./10 cm^2 from inside nodule area and 4,17 ind./10 cm^2 from outside nodule area) is lower than densities of harpacticoid copepods with comparable depth from other ocean regions. Radziejewska (2002) reported the density of harpacticoid copepods between 7,98 to 13,16 ind./10 cm^2, prior to disturbance experiment at IOM claim area of CCFZ in north eastern Pacific, while Bussau *et al*. (1995) found harpacticoid density between 8 to 34 ind./10 cm^2 (average 22 ind./10 cm^2) in sediment from nodule area in south eastern Pacific.

4.1.3. Similarity analysis

The result of similarity analysis shows that meiofauna communities showed different response to the environment in term of mean abundance. MDS plot shows a clear separation between meiofauna samples from outside nodule area and inside nodule area **(Figure 16)**. This result is supported by one-way ANOSIM test **(Appendix 3)** and Minimum Spanning Tree-test **(Appendix 4)**.

The abundance (inds./10 cm^2) of meiofauna from inside nodule area is significantly different from outside nodule area **(Table 8)**. This different seemed to be contributed by nematode as only this taxon showed significant difference between both sites, moreover, nematode is the most abundant meiofauna within both samples. The diversity of meiofauna from inside nodule area also showed significant difference as compared to outside nodule area.

Distribution of meiofauna in the sediment were influenced by the availability of food. In deep-sea environment where the flux of organic matter from surface to seabed is very low most of the food were concentrated on the sediment surface. Therefore, meiofauna were distributed in the top few cm sediment for a greater access to the food (Shirayama, 1984; Thiel, 1983; Snider *et al*., 1984). Within nodule area, the presence of nodule will block the access of meiofauna to the food on the surface sediment therefore the abundance of total meiofauna, nematodes and copepods + nauplii in the sediment below the nodule is lower than from outside nodule area but this also might caused by other factors. However, Snider *et al*. (1984) found that the different of meiofauna abundance in sediment under ferromanganese nodule and open sediment is not consistent, while Parulekar *et al*. (1982) found that the average abundance of meiofauna is related to the nature of the bottom deposits. Meanwhile, Bussau *et al*. (1995) reported that the density of metazoan meiofauna in polymetallic nodule is much lower than in sediment.

Figure 18 A, B and C presented 2D-MDS plot of harpacticoid samples from outside nodule and inside nodule area at family, genus and species level. Distribution of harpacticoid at family, genus and species level indicate the difference of harpacticoid communities between both sites. Furthermore, the ANOSIM test which was based on ranked matrix of Bray-Curtis similarity of abundance also showed that harpacticoid communities between both habitats is different **(Appendix 5)**. However, comparison of density and diversity between harpacticoid species from outside nodule area and inside nodule area showed that there was no significative difference in level confidence of 95% between both habitat as shown by the result of F and t-test **(Table 9)**. This result was supported by k-dominance curve which showed that the harpacticoid species from outside nodule and from inside nodule area have high evenness, and that their evenness was not significant different as shown by **Figure 20**. Additionally, rarefaction curve showed high diversity of harpacticoid species from outside nodule and inside nodule areas, that with [ES(51)] the expected number of species found is 47 species in outside nodule area and 49 species inside nodule area and this different may not statistically significant **(Figure 21)**. This condition revealed that even though both

harpacticoid communities have similar abundance but they may have different in structure composition. This result was supported by SIMPER routine which provided the taxa that responsible for the difference of structure composition of harpacticoid from outside the nodule area with the nodule area **(Appendix 6)**.

4.2. Recovery of meiofauna communities within a 26 years old track

4.2.1. Composition and abundance of meiofauna

The utility of meiofauna for study the deep-sea biology has been argued by Thistle (2003) as better than macro- or megafauna because of their higher metabolic rate, smaller body size, slower movement, short generation times, benthic larvae and more nearly quantitative sampling. Moreover, the potential use of meiofauna for monitoring study of the environment subjected to the physical and chemical stress has been reported (Heip *et al*. 1988; Herman and Heip, 1988).

Penetration of meiofauna to sediment is correlated with organic matter availability in the sediment (Thiel, 1983). In the deep-sea environment, where the flux of organic matter from surface water is very low, benthic meiofauna generally concentrates in the surface layer of sediment (Shirayama, 1984; Tietjen *et al*., 1989). Therefore, sediment disturbance will have impact on abundance and composition of meiofauna communities. Besides, any disturbance in this environment will cause major change to meiofauna communities, because benthic meiofauna has assumed to adapt with the stable condition in the deep-sea. The impact will depends on the nature of disturbance, its frequency and intensity (Schratzberger and Warwick, 1998).

Sediment disturbance could be naturally- or anthropogenic-caused. Naturally-caused sediment disturbance could be from activities of an organism, e. g. creation of tubes, burrows and cast in sediment (Austen *et al.,* 1998), or from physical factors such as hydrodynamic event (Aller, 1989) and submarine landslide for deep-sea area with strong relief (Ahnert and Borowski, 2000). Anthropogenic activities which caused sediment disturbance in deep-sea environment among others: deep-sea fishing, dumping of waste and mining of mineral resource (Ahnert and Borowski, 2000; Bluhm, 2001). Naturally-caused sediment disturbance was argued to have a positive and negative effects (Aller, 1989), it suggested to be important forces in structuring marine benthic communities (Reidenauer and Thistle, 1981; Thistle, 1981), while the anthropogenic-caused disturbance will have severe impact and long lasting to environment (Ahnert and Borrowski, 2000). Meiofauna communities, especially nematodes,

were assumed to be more resistant to mechanical effect of natural physical process that cause sediment disturbance compared with macrofauna (Lambshead et al., 2001), however, whether this will also valid for process involved in nodule mining is unclear.

Ingole *et al*. (2000) and Ahnert and Schriever (2001) reported that meiofaunal abundance was greatly reduce immediate after sediment disturbance during INDEX and DISCOL project. Thiel *et al.* (1993) reported that the fauna associated with polymetallic nodule will be destroyed during nodule mining and will have no chance for recovery because their specific habitat will be removed. Furthermore, Thiel (1992) suggested that the impact of nodule mining on deep-sea meiobenthic communities will last in order of several decades.

In 1978, OMCO conducted a pilot-mining test for polymetallic nodule in PNP. There are no information about the design of mining system which was used by OMCO during pilot-mining test, however 26 years later, during Nodinaut cruise the tracks of 1,5 m wide and approximately 10 cm of depth were still observed (Menot, 2004). Though we have no data about meiobenthic standing stock before and immediately after pilot-mining test, from the track which was observed we could assumed the impact of those pilot mining test on meiobenthic communities such as: removal of top few centimetres of sediment in the path of nodule collector will kill substantial of sediment-dwelling meiofauna since most of meiofauna inhabit top 10 cm surface sediment, meiofauna associated with polymetallic nodule will be terminated during nodule mining as the nodule removed by the collector, subsequently the sediment which the collector vehicle move along, would be squeezed and compressed cause the sediment-dwelling fauna to die immediately, while others may not survive for being caught in compacted sediment (Jumars, 1981; Thiel, 1992). Beside, the sediment plume which was created by nodule collector will covered an area surrounding and buried the deposit organic material at the surface of sediment (Bluhm *et al*., 1995) so that meiobenthic communities, which was surface deposit feeder, from surrounding area would also died because they will lose their food (Smith, 1998).

Previous studies have demonstrated potential recovery of benthic communities following sediment disturbance. Sherman and Coull (1980), Thistle (1980), Reidenauer and Thistle (1981), Cross and Curran (2004), and Szymelfenig *et al*. (2006) reported fast recovery of benthic meiofauna following sediment disturbance in shallow water. However, in the deep-sea where the food availability is very low most of faunal activities are conducted at low rate, including re-colonization (Smith, 1998). Grassle (1977) and Grassle and Morse-Porteous (1987) reported slow re-colonization of benthic macrofauna from defaunated deep-sea sediment. Ahnert and Schriever (2001) reported that after seven years abundance value of

benthic meiofauna had returned to pre-impact level following sediment disturbance experiment in DISCOL project.

In this study I investigate the abundance and diversity of the sediment-dwelling meiofauna communities from pilot-mining test area which was explored by OMCO in 1978 by comparing the sediment-dwelling meiofauna from the track with sediment-dwelling meiofauna from outside the track. In general I found out that composition of meiofauna assemblages in sediment was dominated by nematodes (80 to 84%), followed by copepods (13 to 18%). The other taxa were found very rare with maximum 1% contribution on meiofaunal abundance **(Figure 22 A and B).** This result essentially similar with results from other deep-sea region (Bussau *et al*., 1995; Ahnert and Schriever, 2001; Parulekar *et al*., 1982; Radziejewska, 2002).

Mean density of sediment-dwelling meiofauna observed in both side (outside track and inside track) of this study area is 42,32 and 55,35 ind./10 cm^2, respectively **(Table 10)**. This amount is fall between the range of density reported by other authors from different nodule region in CCFZ (Renaud-Mornant and Gourbault, 1990) and also comparable with the result reported from manganese nodule areas in the South Pacific (Bussau *et al*., 1995) and the Central Indian Basin (Ansari, 2000).

4.2.2. Composition and abundance of harpacticoid copepod

Harpacticoid copepod is the second most abundant meiofauna in deep-sea sediment after nematodes. The use of Harpacticoida in investigating impact of physically sediment disturbance has been reported by some authors (Thistle, 1980; Ingole *et al*., 1999; Radziejewska, 2002). Furthermore, Ahnert and Schriever (2001) identified harpacticoid taxa which might be useful in monitoring impact of polymetallic nodule mining in South of Pacific Ocean. They reported that the best discriminating family for long-term effect of disturbance in deep-sea were Ameiridae, Argestidae and Thalestridae.

Between free-living copepod order, Harpacticoida was the most abundant order found in deep-sea sediment throughout our study. Overall, they were of 97% copepods identified in our samples **(Figure 28)**. In samples from outside and inside the track they make up to 92,75% and 97,73%, respectively **(Table 13)**. This results confirm the successfulness of harpacticoid copepods in the deep-sea sediment as argued by other author (Thistle, 2001) and corresponds with report from other author (Rose *et al*., 2005) and the statement of Seifried (2004) that "nearly all copepod in deep-sea benthos are the species of Harpacticoida".

Within harpacticoid copepods, we found out that Ameiridae, Argestidae, Canthocamptidae, Ectinosomatidae and Neobradyidae is the most abundant families. Most of these families were also found as a dominant families in Angola Basin (Rose *et al*., 2005) and manganese nodule area in South Pacific (Ahnert and Schriever, 2001). Furthermore, the composition of Harpacticoida, in genus level, which was found in this study coincided with typical deep-sea taxa except for cervinid's genera which were found few in our sample (Hicks and Coull, 1983). However, as in other deep-sea samples harpacticoid assemblages in our samples contain high proportion of copepods that could not be identified to species level.

Mean density of harpacticoid copepod from inside and outside track were 9,97/10 cm^2 and 5,54/10cm^2, respectively. These numbers were fall between the range of copepod density reported from other deep-sea region (Parulekar *et al*., 1982; Renaud-Mornant and Gourbault, 1990; Anshari, 2000; Radziejewska, 2002), however less than some other deep-sea localities (Bussau *et al*., 1995; Shimanaga *et al*., 2007)

4.2.3 Similarity analysis

Univariate and multivariate analysis were used to define similarity between communities of both habitats. Mean density of meiofauna observed from outside- and inside track showed that both areas were not statistically significant different in term of abundance as revealed by student's t-test **(Table 11)** and ANOSIM test **(Appendix 6)** which indicated the recovery of meiofauna communities in the sediment within the track after 26 years of disturbance during pilot-mining test conducted by OMCO. However, though in term of abundance the sediment-dwelling meiofauna communities from inside track is assumed to recover, it is difficult to define that those communities had established its original structure and composition as they have before the test mining due to the lack of baseline data.

Within copepods assemblages, several diversity indices were chosen to analyze the similarity between copepod assemblages from outside track and inside track **(Figure 31)**. These indices subsequently were tested with student's t-test and the test revealed that both copepods communities were not statistically significant different **(Table 15)**. This result confirmed potential recovery of harpacticoid community within the track from physical sediment disturbance during pilot mining in 1978.

Similar result was also provided by rarefaction and k-dominance curves which presented high species diversity and evenness of both copepods assemblages **(Figure 34 and 35)**. The rarefaction curve showed that with ES(51) the expected number of species found was 48,25 on samples from outside track and 46,39 from the samples from inside track, and that

this different may not statistically significant. The k-dominance curve showed relative similar of evenness of the copepod assemblages from both habitats which indicated similar diversity for both assemblages.

An ordination of 2D MDS plot based on Bray Curtis similarities showed that the different between both copepods assemblages is less clear **(Figure 32)**. However, one way ANOSIM provide statistically significant different of both assemblages with global R = 0,375 and p = 0,2% **(Appendix 8)**. This result showed slow re-colonization of deep-sea harpacticoid following sediment disturbance. Beside Ingole *et al*. (2005a) and Radziejewska *et al*. (2001) reported that harpacticoid copepods seem more sensitive than nematodes to sediment disturbance. Therefore, it seems that 26 years is not long enough for the communities to achieve its original abundant. However, we should keep in mind that the different of abundance between copepod communities in both areas could be from other factors.

This different result between 2D MDS and one way ANOSIM test showed that even though the copepod assemblages in both habitats were similar in term of abundance, but it seems that they differ in structure composition.

One of the reason for observing less difference between samples from outside track and inside track as showed by 2D-MDS is that the recovery process was taking place in an area where the mining system passed during the pilot-mining test. Thiel (1992) mentioned the potency of deep-sea communities to recovery through re-colonization process in heavily disturbed areas. Re-colonization dependent on the availability of food in the sediment, thus the physical disturbance on the sediment may created entirely new condition in the deep-sea environment, such as bringing up dissolved nutrients from subsurface layer and depositing the organically rich sediment to the surface (Ingole *et al*., 2005a). Re-colonization occurs by lateral migration of adult meiofauna from non or little impacted area and through larval transport which is mainly by current (Thiel, 1992).

In our study area, it is still not known whether re-colonization process is already achieve the similar assemblages which is existed before the disturbance due to lack of baseline data. Besides, we have no information how rapidly the re-colonization process of meiofauna communities inside the track since our sample was taken 26 years after disturbance

Deep-sea nematodes maybe affected by physical disturbance but they were more robust than macrofauna (Lambshead et al., 2001). Ingole *et al*. (2005a) and Radziejewska *et al*. (2001) reported that harpacticoid copepods seem more sensitive than nematodes to sediment disturbance, therefore will need more time to recover to its original condition than

nematodes. However, our results seem to showed that 26 years is enough time for copepod to recover to its original condition, though may not similar in structure and composition.

Even though meiofauna communities and copepod assemblages in this study showed their potential recovery from physical sediment disturbance of polymetallic nodule pilot-mining, we should keep in mind that this condition will not the same with the real condition in nodule mining for industrial scale since the nodule mining for industrial scale will disturb more large area.

4.3. Conclusions

In order to be able in evaluating deep-sea polymetallic nodule mining, the Nodinaut cruise was launched to study the environment of Polymetallic Nodule Province in the North equatorial Pacific Ocean or within French mining claim areas. Environmental study of PNP is important since the future commercial deep-sea mining for polymetallic nodule is predicted to have major impact on ecosystem. Studies of the impact of a large-scale deep-sea polymetallic nodule mining had been conducted by some pioneer investors of polymetallic nodule in the North and South equatorial of Pacific Ocean and Central Indian Basin of Indian Ocean. Those studies include the development of mining techniques, pilot mining and studying the mining impact on the ecosystem.

The assessment of polymetalic nodule mining impact on ecosystem should be based on the knowledge of the disturbing process and subsequent measurable changes on ecosystem. These prerequisites are not fulfilled since the commercial polymetallic nodule mining is not started yet, even the acceptable equipment for collecting nodule is still in development. However, environmental study in an area where the commercial mining is likely to be happened is necessary as the baseline information on the ecosystem so that changes in the ecosystem could be assessed.

This dissertation present information on sediment-dwelling meiofauna from inside nodule and outside nodule area which is valuable for measuring changes on ecosystem and the recovery potential of meiofauna communities after 26 years of pilot mining for polymetallic nodule in Polymetallic Nodule Province.

Meiofauna communities of the Pacific Nodule Province

Meiofaunal studies in deep-sea environments are fewer than in shallow waters due to high operational cost, limited number of specialist for meiofaunal taxa and vast and difficult sampling areas. Within the deep-sea environment most of the studies were conducted in the

marginal zone of the deep-sea where the bottom were affected by high surface productivity and continental influence. Few studies were conducted in the open ocean where the great depth of water, the low surface productivity and the modest degree of horizontal advective input result in extremely low food supply to the bottom (Hessler and Jumars, 1974).

Polymetallic nodule province is located in the open ocean of Pacific Ocean. As reported by some authors this area has characteristic of low sedimentation rate, low productivity and high species diversity. Most of meiofauna studies in polymetallic nodule province related to sediment disturbance caused by nodule mining, study of the composition and abundance of sediment-dwelling meiofauna surrounding the nodule or meiofauna associate with polymetallic nodule. The present study is the first one which compares the composition of sediment-dwelling meiofauna from inside nodule area and from outside nodule area. In this study composition and abundance of meiofauna from inside nodule and outside nodule area were dominated by nematodes and followed by copepods. This result was coincide with reports on similar depth from other deep-sea region. Mean density of meiofauna communities from inside nodule area is tend to lower than outside nodule area. 2D-MDS plot confirmed this finding by showing clear separation between samples within nodule area and outside nodule area. The ANOSIM test based on Bray-Curtis similarity and Minimum Spanning Tree also support this finding. This condition show more or less inverse relation between the abundance of meiofauna and the presence of nodule. Furthermore, similar condition also found in diversity, that the diversity of meiofauna inside nodule area is lower than outside nodule area.

Within harpacticoid taxocene which is found in this study, Ameiridae is found dominant among other families. This finding is similar with the result from other region of polymetallic nodule province as reported by Ahnert and Schriever (2001). Subsequently, this study also confirm the abundance of genera which were traditionally typical deep-sea such as, Bradya, Zosime, Pseudomesochra and Mesocletodes. However, due to the immature deep-sea harpacticoid systematic this study also found different proportion of harpacticoid composition with other report of some authors.

This present study also confirm the presently knowledge that most of deep-sea harpacticoid is unknown. The presence of some harpacticoid species, which were described from other region that separated thousands of kilometer, were also detected in PNP. Those species were *Ceratonotus steiningeri* which was published by George (2006) based on specimen from the Angola basin and *Selenopsyllus antarcticus* which was published by Moura and Pottek (1998) based on specimen from Antarctic Weddel sea.

Similarity analysis between harpacticoid communities from inside nodule area and outside nodule area using different methods showed different result . Student's t-test showed that both communities were not statistically significant different, this result was supported by k-dominance and rarefaction curves. However, ANOSIM test based on Bray-Curtis similarity showed that both communities were not different at significant level of 95% and this result was supported by 2D MDS plot which showed clear separation between harpacticoid samples from inside nodule area and outside nodule area. Different results which were showed by those methods indicated that both assemblages have similar density and diversity but different in meiofaunal composition.

Recovery of meiofauna communities within a 26 years old track

It has been known from previous study that meiofauna communities have potential recovery from sediment disturbance. This study was conducted to study meiofauna communities from 26 years old deep-sea pilot mining area by comparing the sediment-dwelling meiofauna within the track and outside the track. The result showed that meiofauna communities in this area have similar composition with meiofaunal assemblages in other deep-sea region. Nematodes dominated meiofaunal taxa followed by copepods, while the other meiofaunal taxa were found very rare. Beside, mean density of meiofauna communities in this area is fall between the range of density reported by other authors from other polymetallic nodule region.

Harpacticoida is the most abundant copepod found in sediment throughout this study. The most abundant family within harpacticoid were Neobradyidae, Ameiridae, Argestidae, Canthocamptidae, and Ectinosomatidae. Within genus level we also confirmed the abundance of some typical deep-sea taxa such as Bradya, Mesocletodes, and Pseudomesochra. Mean densities of harpacticoid copepod observed in this study (inside the track and outside the track) were fall between the range of harpacticoid densities reported from other deep-sea localities.

The result of similarity analysis for meiofauna communities using univariate analysis (Student's t-test) and multivariate analysis (ANOSIM) showed that mean densities of meiofauna communities from both area were not significant different. For harpacticoid copepods, similarity analysis using Student's t-test showed that both harpacticoid communities from inside the track and outside the track were not significant different in diversity. The rarefaction and k-dominance curves also support this result. However, similarity analysis for harpacticoid abundance using ANOSIM test showed that harpacticoid

from both area were significant different, though 2D-MDS plot showed that the different was less clear. The result of those analysis indicate that though harpacticoid from inside the track and outside the track were different in term of abundance they have similar diversity and structure composition.

4.4. The future prospectus

Knowledge of meiofauna from deep seabed of polymetallic nodule province is poor since study on meiofauna communities in this area is still scarce, even though there are increasingly number of studies, compared with its vast area. The limited knowledge on systematic, abundance, species structure and ecology of meiofauna in this area will cause inaccurate assessment of the risk of deep seabed polymetallic nodule mining. This study is the first which compare the abundance and diversity of the sediment-dwelling meiofauna from inside nodule area and outside nodule area in the Pacific nodule province. Subsequently, the second part of this study reviewed the re-colonization of meiofauna inside the track of 26 years old pilot mining area by comparing the sediment-dwelling meiofauna from inside the track and outside the track.

There are, however, limitations of this study in reviewing abundance and diversity of meiofauna from Pacific nodule province. Other factors than nodule which assumed to influence the abundance and diversity of meiofauna communities from inside nodule area and outside nodule area need to be evaluated. Furthermore, more extensive sampling need to be done following this sampling design in order to get more representatives count on abundance and diversity of meiofauna community from this area. This study also reviewed the abundance, diversity and species composition of harpacticoid copepod. However, this study is far from complete since, at present, systematic study, diversity and species composition of harpacticoid copepod in this area is not well known. No complete species list available for deep-sea harpacticoid from polymetallic nodule province.

Taxonomical study of harpacticoid copepod from the Pacific nodule province is becoming important since this organisms have been assumed to be useful in the study of deep-sea diversity and monitoring impacts of deep-sea mining on benthic organisms (Ahnert and Schriever, 2001). Future taxonomical investigation of harpacticoid species will help to discriminate species which specific to nodule area and the species which resistant to sediment disturbance. Therefore, a better understanding on the sediment-dwelling meiofauna

from Pacific nodule province will certainly helpful in monitoring and management impact of future polymetallic nodule mining in Pacific nodule Province.

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APPENDICES

Appendix 1
List of harpacticoid genera which were found in Pacific nodule province

A. From outside nodule and inside nodule

Genera	Outside the nodule area	Nodule area
Ameira	1	1
Ameiropsis	1	1
Haifameira	1	1
Malacopsyllus	0	1
Nitokra	1	1
Parameiropsis	1	0
Parapseudoleptomesochra	1	1
Proameira	1	1
Sarsameira	1	1
Sicameira	1	1
Ameiridae gen n	1	1
Dorciceratus	1	1
Ceratonotus	1	0
Argestes	1	1
Bodinia	1	1
Coralliclетodes	1	0
Eurycletodes	1	1
Mesocletodes	1	1
Odiliacletodes	1	0
Parargestes	1	1
Argestidae gen n	1	1
Barbaracletodes	1	0
Boreolimella	1	1
Heteropsyllus	1	1
Perucamptus	1	0
Psammocamptus	1	1
Canthocamptidae gen n	1	1
Canuelidae sp. 1	1	0
Cervinia	0	1
Cerviniopsis	0	1
Stratiopontotes	0	1
Tonpostratiotes	0	1
Selenopsyllus	1	0
Amphiascus	1	0
Paramphiascopsis	1	1
Paradiosaccus	1	0
Stenhelia (Delavalia)	1	0
Diosaccidae gen 1	0	1
Arenosetella	1	0
Bradya	1	1

Ectinosoma	0	1
Halectinosoma	1	0
Lineosoma	1	0
Microsetella	1	1
Pseudobradya	1	1
Metahuntemannia	1	1
Talpina	0	1
Aspinothorax	1	0
Idyella	0	1
Tachidiella	1	0
Idyanthidae gen n	0	1
Leptastaciidae	1	0
Marsteinia	1	1
Paramesochra	0	1
Paramesochridae gen n	0	1
(Paranannopinae) Paradanielsennia	1	1
(Paranannopinae) Paranannopus	0	1
(Pseudomesochrinae) Pseudomesochra	1	1
(Pseudotachidiinae) Pseudotachidius	0	1
Pseudotachidiidae gen n	1	1
Romete	1	0
Tisbe	1	0
Pseudozosime	1	1
Zosime	1	1
Zosimidae gen n	1	0
Harpacticoida Incertae Sedis	1	1
Cyclopinella	1	1
Einslepinella	1	0
Giselina	1	0

B. From outside track and inside track

Genera	Outside track	Inside track
Cyclopinella	0	1
Schminkepinella	1	0
Einslepinella	0	1
Giselina	1	1
Centobnaster	1	0
Oncaea	0	1
Neobrychiopontius n. gen.	1	0
Unknown *Siphonostomatoid*	1	1
Unknown *Aegisthidae*	0	1
Unknown *Adenopleuriidae*	0	1
Ameira	1	1
Ameiropsis	1	1
Anoplosoma	0	1
Leptomesochra	1	0
Malacopsyllus	1	0

Nitokra	1	1
Parameiropsis	1	1
Parapseudoleptomesochra	0	1
Parevansula	0	1
Proameira	0	1
Sarsameira	1	1
Sicameira	1	1
Stenocopia	1	0
Unknown *Ameiridae*	1	1
Argestes	1	1
Bodinia	1	1
Eurycletodes	1	1
Mesocletodes	1	1
Mesocletodes (abyssicola)	1	1
Neoargestes	0	1
Parargestes	1	1
Unknown *Argestidae*	0	1
Canuellina	0	1
Boreolimella	1	1
Heteropsyllus	1	1
Perucamptus	0	1
Psammocamptus	1	1
Unknown *Canthocamptidae*	1	1
Cerviniopsis	1	1
Expansicervinia	0	1
Unknown *Cerviniidae*	0	1
Selenopsyllus	1	1
Unknown *D'arcythompsoniidae*	0	1
Arenosetella	0	1
Bradya	1	1
Ectinosoma	1	0
Halectinosoma	0	1
Microsetella	1	1
Pseudobradya	1	1
Sigmatidium	0	1
Unknown Ectinosomatidae	1	1
Metahuntemannia	1	1
Talpina	0	1
Idyanthe	1	1
Idyella	0	1
Tachidiella	0	1
Unknown *Idyanthidae*	1	1
Unknown *Laophontidae*	1	0
Bulbamphiascopsis	0	1
Haloschizopera	0	1
Paramphiascopsis	1	1
Robertgurneya	1	0
Marsteinia	1	1
Tachidiopsis	1	1
Unknown *Neobradyidae*	1	1
Paramesochra	1	1
Tisbisoma	0	1
Bathypsammis	0	1

Cylindronannopus	1	1
Danielsennia	1	1
Leptotachidia	1	1
Micropsammis	1	1
Paradanielsennia	0	1
Paranannopus	0	1
Pseudomesochra	1	1
Unknown *Pseudotachidiidae*	1	0
Romete	0	1
Pseudozosime	1	1
Zosime	1	1
Unknown Harpacticoida	1	1

Note: 1 = present 0 =absent

Appendix 2

The result of Shapiro-Wiks test for analysis of similarity of mean density of total meiofauna and some dominant taxa in nodule area and outside the nodule area.

Meiofauna	151,836158	74,5762712
	192,090395	83,3333333
	170,621469	92,6553672
	144,774011	112,146893
	197,59887	107,768362
N	5	5
W	0,9105	0,9418
P	0,4707	0,679
Nematoda	127,824859	57,6271186
	163,418079	67,2316384
	145,621469	68,6440678
	115,112994	82,9096045
	164,689266	89,8305085
N	5	5
W	0,9075	0,9473
P	0,4526	0,7177
Copepoda	17,9378531	13,8418079
	21,0451977	13,700565
	17,0903955	17,7966102
	25,8474576	25,4237288
	29,0960452	13,9830508
N	5	5
W	0,9184	0,7533
P	0,5199	0,03195
Other	6,07344633	3,10734463
	7,62711864	2,40112994
	7,90960452	6,21468927

	3,81355932	3,81355932
	3,81355932	3,95480226
N	5	5
W	0,8429	0,9102
P	0,173	0,4689

Appendix 3

The result of Shapiro-Wilks test for analysis of similarity of some diversity indices of total meiofauna in nodule area and outside the nodule area.

Shannon	0,5999	0,7002
H' (log e)	0,562	0,6164
	0,572	0,8136
	0,6183	0,7267
	0,5399	0,5898
N	5	5
W	0,9755	0,9556
p(normal)	0,9093	0,7771
Pielou (J')	0,2414	0,3598
	0,2703	0,2964
	0,2751	0,3703
	0,3177	0,3308
	0,2596	0,2836
N	5	5
W	0,9302	0,9204
p(normal)	0,5975	0,5326
Simpson	0,2772	0,3686
1-Lambda'	0,2639	0,3224
	0,2611	0,4133
	0,336	0,4022
	0,2838	0,2883
N	5	5
W	0,8101	0,9314
p(normal)	0,0977	0,606

Appendix 4

Anosim test of total meiofauna for analysis of similarity between nodule area and outside the nodule area.

ANOSIM

Analysis of Similarities

One-Way Analysis

Resemblance worksheet

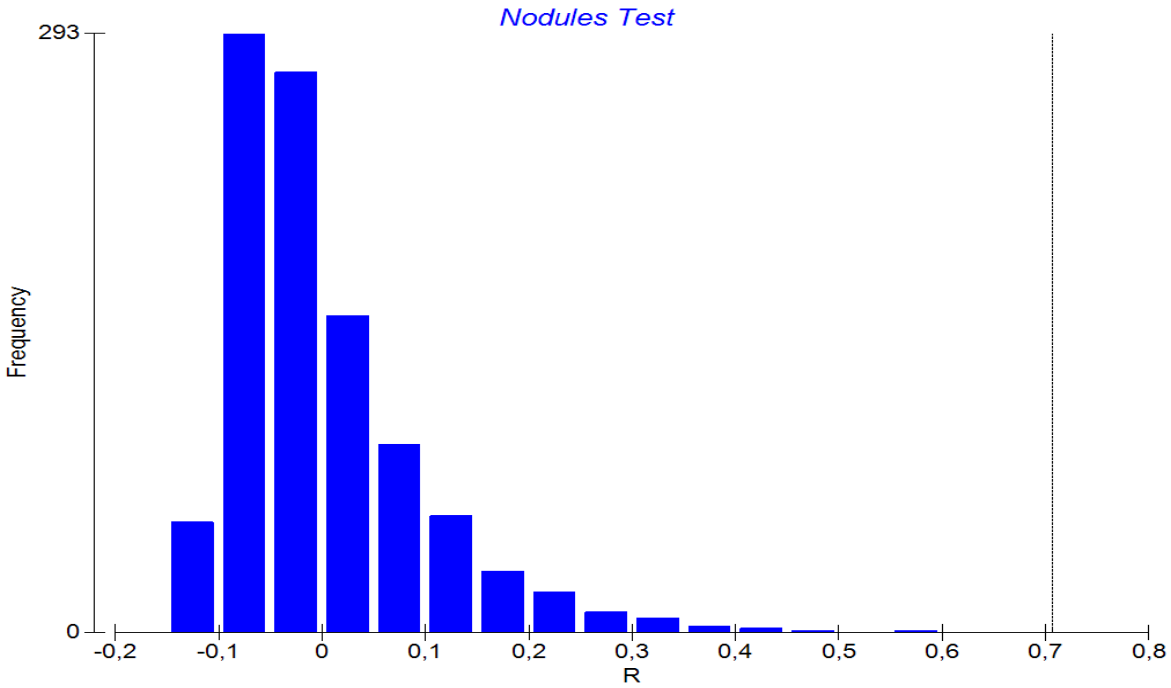
Name: Resem1
Data type: Similarity
Selection: All

Factor Values
Factor: Nodules
n
y

Factor Groups

Sample	Nodules
M6C2	n
M6C3	n
M7C6	n
M7C7	n
M8C2	n
M8C4	n
M10C8	n
M11C8	n
M14C5N	y
M15C1N	y
M15C2N	y
M16C3N	y
M17C6N	y
M18C2N	y
M18C3N	y
M18C7N	y

Global Test
Sample statistic (Global R): 0,707
Significance level of sample statistic: 0,1%
Number of permutations: 999 (Random sample from 6435)
Number of permuted statistics greater than or equal to Global R: 0
Outputs
Plot: Graph5



Appendix 5
The Minimum Spanning Tree test of total meiofauna for analysis of similarity between nodule area and outside the nodule area.

Bray-Curtis similarity matrix:

79.120
87.639 90.799
78.934 96.752 90.355
92.247 83.837 91.900 82.922
95.543 75.578 84.036 74.952 88.666
92.190 77.812 83.103 77.330 85.446 95.829
85.368 91.550 96.484 92.364 90.142 81.575 84.076
64.629 49.087 54.979 48.282 60.714 68.161 66.581 54.074
70.150 53.437 60 52.708 65.517 73.844 71.950 58.824 92.844
86.285 67.844 75.320 66.993 80.550 90.259 88.397 73.372 76.844 82.934
73.484 56.297 63.492 55.390 68.455 77.082 74.717 61.606 88.682 94.543 81.806
78.545 65.889 70.195 65.124 73.127 81.884 86.201 71.865 79.274 84.682 86.930 87.586
81.502 63.544 70.749 62.788 76.814 85.388 83.333 69.195 81.332 86.918 94.532 85.130 90.430
53.768 39.302 44.937 39.032 49.315 56.813 55.095 43.851 85.097 79.960 64.274 74.953 65.940 68.045
88.639 69.831 77.445 69.381 82.511 92.505 90.441 75.329 74.200 80.191 96.895 80.391 85.475 92.205 61.864

DATAFILE D:\spantree\MeiofaunaNotransform.MTX
FORMAT MATRIX
NUMBER 15
FIRST 7
TYPE SIMILAR
TRIANGLE LOWER
DIAG FALSE
COMPUTE EXACT
MAXTREES 0

OUTPUT   LONG
OUTFILE MeiofaunaNotransform.OUT
LANGUAGE English
sp - minimal spanning tree test - version 1.0 (20.03.97)
date: Wed Oct 17 10:37:05 2007

the options used are:

DATAFILE = D:\spantree\MeiofaunaNotransform.MTX name of input file
FORMAT   = matrix   the distance or similarity matrix
NUMBER   = 15   number of subsamples
FIRST   = 7   number in first sample
DATATYPE = quanti   quantitative data (numbers)
TYPE   = similar   similarity matrix
TRIANGLE = lower   lower triangular matrix
DIAG   = false   the diagonal of the matrix is not in the file
COMPUTE = exact   the computation is based on the exact distribution
MAXTREES = 0   all the minimal spanning trees are taken into consideration
OUTPUT   = long   long output (with tree)
OUTFILE = MeiofaunaNotransform.OUTthe name of the output file
LANGUAGE = english   the output is in English

expected number of trees if H0 is true: 8.46667
observed number of subtrees: 4
variance of number of subtrees: 3.40786
probability for this number if H0 is true (exact):   p = 0.0146076
probability for this number if H0 is true (asymptotic): p = 0.00776893
number of minimal spanning trees found: 1
the first tree found:
(.) = subsamples of the 1st sample, [.] = subsamples of the 2nd sample
(1)(5)
   (5)(3)
      (3)[8]
         [8](4)
            (4)(2)
(1)(6)
   (6)(7)
   (6)[11]
      [11][14]
         [14][13]
            [13][12]
               [12][10]
                  [10][9]
                     [9][15]

Appendix 6
Anosim test of harpacticoid community in family, genera and species level for analysis similarity between nodule area and outside the nodule area.

Family level:

ANOSIM

Analysis of Similarities

One-Way Analysis

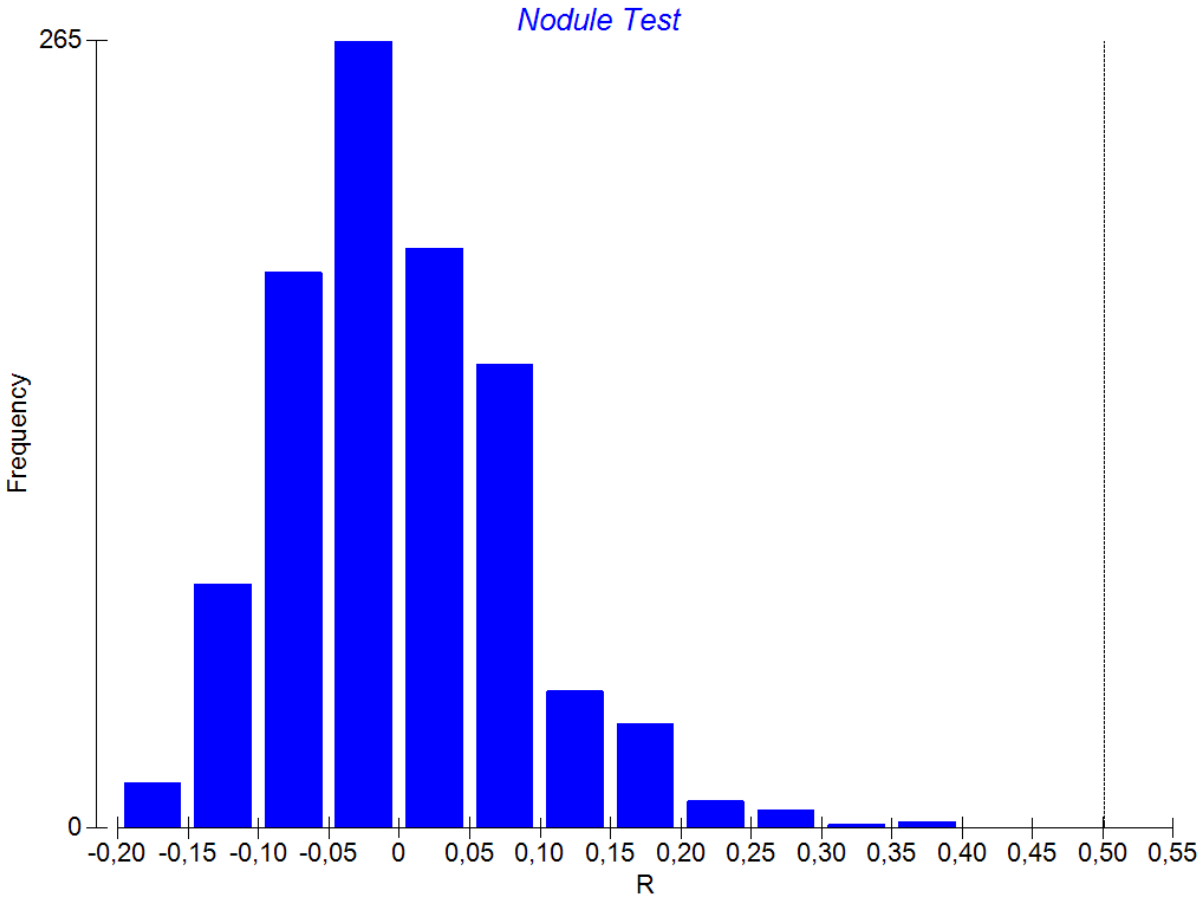
Resemblance worksheet
Name: Resem2
Data type: Similarity
Selection: All

Factor Values
Factor: Nodule
n
y

Factor Groups

Sample	Nodule
M6C2	n
M6C3	n
M7C6	n
M7C7	n
M8C2	n
M8C4	n
M10C8	n
M11C8	n
M14C5	y
M15C1	y
M15C2	y
M16C3	y
M17C6	y
M18C2	y
M18C3	y
M18C7	y

Global Test
Sample statistic (Global R): 0,501
Significance level of sample statistic: 0,1%
Number of permutations: 999 (Random sample from 6435)
Number of permuted statistics greater than or equal to Global R: 0
Outputs
Plot: Graph8



Genera level:

ANOSIM

Analysis of Similarities

One-Way Analysis

Resemblance worksheet
Name: Resem2
Data type: Similarity
Selection: All

Factor Values
Factor: Nodule
n
y

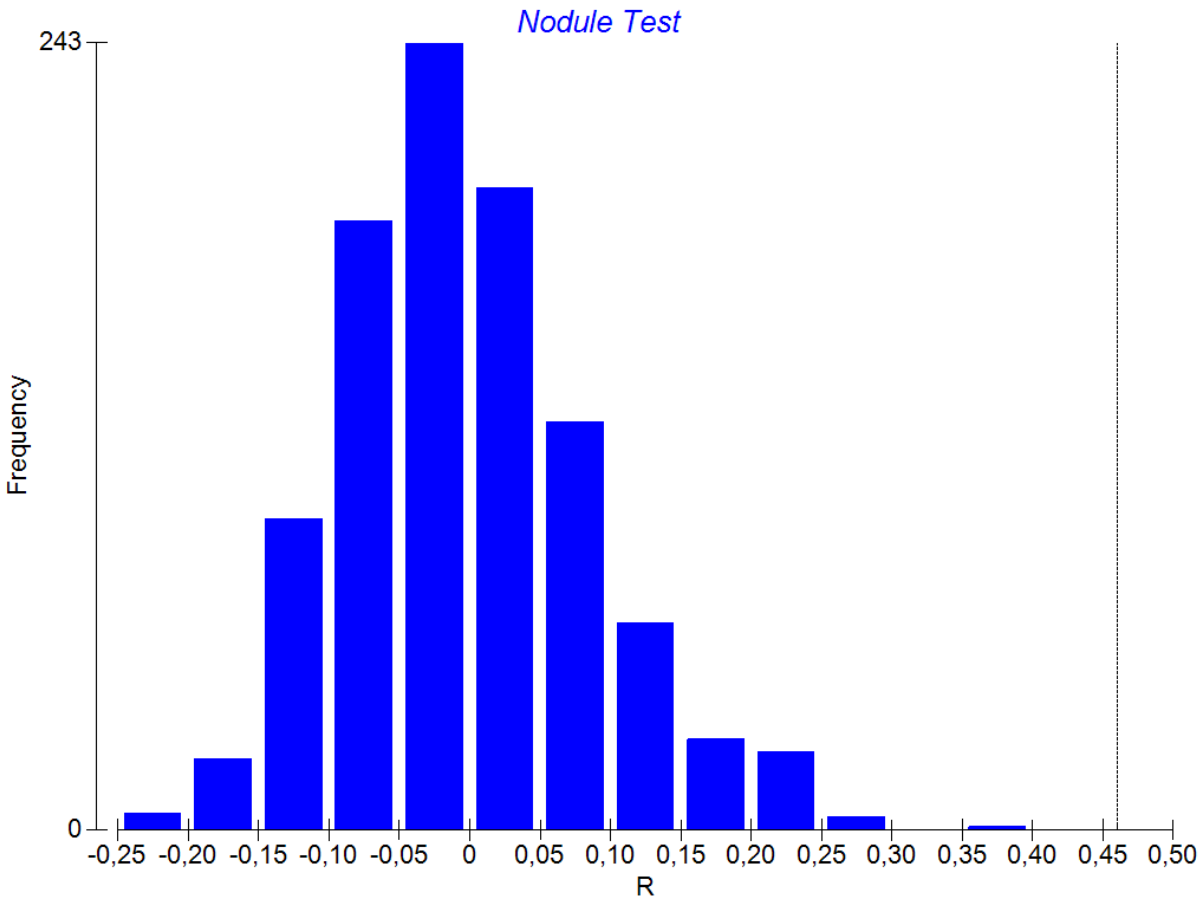
Factor Groups

Sample	Nodule
M6C2	n
M6C3	n
M7C6	n
M7C7	n
M8C2	n
M8C4	n
M10C8	n
M11C8	n
M14C5	y
M15C1	y

M15C2 y
M16C3 y
M17C6 y
M18C2 y
M18C3 y
M18C7 y

Global Test
Sample statistic (Global R): 0,461
Significance level of sample statistic: 0,1%
Number of permutations: 999 (Random sample from 6435)
Number of permuted statistics greater than or equal to Global R: 0

Outputs
Plot: Graph8



Species level:

ANOSIM

Analysis of Similarities

One-Way Analysis

Resemblance worksheet
Name: Resem2
Data type: Similarity
Selection: All

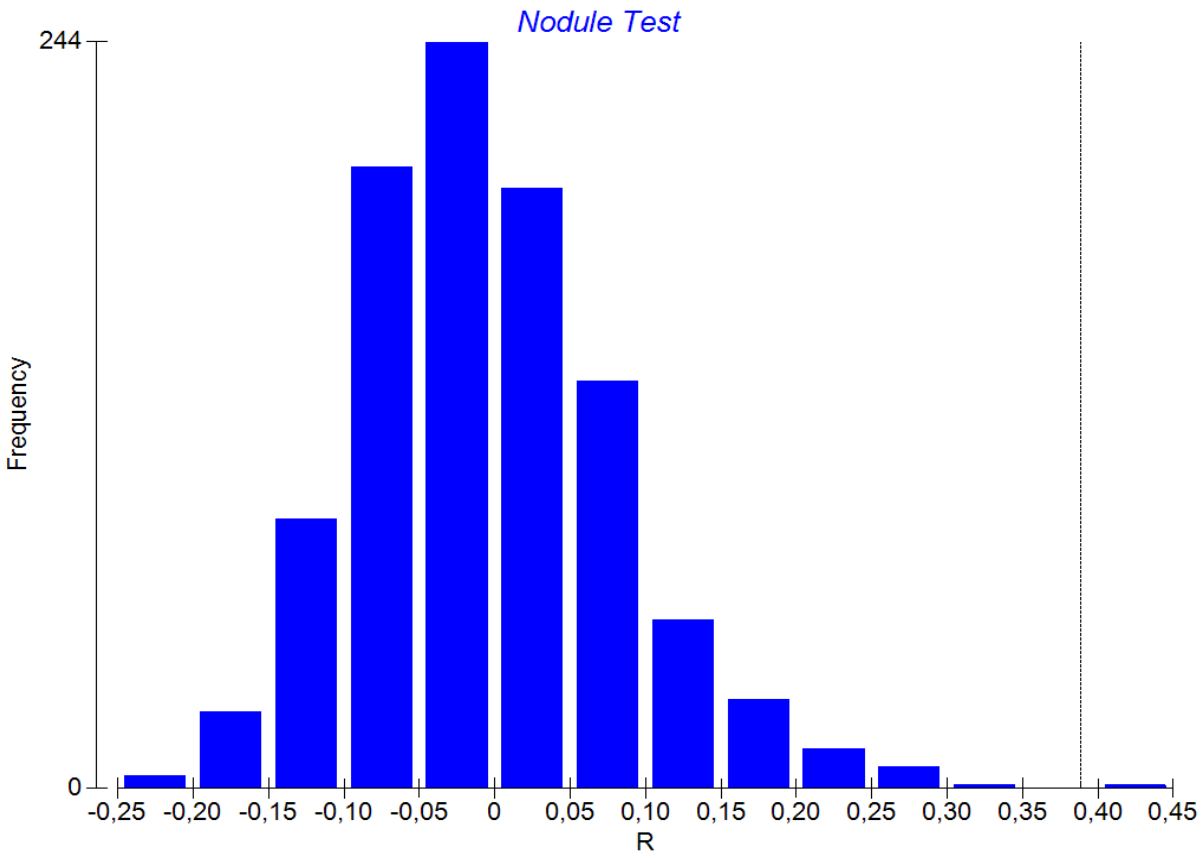
Factor Values
Factor: Nodule
n
y

Factor Groups

Sample	Nodule
M6C2	n
M6C3	n
M7C6	n
M7C7	n
M8C2	n
M8C4	n
M10C8	n
M11C8	n
M14C5	y
M15C1	y
M15C2	y
M16C3	y
M17C6	y
M18C2	y
M18C3	y
M18C7	y

Global Test
Sample statistic (Global R): 0,389
Significance level of sample statistic: 0,2%
Number of permutations: 999 (Random sample from 6435)
Number of permuted statistics greater than or equal to Global R: 1

Outputs
Plot: Graph9



Appendix 7
SIMPER routine of harpacticoid community in family, genera and species level for analysis similarity between nodule area and outside the nodule.area.

Family level:

SIMPER

Similarity Percentages - species contributions

One-Way Analysis

Data worksheet
Name: Muc_Harpacticoid Family
Data type: Abundance
Sample selection: All
Variable selection: All

Parameters
Resemblance: S17 Bray Curtis similarity
Cut off for low contributions: 90,00%

Factor Groups

Sample	Nodule
M6C2	n
M6C3	n
M7C6	n
M7C7	n
M8C2	n
M8C4	n
M10C8	n
M11C8	n
M14C5	y
M15C1	y
M15C2	y
M16C3	y
M17C6	y
M18C2	y
M18C3	y
M18C7	y

Group n
Average similarity: 65,28

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Canthocamptoidea	5,13	12,35	2,97	18,92	18,92
Ameiridae	5,25	12,32	2,70	18,88	37,80
Argestidae	4,13	11,15	3,06	17,08	54,88
Ectinosomatidae	3,63	10,01	3,07	15,34	70,22
Zosimidae	4,13	9,89	2,05	15,16	85,38
Neobradyidae	1,75	3,38	1,37	5,18	90,56

Group y
Average similarity: 58,37

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Ameiridae	6,25	19,90	2,50	34,10	34,10
Argestidae	3,75	10,17	1,33	17,43	51,53
Pseudotachidiidae	2,75	8,89	3,01	15,24	66,77
Ectinosomatidae	2,88	6,10	1,01	10,45	77,22
Neobradyidae	2,75	4,95	0,87	8,48	85,70
Canthocamptoidea	1,13	2,45	0,69	4,19	89,89

Zosimidae	0,63	1,65	0,73	2,83	92,71

Groups n & y
Average dissimilarity = 46,58

Species	Group n Av.Abund	Group y Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Canthocamptoidea	5,13	1,13	7,38	1,76	15,83	15,83
Zosimidae	4,13	0,63	6,37	2,01	13,69	29,52
Ameiridae	5,25	6,25	5,94	1,28	12,74	42,26
Neobradyidae	1,75	2,75	4,09	1,25	8,77	51,03
Ectinosomatidae	3,63	2,88	4,08	1,38	8,75	59,78
Argestidae	4,13	3,75	4,05	1,40	8,69	68,47
Pseudotachidiidae	1,75	2,75	3,73	1,57	8,01	76,48
Diosaccidae	1,25	0,38	2,18	1,25	4,68	81,16
Idyanthidae	0,38	1,00	1,91	1,02	4,11	85,27
Paramesochridae	0,00	0,75	1,44	1,06	3,08	88,36
Huntemanniidae	0,63	0,25	1,22	0,94	2,62	90,98

Genera level:

SIMPER

Similarity Percentages - species contributions

One-Way Analysis

Data worksheet
Name: Muc_Harpacticoida Genus
Data type: Abundance
Sample selection: All
Variable selection: All

Parameters
Resemblance: S17 Bray Curtis similarity
Cut off for low contributions: 90,00%

Factor Groups

Sample	Nodule
M6C2	n
M6C3	n
M7C6	n
M7C7	n
M8C2	n
M8C4	n
M10C8	n
M11C8	n
M14C5	y
M15C1	y
M15C2	y
M16C3	y
M17C6	y
M18C2	y
M18C3	y
M18C7	y

Group n
Average similarity: 41,90

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Heteropsyllus	3,13	5,86	1,50	13,99	13,99
Bradya	2,38	5,39	1,52	12,87	26,86
Sarsameira	2,25	3,71	1,27	8,87	35,73
Pseudozosime	2,13	3,53	1,22	8,42	44,15
Marsteinia	1,75	3,38	1,37	8,07	52,22
Mesocletodes	1,63	3,01	0,71	7,18	59,40
Canthocamptidae gen n	1,25	2,12	0,93	5,05	64,45
Zosime	1,25	2,00	0,88	4,77	69,21
Argestes	0,88	1,87	1,03	4,46	73,67
Pseudomesochra	1,25	1,81	1,01	4,32	77,99
Zosimidae gen n	0,75	1,25	0,73	2,99	80,98
Pseudobradya	0,75	1,24	0,72	2,95	83,93
Paramphiascopsis	0,88	1,08	0,47	2,58	86,51
Ameira	0,75	0,85	0,46	2,02	88,53
Ameiropsis	0,50	0,82	0,51	1,95	90,48

Group y
Average similarity: 37,20

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Marsteinia	2,75	4,95	0,87	13,31	13,31
Sarsameira	1,75	4,54	1,17	12,20	25,50
Ameira	1,38	4,03	1,41	10,84	36,35
Pseudomesochra	1,38	3,60	1,46	9,68	46,03
Bradya	1,63	3,20	0,94	8,60	54,63
Parargestes	1,13	2,79	0,90	7,51	62,14
Haifameira	0,88	2,32	1,04	6,23	68,37
Pseudobradya	1,00	1,68	0,70	4,51	72,89
Mesocletodes	1,00	1,25	0,48	3,35	76,24
Zosime	0,50	1,05	0,51	2,81	79,06
Paramesochra	0,50	0,96	0,51	2,57	81,63
Bodinia	0,63	0,95	0,51	2,56	84,19
Ameiridae gen n	0,50	0,85	0,51	2,29	86,48
Sicameira	0,63	0,58	0,33	1,55	88,03
Idyanthidae gen n	0,63	0,55	0,32	1,49	89,52
Idyella	0,38	0,50	0,34	1,34	90,85

Groups n & y
Average dissimilarity = 67,61

	Group n	Group y				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Heteropsyllus	3,13	0,13	5,56	1,44	8,23	8,23
Marsteinia	1,75	2,75	4,09	1,25	6,04	14,27
Pseudozosime	2,13	0,13	3,66	1,31	5,41	19,69
Sarsameira	2,25	1,75	3,11	1,07	4,60	24,29
Bradya	2,38	1,63	3,01	1,33	4,45	28,74
Mesocletodes	1,63	1,00	2,81	1,21	4,15	32,89
Pseudomesochra	1,25	1,38	2,09	1,08	3,09	35,99
Canthocamptidae gen n	1,25	0,50	2,06	1,23	3,04	39,03
Parargestes	0,63	1,13	1,93	1,24	2,85	41,88
Ameira	0,75	1,38	1,93	1,28	2,85	44,73
Zosime	1,25	0,50	1,87	1,01	2,77	47,50
Pseudobradya	0,75	1,00	1,68	1,14	2,48	49,98
Paramphiascopsis	0,88	0,25	1,68	1,05	2,48	52,46
Haifameira	0,13	0,88	1,60	1,24	2,36	54,82
Argestes	0,88	0,38	1,59	1,40	2,36	57,18
Zosimidae gen n	0,75	0,00	1,45	1,12	2,15	59,33
Nitokra	0,63	0,38	1,39	1,01	2,05	61,38
Ameiropsis	0,50	0,25	1,26	1,03	1,87	63,25
Argestidae gen n	0,25	0,50	1,24	0,64	1,83	65,08
Metahuntemannia	0,63	0,13	1,23	0,91	1,82	66,89
Bodinia	0,38	0,63	1,22	0,94	1,81	68,70
Sicameira	0,13	0,63	1,22	0,79	1,80	70,50

Idyanthidae gen n	0,00	0,63	1,16	0,71	1,71	72,21
Paradanielsennia	0,25	0,38	0,99	0,85	1,46	73,67
Paramesochra	0,00	0,50	0,98	0,97	1,45	75,12
Psammocamptus	0,25	0,38	0,96	0,76	1,41	76,53
Ameiridae gen n	0,13	0,50	0,94	0,97	1,39	77,92
Harpacticoida Incertae Sedis	0,38	0,38	0,91	0,91	1,34	79,26
Parapseudoleptomesochra	0,38	0,13	0,82	0,66	1,22	80,48
Idyella	0,00	0,38	0,75	0,76	1,10	81,58
Selenopsyllus	0,38	0,00	0,71	0,75	1,05	82,63
Pseudotachidiidae gen n	0,25	0,25	0,71	0,76	1,05	83,69
Paranannopus	0,00	0,38	0,71	0,76	1,05	84,74
Pseudotachidius	0,00	0,38	0,65	0,76	0,97	85,70
Boreolimella	0,25	0,13	0,61	0,66	0,91	86,61
Proameira	0,25	0,13	0,57	0,66	0,85	87,46
Malacopsyllus	0,00	0,25	0,50	0,57	0,74	88,19
Tachidiella	0,25	0,00	0,49	0,56	0,72	88,92
Microsetella	0,13	0,13	0,46	0,52	0,68	89,60
Paramesochridae gen n	0,00	0,25	0,46	0,56	0,68	90,27

Species level:

SIMPER

Similarity Percentages - species contributions

One-Way Analysis

Data worksheet
Name: Muc_Harpacticoida Species
Data type: Abundance
Sample selection: All
Variable selection: All

Parameters
Resemblance: S17 Bray Curtis similarity
Cut off for low contributions: 90,00%

Factor Groups

Sample	Nodule
M6C2	n
M6C3	n
M7C6	n
M7C7	n
M8C2	n
M8C4	n
M10C8	n
M11C8	n
M14C5	y
M15C1	y
M15C2	y
M16C3	y
M17C6	y
M18C2	y
M18C3	y
M18C7	y

Group n
Average similarity: 6,78

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Heteropsyllus sp. 3	1,00	1,42	0,67	20,92	20,92
Heteropsyllus sp. 1	1,13	1,38	0,71	20,38	41,29
Zosime sp. 1	0,50	0,74	0,51	10,92	52,21
Pseudomesochra sp. 1	0,75	0,63	0,51	9,25	61,46
Pseudozosime sp. 2	0,63	0,42	0,32	6,18	67,64
Zosimidae sp. 2	0,50	0,39	0,34	5,81	73,46
Zosime sp. 3	0,50	0,35	0,34	5,12	78,58
Pseudozosime sp. 3	0,38	0,32	0,34	4,71	83,28
Argestes sp. 1	0,25	0,13	0,19	1,88	85,16
Paramphiascopsis sp. 4	0,25	0,13	0,19	1,85	87,01
Boreolimella sp. 1	0,25	0,12	0,19	1,82	88,83
Zosimidae sp. 1	0,25	0,12	0,19	1,70	90,53

Group y
Average similarity: 4,04

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Zosime sp. 3	0,50	1,05	0,51	25,92	25,92
Pseudomesochra sp. 1	0,38	0,54	0,34	13,49	39,41
Pseudobradya sp. 12	0,38	0,41	0,34	10,18	49,59
Bodinia sp. 6	0,25	0,18	0,19	4,42	54,01
Nitokra sp. 2	0,25	0,17	0,19	4,11	58,12
Sarsameira sp. 19	0,25	0,17	0,19	4,11	62,23
Parargestes sp. 7	0,25	0,17	0,19	4,11	66,34
Paramphiascopsis sp. 6	0,25	0,17	0,19	4,11	70,46
Paramesochra sp. 2	0,25	0,17	0,19	4,11	74,57
Psammocamptus sp. 1	0,25	0,16	0,19	3,84	78,41
Idyella sp.2	0,25	0,16	0,19	3,84	82,26
Marsteinia sp. 27	0,25	0,16	0,19	3,84	86,10
Pseudomesochra sp. 10	0,38	0,15	0,19	3,76	89,86
Bradya sp. 21	0,25	0,14	0,19	3,40	93,26

Groups n & y
Average dissimilarity = 97,72

Species	Group n Av.Abund	Group y Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Heteropsyllus sp. 1	1,13	0,00	2,09	0,95	2,14	2,14
Heteropsyllus sp. 3	1,00	0,00	1,80	1,12	1,84	3,98
Pseudomesochra sp. 1	0,75	0,38	1,37	0,91	1,40	5,38
Zosime sp. 3	0,50	0,50	1,23	1,02	1,26	6,65
Pseudozosime sp. 2	0,63	0,00	1,10	0,72	1,12	7,77
Zosimidae sp. 2	0,50	0,00	0,99	0,71	1,01	8,78
Marsteinia sp. 4	0,13	0,50	0,97	0,60	1,00	9,77
Zosime sp. 1	0,50	0,00	0,97	0,97	0,99	10,76
Pseudomesochra sp. 10	0,00	0,38	0,74	0,52	0,75	11,52
Pseudobradya sp. 12	0,00	0,38	0,69	0,75	0,70	12,22
Pseudozosime sp. 3	0,38	0,00	0,66	0,76	0,68	12,90
Nitokra sp. 2	0,13	0,25	0,63	0,66	0,65	13,54
Psammocamptus sp. 1	0,13	0,25	0,62	0,66	0,64	14,18
Boreolimella sp. 1	0,25	0,13	0,61	0,66	0,63	14,81
Heteropsyllus sp. 5	0,25	0,13	0,56	0,66	0,58	15,38
Bodinia sp. 6	0,00	0,25	0,51	0,57	0,52	15,91
Argestes sp. 1	0,25	0,00	0,50	0,56	0,51	16,42
Sarsameira sp. 19	0,00	0,25	0,50	0,57	0,51	16,93
Parargestes sp. 7	0,00	0,25	0,50	0,57	0,51	17,44
Paramphiascopsis sp. 6	0,00	0,25	0,50	0,57	0,51	17,95
Paramesochra sp. 2	0,00	0,25	0,50	0,57	0,51	18,46
Paramphiascopsis sp. 4	0,25	0,00	0,49	0,57	0,50	18,96
Idyella sp.2	0,00	0,25	0,48	0,57	0,50	19,45
Marsteinia sp. 27	0,00	0,25	0,48	0,57	0,50	19,95
Paramphiascopsis sp. 2	0,25	0,00	0,48	0,37	0,49	20,44
Metahuntemannia sp. 3	0,25	0,00	0,48	0,37	0,49	20,93
Zosimidae sp. 1	0,25	0,00	0,47	0,57	0,48	21,41
Bradya sp. 21	0,00	0,25	0,46	0,56	0,47	21,88
Idyanthidae sp. 2	0,00	0,25	0,46	0,56	0,47	22,36
Heteropsyllus sp. 4	0,25	0,00	0,45	0,57	0,46	22,82
Canthocamptidae sp. 3	0,25	0,00	0,45	0,57	0,46	23,28
Canthocamptidae sp. 6	0,25	0,00	0,45	0,57	0,46	23,74
Argestes sp. 8	0,00	0,25	0,45	0,37	0,46	24,20
Bradya sp. 27	0,00	0,25	0,45	0,37	0,46	24,66
Pseudozosime sp. 6	0,25	0,00	0,44	0,57	0,45	25,11

Bodinia sp. 2	0,13	0,13	0,43	0,52	0,44	25,55
Zosime sp. 2	0,25	0,00	0,42	0,37	0,43	25,98
Selenopsyllus antarcticus	0,25	0,00	0,42	0,57	0,43	26,41
Sarsameira sp. 4	0,13	0,13	0,41	0,52	0,42	26,83
Paradanielsennia sp. 1	0,13	0,13	0,41	0,52	0,42	27,26
Paradanielsennia sp. 2	0,13	0,13	0,40	0,52	0,41	27,67
Ameira sp. 1	0,13	0,00	0,29	0,37	0,30	27,96
Ameira sp. 2	0,13	0,00	0,29	0,37	0,30	28,26
Ameiropsis sp. 1	0,13	0,00	0,29	0,37	0,30	28,56
Nitokra sp. 1	0,13	0,00	0,29	0,37	0,30	28,85
Parapseudoleptomesochra sp. 1	0,13	0,00	0,29	0,37	0,30	29,15
Sarsameira sp. 1	0,13	0,00	0,29	0,37	0,30	29,45
Mesocletodes sp. 1	0,13	0,00	0,29	0,37	0,30	29,74
Mesocletodes sp. 2	0,13	0,00	0,29	0,37	0,30	30,04
Parargestes sp. 1	0,13	0,00	0,29	0,37	0,30	30,34
Heteropsyllus sp. 2	0,13	0,00	0,29	0,37	0,30	30,64
Canuelidae sp. 1	0,13	0,00	0,29	0,37	0,30	30,93
Selenopsyllus sp. 1	0,13	0,00	0,29	0,37	0,30	31,23
Arenosetella sp. 1	0,13	0,00	0,29	0,37	0,30	31,53
Pseudobradya sp. 1	0,13	0,00	0,29	0,37	0,30	31,82
Metahuntemannia sp.1	0,13	0,00	0,29	0,37	0,30	32,12
Marsteinia sp. 1	0,13	0,00	0,29	0,37	0,30	32,42
Pseudozosime sp. 1	0,13	0,00	0,29	0,37	0,30	32,72
Ameiropsis sp. 3	0,13	0,00	0,28	0,37	0,28	33,00
Sarsameira sp. 3	0,13	0,00	0,28	0,37	0,28	33,28
Ceratonotus steiningeri	0,13	0,00	0,28	0,37	0,28	33,57
Argestes sp. 4	0,13	0,00	0,28	0,37	0,28	33,85
Mesocletodes sp. 3	0,13	0,00	0,28	0,37	0,28	34,13
Mesocletodes sp. 4	0,13	0,00	0,28	0,37	0,28	34,42
Mesocletodes sp. 5	0,13	0,00	0,28	0,37	0,28	34,70
Barbaracletodes sp. 1	0,13	0,00	0,28	0,37	0,28	34,99
Canthocamptidae sp. 2	0,13	0,00	0,28	0,37	0,28	35,27
Bradya sp. 3	0,13	0,00	0,28	0,37	0,28	35,55
Bradya sp. 4	0,13	0,00	0,28	0,37	0,28	35,84
Bradya sp. 5	0,13	0,00	0,28	0,37	0,28	36,12
Microsetella sp. 1	0,13	0,00	0,28	0,37	0,28	36,40
Tachidiella sp. 2	0,13	0,00	0,28	0,37	0,28	36,69
Marsteinia sp. 5	0,13	0,00	0,28	0,37	0,28	36,97
Marsteinia sp. 6	0,13	0,00	0,28	0,37	0,28	37,25
Pseudomesochra sp. 3	0,13	0,00	0,28	0,37	0,28	37,54

Harpacticoida Incertae Sedis sp. 1	0,13	0,00	0,28	0,37	0,28	37,82
Ameira sp. 9	0,00	0,13	0,26	0,37	0,27	38,09
Ameira sp. 10	0,00	0,13	0,26	0,37	0,27	38,36
Ameiropsis sp. 5	0,00	0,13	0,26	0,37	0,27	38,63
Ameiropsis sp. 6	0,00	0,13	0,26	0,37	0,27	38,89
Haifameira sp. 4	0,00	0,13	0,26	0,37	0,27	39,16
Sarsameira sp. 23	0,00	0,13	0,26	0,37	0,27	39,43
Argestes sp. 7	0,00	0,13	0,26	0,37	0,27	39,70
Diosaccidae sp. 1	0,00	0,13	0,26	0,37	0,27	39,97
Bradya sp. 22	0,00	0,13	0,26	0,37	0,27	40,23
Pseudobradya sp. 8	0,00	0,13	0,26	0,37	0,27	40,50
Pseudobradya sp. 9	0,00	0,13	0,26	0,37	0,27	40,77
Idyella sp. 1	0,00	0,13	0,26	0,37	0,27	41,04
Idyanthidae sp. 1	0,00	0,13	0,26	0,37	0,27	41,31
Pseudotachidiidae sp. 3	0,00	0,13	0,26	0,37	0,27	41,57
Ameira sp. 14	0,00	0,13	0,26	0,37	0,26	41,84
Ameira sp. 15	0,00	0,13	0,26	0,37	0,26	42,10
Haifameira sp. 2	0,00	0,13	0,26	0,37	0,26	42,36
Haifameira sp. 6	0,00	0,13	0,26	0,37	0,26	42,62
Haifameira sp. 7	0,00	0,13	0,26	0,37	0,26	42,89
Malacopsyllus sp. 1	0,00	0,13	0,26	0,37	0,26	43,15
Nitokra sp. 6	0,00	0,13	0,26	0,37	0,26	43,41
Sarsameira sp. 20	0,00	0,13	0,26	0,37	0,26	43,67
Sarsameira sp. 27	0,00	0,13	0,26	0,37	0,26	43,94
Sicameira sp. 4	0,00	0,13	0,26	0,37	0,26	44,20
Ameiridae sp. 4	0,00	0,13	0,26	0,37	0,26	44,46
Dorciceratus sp. 2	0,00	0,13	0,26	0,37	0,26	44,72
Bodinia sp. 5	0,00	0,13	0,26	0,37	0,26	44,99
Eurycletodes sp. 2	0,00	0,13	0,26	0,37	0,26	45,25
Mesocletodes sp. 20	0,00	0,13	0,26	0,37	0,26	45,51
Mesocletodes sp. 21	0,00	0,13	0,26	0,37	0,26	45,77
Parargestes sp. 6	0,00	0,13	0,26	0,37	0,26	46,04
Parargestes sp. 11	0,00	0,13	0,26	0,37	0,26	46,30
Parargestes sp. 12	0,00	0,13	0,26	0,37	0,26	46,56
Parargestes sp. 13	0,00	0,13	0,26	0,37	0,26	46,82
Argestidae sp. 4	0,00	0,13	0,26	0,37	0,26	47,09
Argestidae sp. 5	0,00	0,13	0,26	0,37	0,26	47,35
Argestidae sp. 6	0,00	0,13	0,26	0,37	0,26	47,61
Canthocamptidae sp. 9	0,00	0,13	0,26	0,37	0,26	47,87
Cervinia sp. 1	0,00	0,13	0,26	0,37	0,26	48,14

Stratiopontotes sp. 1	0,00	0,13	0,26	0,37	0,26	48,40
Bradya sp. 20	0,00	0,13	0,26	0,37	0,26	48,66
Bradya sp. 29	0,00	0,13	0,26	0,37	0,26	48,92
Microsetella sp. 2	0,00	0,13	0,26	0,37	0,26	49,19
Pseudobradya sp. 7	0,00	0,13	0,26	0,37	0,26	49,45
Marsteinia sp. 15	0,00	0,13	0,26	0,37	0,26	49,71
Marsteinia sp. 16	0,00	0,13	0,26	0,37	0,26	49,97
Marsteinia sp. 17	0,00	0,13	0,26	0,37	0,26	50,24
Marsteinia sp. 28	0,00	0,13	0,26	0,37	0,26	50,50
Marsteinia sp. 29	0,00	0,13	0,26	0,37	0,26	50,76
Marsteinia sp. 30	0,00	0,13	0,26	0,37	0,26	51,02
Paramesochra sp. 1	0,00	0,13	0,26	0,37	0,26	51,29
Paramesochridae sp. 2	0,00	0,13	0,26	0,37	0,26	51,55
Paranannopus sp. 1	0,00	0,13	0,26	0,37	0,26	51,81
Sarsameira sp. 17	0,13	0,00	0,25	0,37	0,26	52,07
Sarsameira sp. 18	0,13	0,00	0,25	0,37	0,26	52,33
Dorciceratus sp. 1	0,13	0,00	0,25	0,37	0,26	52,59
Argestes sp. 6	0,13	0,00	0,25	0,37	0,26	52,85
Bodinia sp. 3	0,13	0,00	0,25	0,37	0,26	53,11
Argestidae sp. 2	0,13	0,00	0,25	0,37	0,26	53,37
Canthocamptidae sp. 7	0,13	0,00	0,25	0,37	0,26	53,63
Canthocamptidae sp. 8	0,13	0,00	0,25	0,37	0,26	53,89
Paramphiascopsis sp. 5	0,13	0,00	0,25	0,37	0,26	54,15
Bradya sp. 18	0,13	0,00	0,25	0,37	0,26	54,41
Bradya sp. 19	0,13	0,00	0,25	0,37	0,26	54,67
Halectinosoma sp. 1	0,13	0,00	0,25	0,37	0,26	54,94
Pseudobradya sp. 6	0,13	0,00	0,25	0,37	0,26	55,20
Metahuntemannia sp. 4	0,13	0,00	0,25	0,37	0,26	55,46
Aspinothorax sp. 1	0,13	0,00	0,25	0,37	0,26	55,72
Marsteinia sp. 14	0,13	0,00	0,25	0,37	0,26	55,98
Pseudozosime sp. 10	0,13	0,00	0,25	0,37	0,26	56,24
Harpacticoida Incertae Sedis sp. 3	0,13	0,00	0,25	0,37	0,26	56,50
Ameira sp. 7	0,00	0,13	0,24	0,37	0,25	56,75
Ameira sp. 8	0,00	0,13	0,24	0,37	0,25	56,99
Haifameira sp. 3	0,00	0,13	0,24	0,37	0,25	57,24
Malacopsyllus sp. 2	0,00	0,13	0,24	0,37	0,25	57,49
Sarsameira sp. 21	0,00	0,13	0,24	0,37	0,25	57,73
Sarsameira sp. 22	0,00	0,13	0,24	0,37	0,25	57,98
Ameiridae sp. 2	0,00	0,13	0,24	0,37	0,25	58,23
Mesocletodes sp. 14	0,00	0,13	0,24	0,37	0,25	58,47

Parargestes sp. 8	0,00	0,13	0,24	0,37	0,25	58,72
Argestidae sp. 3	0,00	0,13	0,24	0,37	0,25	58,97
Canthocamptidae sp. 10	0,00	0,13	0,24	0,37	0,25	59,22
Canthocamptidae sp. 11	0,00	0,13	0,24	0,37	0,25	59,46
Cervinopsis sp. 1	0,00	0,13	0,24	0,37	0,25	59,71
Pseudomesochra sp. 6	0,00	0,13	0,24	0,37	0,25	59,96
Pseudomesochra sp. 7	0,00	0,13	0,24	0,37	0,25	60,20
Harpacticoida Incertae Sedis sp. 4	0,00	0,13	0,24	0,37	0,25	60,45
Ameiropsis sp. 4	0,13	0,00	0,24	0,37	0,25	60,70
Proameira sp. 2	0,13	0,00	0,24	0,37	0,25	60,94
Sarsameira sp. 11	0,13	0,00	0,24	0,37	0,25	61,19
Sarsameira sp. 12	0,13	0,00	0,24	0,37	0,25	61,43
Sarsameira sp. 13	0,13	0,00	0,24	0,37	0,25	61,68
Ameiridae sp. 1	0,13	0,00	0,24	0,37	0,25	61,92
Mesocletodes sp. 6	0,13	0,00	0,24	0,37	0,25	62,17
Mesocletodes (abyssicola) sp. 7	0,13	0,00	0,24	0,37	0,25	62,41
Mesocletodes (abyssicola) sp. 8	0,13	0,00	0,24	0,37	0,25	62,66
Paradiosaccus sp. 1	0,13	0,00	0,24	0,37	0,25	62,90
Bradya sp. 10	0,13	0,00	0,24	0,37	0,25	63,15
Bradya sp. 11	0,13	0,00	0,24	0,37	0,25	63,39
Pseudobradya sp. 5	0,13	0,00	0,24	0,37	0,25	63,64
Pseudotachidiidae sp. 1	0,13	0,00	0,24	0,37	0,25	63,89
Romette sp. 1	0,13	0,00	0,24	0,37	0,25	64,13
Tisbe sp. 1	0,13	0,00	0,24	0,37	0,25	64,38
Harpacticoida Incertae Sedis sp. 2	0,13	0,00	0,24	0,37	0,25	64,62
Ameira sp. 5	0,13	0,00	0,23	0,37	0,24	64,86
Ameira sp. 6	0,13	0,00	0,23	0,37	0,24	65,09
Sarsameira sp. 14	0,13	0,00	0,23	0,37	0,24	65,33
Sarsameira sp. 15	0,13	0,00	0,23	0,37	0,24	65,57
Sarsameira sp. 16	0,13	0,00	0,23	0,37	0,24	65,80
Mesocletodes sp. 12	0,13	0,00	0,23	0,37	0,24	66,04
Mesocletodes sp. 13	0,13	0,00	0,23	0,37	0,24	66,27
Parargestes sp. 4	0,13	0,00	0,23	0,37	0,24	66,51
Parargestes sp. 5	0,13	0,00	0,23	0,37	0,24	66,75
Heteropsyllus sp. 8	0,13	0,00	0,23	0,37	0,24	66,98
Perucamptus sp. 1	0,13	0,00	0,23	0,37	0,24	67,22
Paramphiascopsis sp. 3	0,13	0,00	0,23	0,37	0,24	67,46
Bradya sp. 14	0,13	0,00	0,23	0,37	0,24	67,69
Bradya sp. 15	0,13	0,00	0,23	0,37	0,24	67,93
Bradya sp. 16	0,13	0,00	0,23	0,37	0,24	68,16

Bradya sp. 17	0,13	0,00	0,23	0,37	0,24	68,40
Marsteinia sp. 12	0,13	0,00	0,23	0,37	0,24	68,64
Marsteinia sp. 13	0,13	0,00	0,23	0,37	0,24	68,87
Pseudomesochra sp. 5	0,13	0,00	0,23	0,37	0,24	69,11
Pseudozosime sp. 9	0,13	0,00	0,23	0,37	0,24	69,35
Ameira sp. 16	0,00	0,13	0,23	0,37	0,23	69,58
Ameira sp. 17	0,00	0,13	0,23	0,37	0,23	69,81
Haifameira sp. 8	0,00	0,13	0,23	0,37	0,23	70,05
Parapseudoleptomesochra sp. 4	0,00	0,13	0,23	0,37	0,23	70,28
Proameira sp. 3	0,00	0,13	0,23	0,37	0,23	70,51
Sarsameira sp. 28	0,00	0,13	0,23	0,37	0,23	70,75
Sarsameira sp. 29	0,00	0,13	0,23	0,37	0,23	70,98
Sarsameira sp. 30	0,00	0,13	0,23	0,37	0,23	71,21
Sicameira sp. 5	0,00	0,13	0,23	0,37	0,23	71,45
Sicameira sp. 6	0,00	0,13	0,23	0,37	0,23	71,68
Ameiridae sp. 5	0,00	0,13	0,23	0,37	0,23	71,91
Psammocamptus sp. 3	0,00	0,13	0,23	0,37	0,23	72,15
Bradya sp. 28	0,00	0,13	0,23	0,37	0,23	72,38
Bradya sp. 30	0,00	0,13	0,23	0,37	0,23	72,61
Talpina sp. 1	0,00	0,13	0,23	0,37	0,23	72,85
Idyanthidae sp. 4	0,00	0,13	0,23	0,37	0,23	73,08
Marsteinia sp. 31	0,00	0,13	0,23	0,37	0,23	73,31
Paradanielsennia sp. 3	0,00	0,13	0,23	0,37	0,23	73,55
Paranannopus sp. 3	0,00	0,13	0,23	0,37	0,23	73,78
Pseudomesochra sp. 11	0,00	0,13	0,23	0,37	0,23	74,01
Pseudotachidius sp. 3	0,00	0,13	0,23	0,37	0,23	74,25
Pseudotachidiidae sp. 4	0,00	0,13	0,23	0,37	0,23	74,48
Ameira sp. 13	0,00	0,13	0,22	0,37	0,23	74,71
Sarsameira sp. 25	0,00	0,13	0,22	0,37	0,23	74,94
Sarsameira sp. 26	0,00	0,13	0,22	0,37	0,23	75,17
Sicameira sp. 2	0,00	0,13	0,22	0,37	0,23	75,40
Sicameira sp. 3	0,00	0,13	0,22	0,37	0,23	75,62
Mesocletodes sp. 17	0,00	0,13	0,22	0,37	0,23	75,85
Mesocletodes sp. 18	0,00	0,13	0,22	0,37	0,23	76,08
Mesocletodes sp. 19	0,00	0,13	0,22	0,37	0,23	76,31
Parargestes sp. 10	0,00	0,13	0,22	0,37	0,23	76,54
Canthocamptidae sp. 12	0,00	0,13	0,22	0,37	0,23	76,77
Bradya sp. 26	0,00	0,13	0,22	0,37	0,23	77,00
Metahuntemannia sp. 5	0,00	0,13	0,22	0,37	0,23	77,23
Marsteinia sp. 23	0,00	0,13	0,22	0,37	0,23	77,46

Marsteinia sp. 24	0,00	0,13	0,22	0,37	0,23	77,69
Marsteinia sp. 25	0,00	0,13	0,22	0,37	0,23	77,91
Marsteinia sp. 26	0,00	0,13	0,22	0,37	0,23	78,14
Paramesochra sp. 3	0,00	0,13	0,22	0,37	0,23	78,37
Paranannopus sp. 2	0,00	0,13	0,22	0,37	0,23	78,60
Pseudotachidius sp. 2	0,00	0,13	0,22	0,37	0,23	78,83
Pseudozosime sp. 11	0,00	0,13	0,22	0,37	0,23	79,06
Harpacticoida Incertae Sedis sp. 6	0,00	0,13	0,22	0,37	0,23	79,29
Ameira sp. 3	0,13	0,00	0,21	0,37	0,22	79,51
Ameira sp. 4	0,13	0,00	0,21	0,37	0,22	79,72
Ameiropsis sp. 2	0,13	0,00	0,21	0,37	0,22	79,94
Haifameira sp. 1	0,13	0,00	0,21	0,37	0,22	80,15
Nitokra sp. 3	0,13	0,00	0,21	0,37	0,22	80,37
Nitokra sp. 4	0,13	0,00	0,21	0,37	0,22	80,59
Nitokra sp. 5	0,13	0,00	0,21	0,37	0,22	80,80
Parameiropsis sp. 1	0,13	0,00	0,21	0,37	0,22	81,02
Parapseudoleptomesochra sp. 2	0,13	0,00	0,21	0,37	0,22	81,23
Parapseudoleptomesochra sp. 3	0,13	0,00	0,21	0,37	0,22	81,45
Proameira sp. 1	0,13	0,00	0,21	0,37	0,22	81,67
Sarsameira sp. 2	0,13	0,00	0,21	0,37	0,22	81,88
Sarsameira sp. 5	0,13	0,00	0,21	0,37	0,22	82,10
Sarsameira sp. 6	0,13	0,00	0,21	0,37	0,22	82,32
Sarsameira sp. 7	0,13	0,00	0,21	0,37	0,22	82,53
Sarsameira sp. 8	0,13	0,00	0,21	0,37	0,22	82,75
Sarsameira sp. 9	0,13	0,00	0,21	0,37	0,22	82,96
Sarsameira sp.10	0,13	0,00	0,21	0,37	0,22	83,18
Sicameira sp. 1	0,13	0,00	0,21	0,37	0,22	83,40
Argestes sp. 2	0,13	0,00	0,21	0,37	0,22	83,61
Argestes sp. 3	0,13	0,00	0,21	0,37	0,22	83,83
Argestes sp. 5	0,13	0,00	0,21	0,37	0,22	84,05
Bodinia sp. 1	0,13	0,00	0,21	0,37	0,22	84,26
Coralliclетodes sp. 1	0,13	0,00	0,21	0,37	0,22	84,48
Eurycletodes sp. 1	0,13	0,00	0,21	0,37	0,22	84,69
Mesocletodes sp. 9	0,13	0,00	0,21	0,37	0,22	84,91
Mesocletodes sp. 10	0,13	0,00	0,21	0,37	0,22	85,13
Mesocletodes sp. 11	0,13	0,00	0,21	0,37	0,22	85,34
Odiliacletodes sp. 1	0,13	0,00	0,21	0,37	0,22	85,56
Parargestes sp. 2	0,13	0,00	0,21	0,37	0,22	85,77
Parargestes sp. 3	0,13	0,00	0,21	0,37	0,22	85,99
Argestidae sp. 1	0,13	0,00	0,21	0,37	0,22	86,21

Heteropsyllus sp. 6	0,13	0,00	0,21	0,37	0,22	86,42
Heteropsyllus sp. 7	0,13	0,00	0,21	0,37	0,22	86,64
Psammocamptus sp. 2	0,13	0,00	0,21	0,37	0,22	86,86
Canthocamptidae sp. 1	0,13	0,00	0,21	0,37	0,22	87,07
Canthocamptidae sp. 4	0,13	0,00	0,21	0,37	0,22	87,29
Canthocamptidae sp. 5	0,13	0,00	0,21	0,37	0,22	87,50
Amphiascus sp. 1	0,13	0,00	0,21	0,37	0,22	87,72
Paramphiascopsis sp. 1	0,13	0,00	0,21	0,37	0,22	87,94
Stenhelia (Delavalia) sp. 1	0,13	0,00	0,21	0,37	0,22	88,15
Bradya sp. 1	0,13	0,00	0,21	0,37	0,22	88,37
Bradya sp. 2	0,13	0,00	0,21	0,37	0,22	88,58
Bradya sp. 6	0,13	0,00	0,21	0,37	0,22	88,80
Bradya sp. 7	0,13	0,00	0,21	0,37	0,22	89,02
Bradya sp. 8	0,13	0,00	0,21	0,37	0,22	89,23
Bradya sp. 9	0,13	0,00	0,21	0,37	0,22	89,45
Bradya sp. 12	0,13	0,00	0,21	0,37	0,22	89,67
Bradya sp. 13	0,13	0,00	0,21	0,37	0,22	89,88
Lineosoma sp. 1	0,13	0,00	0,21	0,37	0,22	90,10

Appendix 8
Anosim test of meiofauna community for analysis difference between track and outside the track

ANOSIM
Analysis of Similarities

One-Way Analysis

Resemblance worksheet
Name: Resem2
Data type: Similarity
Selection: All

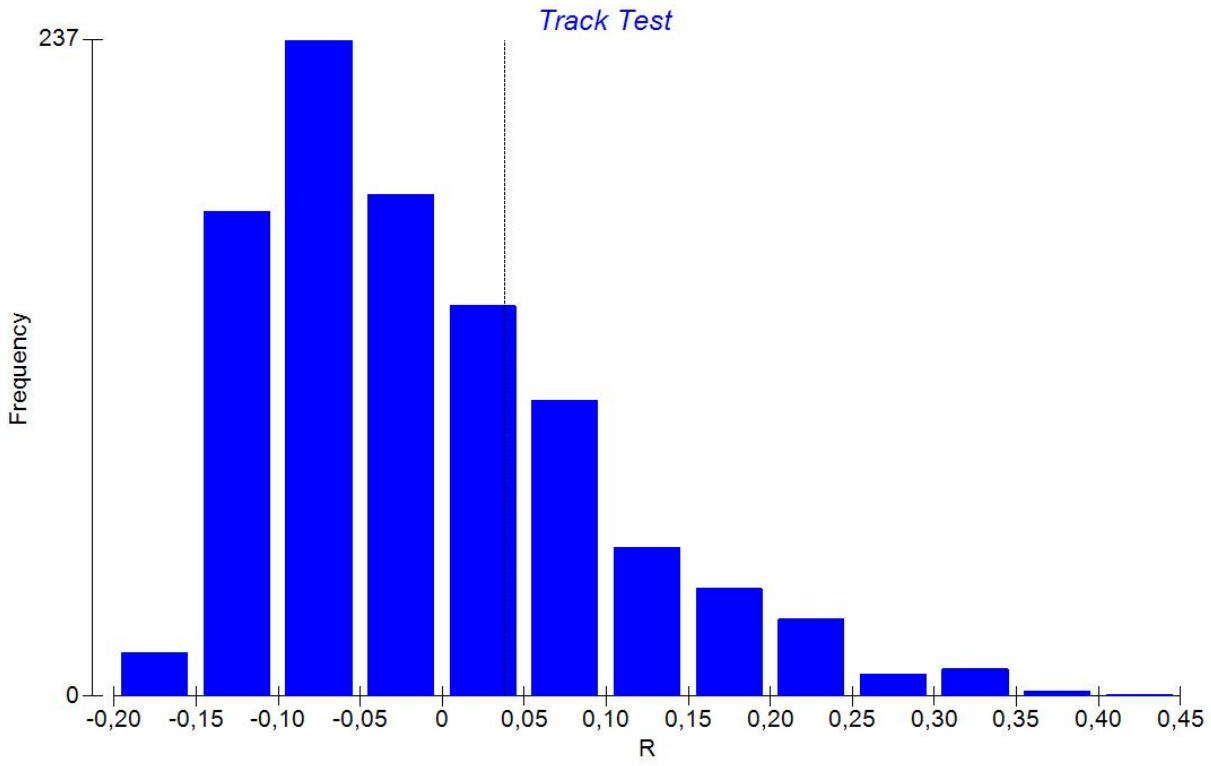
Factor Values
Factor: Track
n
y

Factor Groups

Sample	Track
PL1595-3CL5	n
PL1596-4CL5	n
PL1597-5CL6	n
PL1598-6CL6	n
PL1603-11CL1	n
PL1603-11CL2	n
PL1599-7CL1	y
PL1599-7CL2	y
PL1599-7CL3	y
PL1599-7CL4	y
PL1599-7CL5	y
PL1599-7CL6	y
PL1599-7CL7	y
PL1599-7CL8	y
PL1602-10CL1	y
PL1602-10CL2	y
PL1602-10CL3	y
PL1602-10CL4	y
PL1602-10CL5	y
PL1602-10CL6	y
PL1602-10CL7	y
PL1602-10CL8	y

Global Test
Sample statistic (Global R): 0,039
Significance level of sample statistic: 27,8%
Number of permutations: 999 (Random sample from 74613)
Number of permuted statistics greater than or equal to Global R: 277

Outputs
Plot: Graph8



Appendix 9
Anosim test of harpacticoid species for analysis difference between track and outside track

ANOSIM
Analysis of Similarities

One-Way Analysis

Resemblance worksheet
Name: Resem2
Data type: Similarity
Selection: All

Factor Values
Factor: Track
n
y

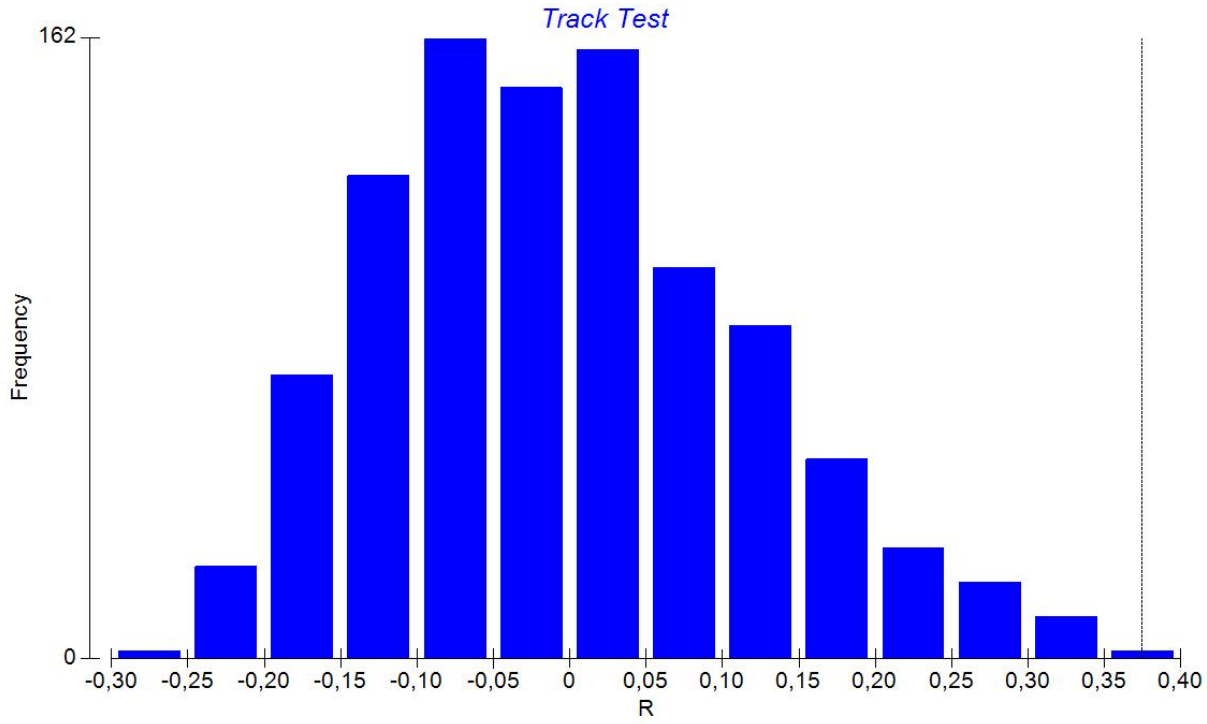
Factor Groups

Sample	Track
PL1595-3CL5	n
PL1596-4CL5	n
PL1597-5CL6	n
PL1598-6CL6	n
PL1603-11CL1	n
PL1603-11CL2	n
PL1599-7CL1	y
PL1599-7CL2	y
PL1599-7CL3	y

PL1599-7CL4 y
PL1599-7CL5 y
PL1599-7CL6 y
PL1599-7CL7 y
PL1599-7CL8 y
PL1602-10CL1 y
PL1602-10CL2 y
PL1602-10CL3 y
PL1602-10CL4 y
PL1602-10CL5 y
PL1602-10CL6 y
PL1602-10CL7 y
PL1602-10CL8 y

Global Test
Sample statistic (Global R): 0,375
Significance level of sample statistic: 0,2%
Number of permutations: 999 (Random sample from 74613)
Number of permuted statistics greater than or equal to Global R: 1

Outputs
Plot: Graph8



Summary

Knowledge about deep-sea ecosystem has change during several past decades. Quantitative sampling of deep-sea bottom has revealed that the deep-sea harbor an extraordinary high diversity. However, study on deep-sea meiofauna mainly coming from marginal zone of deep-sea where the deep-sea bottom were affected by high surface productivity and continental factors. Meanwhile, meiofauna studies from open ocean where the deep-sea bottom received extremely low food supply is limited due to the expensive cost as well as vast and difficult area for quantitatively sampling meiofauna. Furthermore, the study of meiofauna associated with polymetallic nodule from the deep-sea is even more limited.

The Nodinaut cruise was launched to study the environment of Polymetallic Nodule Province (PNP) in the North equatorial Pacific Ocean or within French mining claim areas. Environmental study of PNP is important, since the future commercial deep-sea mining for polymetallic nodule is predicted to have major impact on ecosystem, for evaluating impact on deep-sea polymetallic nodule mining. Environmental study in an area where the commercial mining is likely to be happened is necessary as the baseline information on the ecosystem so that changes in the ecosystem could be assessed.

Information about sediment-dwelling meiofauna from inside nodule and outside nodule area which is functioned as a baseline information for measuring changes on ecosystem as well as the recovery potential of meiofauna communities after 26 years of pilot mining for polymetallic nodule in Polymetallic Nodule Province are presented.

Meiofauna communities of the Pacific Nodule Province

In order to study meiofauna communities of the Pacific nodule province ten stations within French mining-claimed area were quantitatively sampled during the Nodinaut Cruise in May 17th - June 28th 2004. Ten stations were sampled from two sites, 5 stations from nodule area (Facies B) and 5 from outside nodule area using 9,5 cm diameter multicorer. The study sites represent different substratum of deep-sea floor, soft sediment and soft sediment covered with polymetallic nodules on the surface.

Most of meiofauna studies in polymetallic nodule province related to sediment disturbance caused by nodule mining, study of the composition and abundance of sediment-dwelling meiofauna surrounding the nodule or meiofauna associate with polymetallic nodule.

The present study is the first study which compare the composition of sediment-dwelling meiofauna from inside nodule area and from outside nodule area. In this study composition and abundance of meiofauna from inside nodule and outside nodule area were dominated by nematodes and followed by copepods. This result was coincide with reports on similar depth from other deep-sea region. Mean density of meiofauna communities from inside nodule area is tend to lower than outside nodule area. 2D-MDS plot confirmed this finding by showing clear separation between samples within nodule area and outside nodule area. The ANOSIM test based on Bray-Curtis similarity and Minimum Spanning Tree also support this finding. This condition show more or less inverse relation between the abundance of meiofauna and the presence of nodule. Furthermore, similar condition also found in diversity, that the diversity of meiofauna inside nodule area is lower than outside nodule area.

Ameiridae is found dominant among other families within Harpacticoida found in this study. This result is similar with the result from other region of polymetallic nodule province. Besides, this study also confirmed the abundance of traditionally-typical deep-sea genera such as, Bradya, Zosime, Pseudomesochra and Mesocletodes, though the proportion of harpacticoid composition is differ.

Similarity analysis between harpacticoid communities from inside nodule area and outside nodule area using different methods showed different result . Student's t-test showed that both communities were not statistically significant different, this result was supported by k-dominance and rarefaction curves. However, ANOSIM test based on Bray-Curtis similarity showed that both communities were different at significant level of 95% and this result wa supported by 2D MDS plot which showed clear separation between harpacticoid samples from inside nodule area and outside nodule area. Different results which were showed by those methods indicated that both assemblages have similar density and diversity but different in meiofaunal composition.

Recovery of Meiofauna communities within 26 years old track

It has been known from previous study that meiofauna communities have potential recovery from sediment disturbance. Potential recovery of meiofauna communities dependent on the scale of disturbance. The present study was conducted to study meiofauna communities from 26 years old deep-sea pilot mining area by comparing the sediment-dwelling meiofauna inside the track and outside the track.

Sampling was conducted in the eastern part of French mining claim area of Clarion-Clipperton Fracture Zone using a 20 cm x 9 cm blade corer operated from ROV "Nautile". On the deep-sea floor in study area many tracks of 1,5 m wide and 10 cm depth were observed, which are the remnant of a nodule-collecting activities in 1978. Samples were taken from inside the track and outside the track. Furthermore, the data were analysed with univariate methods (Student's T test) to find out whether the mean abundances of two assemblages related to two independent and random samples (from normal distribution) are equal. The diversity indices which were used for univariate analysis e.g. Shannon index (H') for diversity, Pielou's for Evennes and Simpson index (1-λ) for dominance. Besides, a multivariate analysis for measuring a similarity between sites in term of biological communities they contain e.g. abundance, structure community etc. was conducted using Bray-Curtis coefficient through triangular matrices of similarity.

The result revealed that meiofauna communities in this area have similar composition with meiofaunal assemblages in other deep-sea region. Nematodes dominated meiofaunal taxa followed by copepods, while the other meiofaunal taxa were found very rare. Mean density of meiofauna communities in this area (outside track and inside track) is 42,32 and 55,35 ind./10 cm^2, respectively. This amount fall between the range of density reported by other authors from other polymetallic nodule region.

Harpacticoid copepod is the most abundant copepod found in sediment throughout this study. This result confirm reports from other authors who are working in other deep-sea region. The most abundant family within Harpacticoida were Neobradyidae, Ameiridae, Argestidae, Canthocamptidae, and Ectinosomatidae. Within genus level we also confirmed the abundance of some typical deep-sea taxa such as Bradya, Mesocletodes, and Pseudomesochra. Mean densities of harpacticoid copepod observed in this study (inside the track and outside the track) were fall between the range of harpacticoid densities reported from other deep-sea localities.

The result of similarity analysis for meiofauna communities using univariate analysis (Student's t-test) and multivariate analysis (ANOSIM) showed that mean densities of meiofauna communities from both area were not significant different. For harpacticoid copepods, similarity analysis using Student's t-test showed that both harpacticoid communities from inside the track and outside the track were not significant different in diversity. The rarefaction and k-dominance curves also support this result. However, similarity analysis for harpacticoid abundance using ANOSIM test showed that harpacticoid

from both area were significant different, though 2D-MDS plot showed that the different was less clear. The result of those analysis indicate that though harpacticoid from inside the track and outside the track were different in term of abundance they have similar diversity and structure composition. This study indicate that 26 years is long enough for meiofauna communities in the track to recover from sediment disturbance to their initial density.

Zusammenfassung

Das Wissen über die Ökosysteme der Tiefsee hat sich in den vergangenen Jahrzehnten verändert. Quantitative Beprobungen des Tiefseebodens konnten deutlich machen, dass die Tiefsee eine außerordentlich hohe Diversität aufweist. Die meisten Studien über die Meiofauna der Tiefsee jedoch sind nahe der Kontinentalsockel durchgeführt worden, wo der Ozeanboden durch hohe Oberflächenproduktivität und kontinentale Faktoren beeinflusst wird. Aufgrund der hohen Kosten und des hohen Probenahmeaufwandes sind Untersuchungen der Meiofauna der durch geringen Nährstoffeintrag gekennzeichneten Böden des offenen Ozeans eher selten. Untersu-chungen der mit polymetallischen Knollen assoziierten Meiofauna sind dementspre-chend noch seltener. Die Nodinaut Expedition wurde mit der Zielsetzung durchge-führt, die Umweltbedingungen in der Polymetallic Nodule Province (PNP) im pazifischen Ozean nördlich des Äquators zu untersuchen. Diese Region liegt innerhalb eines Gebietes für das Frankreich die Abbaurechte besitzt. Da angenommen wird, dass die kommerzielle Ausbeutung der Tiefsee durch Abbau von Erzknollen einen massiven Einfluss auf das Ökosystem haben wird, ist die Untersuchung der aktuellen Umweltbedingungen der PNP von besonderer Bedeutung, um diesen Einfluss in der Zukunft beurteilen zu können. Die Untersuchung der Umweltbedingungen in einem Gebiet, das mit großer Wahrscheinlichkeit zu den Abbaugebieten zählen wird, stellt also grundlegende Informationen zur Verfügung, die die Veränderungen in einem solchen Ökosystem messbar machen. In der vorliegenden Untersuchung werden über sedimentbewohnende Meiofauna sowohl aktuelle Daten präsentiert, auf deren Grundlage zukünftige Veränderungen abgeschätzt werden können, als auch Daten über das Potential der Meiofauna sich von derartigen Eingriffen zu erholen. Diese Daten beruhen auf Vergleichen mit Teilgebieten, in denen vor 26 Jahren Probeabbau durchgeführt worden ist.

Meiofauna Gemeinschaften der PNP

Die quantitative Probenahme wurde während der Nodinaut Expedition vom 17. Mai bis zum 28. Juni 2004 durchgeführt. Es wurden zehn Stationen aus zwei Bereichen innerhalb der PNP mit einem Multicorer beprobt, dessen einzelne Corer einen Durchmesser von 9,5 cm hatten. Fünf Stationen lagen in einem Bereich dessen wei-ches Sediment an der Oberfläche mit Erzknollen bedeckt war (Facies B) und fünf Kontrollstationen lagen in einem Bereich mit ausschließlich weichem Sediment. Die meisten der bisher durchgeführten Untersuchungen der Meiofauna in der PNP bezo-gen sich auf durch Abbau hervorgerufene Störungen, sowie auf die Zusammenset-zungen und Abundanzen der Meiofauna Gemeinschaften in unmittelbarer

Umgebung der Knollen oder die direkt mit den Knollen assoziierten Gemeinschaften. Die vorlie-gende Untersuchung ist die erste, die einen Vergleich zieht zwischen den Meiofauna – Gemeinschaften der Erzknollenbereiche mit den Gemeinschaften der Bereiche, in denen keine Erzknollen vorkommen. Die Ergebnisse dieser Studie zeigen, dass die Meiofauna sowohl innerhalb der Erzknollenbereiche als auch außerhalb dieser von Nematoden und Copepoden dominiert wird. Diese Befunde decken sich mit Ergeb-nissen anderer Untersuchungen, die in ähnlichen Tiefen durchgeführt wurden. Die durchschnittliche Individuendichte der Gemeinschaften innerhalb der Erzknollenbe-reiche ist tendenziell geringer als die außerhalb. Dies wird durch 2D-MDS Darstel-lungen gestützt, die eine klare Trennung der verschiedenen Bereiche zeigen. Die auf dem Bray – Curtis Similaritätsindex und dem Minimum Spanning – Tree basierende durchgeführte ANOSIM unterstützt dieses Ergebnis ebenfalls. Diese Befunde belegen ein mehr oder weniger inverses Verhältnis zwischen der Abundanz der Meiofau-na und der Anwesenheit von Erzknollen. Dieses Verhältnis zeigt sich auch bei Be-trachtung der Diversität, sie ist außerhalb der Erzknollenbereiche größer als inner-halb. Die Ameiridae sind die dominante Familie der in dieser Untersuchung vorge-fundenen Familien innerhalb Harpacticoida. Das konnte auch in Untersuchungen an-derer Erzknollengebiete festgestellt werden. Darüber hinaus konnte in dieser Studie das Vorkommen typischer Tiefsee-Gattungen, wie Bradya, Zosime, Pseudomesochra und Mesocletodes, bestätigt werden, obwohl die Verhältnisse der Zusammensetzung andere sind. Die Similaritätsanalyse zwischen den Harpacticoiden Gemeinschaften der Erzknollen Bereiche mit denen der Bereiche außerhalb zeigte unterschiedliche Ergebnisse bei Anwendung verschiedener Methoden. Der T-Test zeigte, dass die Gemeinschaften nicht signifikant voneinander verschieden waren, was sowohl durch die k-Dominanz – Kurven als auch durch die Rarefaction – Kurven unterstützt wurde. Die auf dem Bray – Curtis – Index basierende ANOSIM hingegen zeigte, dass die Gemeinschaften auf dem 95% Signifikanzniveau sehr wohl verschieden voneinander waren, was wiederum von 2D – MDS – Darstellungen unterstützt wurde. Diese wie-sen eine klare Trennung der Gemeinschaften der beiden Bereiche auf. Die unter-schiedlichen Ergebnisse der verschiedenen Methoden weisen darauf hin, dass die beiden Gemeinschaften die Individuendichten und die Diversitäten sehr ähnlich sind, sich jedoch in der Zusammensetzung der Fauna unterscheiden.

Wiederbesiedlung einer 26 Jahre alten Abbauspur durch Meiofauna

Aus früheren Studien ist bekannt, dass Meiofaunagemeinschaften durchaus das Vermögen besitzen, sich von Störungen des Sedimentes zu erholen, was in erster Linie vom

Ausmaß der Störung abhängt. Die vorliegende Untersuchung wurde unter anderem mit der Absicht durchgeführt Erkenntnisse über das Erholungsvermögen der Meiofaunagemeinschaften nach Störungen durch den Abbau der Erzknollen zu gewinnen. Dazu wurde die Meiofaunagemeinschaft einer 26 Jahre alten Abbauspur mit der Gemeinschaft im unberührten Sediment außerhalb dieser Abbauspur verglichen. Die Probenahme mit einem 20cm x 9cm großen Kastengreifer wurde im östli-chen Teil des französischen Abbaugebietes der Clarion-Clipperton Fracture Zone unter Zuhilfenahme des ROV „Nautile“ durchgeführt. Die beprobten Abbauspuren auf dem Boden der Tiefsee sind 1,5m breit und haben eine Tiefe von 10cm. Sie sind die Überreste von Erzknollen Sammelmaßnahmen, die im Jahr 1978 probehalber durch-geführt wurden.

Die mittleren Abundanzen wurden mit dem T – Test verglichen. Die in der Analyse verwendeten Diversitätsindizes sind der Shannon Index (H’) für die Diversität, die Evenness (J) nach Pielou und der Simpson Index (1-λ) zur Bestimmung der Domi-nanz. Des weiteren wurde eine multivariate Similaritätsanalyse basierend auf der Bray – Curtis – Index in triangulären Matrizen zum Vergleich der unterschiedlichen Gebiete durchgeführt, in welche die Abundanzen, die Gemeinschaftsstruktur etc. einbezogen wurden.

Die Ergebnisse zeigen, dass die Meiofaunagemeinschaften in diesem Gebiet ähnlich denen in anderen Regionen der Tiefsee zusammengesetzt sind. Die Nematoden sind das dominierende Taxon, gefolgt von den Copepoden, während alle anderen Taxa eher selten gefunden wurden. Die mittlere Individuendichte der Meiofauna beträgt innerhalb der Abbauspuren 55,35 Ind./10cm² und außerhalb der Spuren beträgt sie 42,32 Ind./10cm². Diese Werte entsprechen den Angaben, die von anderen Autoren für Erzknollenareale ermittelt wurden.

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Erklärung

Hiermit bestätige ich, dass ich die vorliegende Dissertation selbständig verfasst und keine anderen als die angegebenen Quellen und Hilfsmittel verwandt habe.

Oldenburg, June 2009

Radith Mahatma