

**MEIOFAUNA AND NEMATODE COMMUNITY ASSEMBLAGE AS AN INDICATOR
OF SEDIMENT DISTURBANCE; A CASE STUDY OF MIDA CREEK, KENYA**

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156/80244/2015

B.Sc (Environmental Conservation and Natural Resource Management)

**A project dissertation submitted to the School of Biological Sciences in partial fulfillment of
the requirement for the degree of M.Sc. in Marine Biodiversity Conservation and Fisheries
Management**

UNIVERSITY OF NAIROBI

December 2019

DECLARATION

I MATTHEWS WAFULA, declare that this dissertation is my original work and it has not been presented for a degree in any other university.

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DEDICATION

My dissertation is dedicated to my Family; dad, mum, Sisters, Brothers, Nephews, and Niece for their continuous push and support that gave me the extra drive to successfully complete this project.

ACKNOWLEDGEMENTS

I give honor and glory to God for the guidance, care, and patience through my work from the start, to the end. He is a faithful God. I wish to give special thanks to my Supervisors Prof. A. Muthumbi and Dr. V. Wang'ondur. They are special people who are dedicated to their work whole heartedly. I am indebted to them for they never got tired spending long hours with me to see that this work is a success. May God's blessings rein upon them. I also take this opportunity to thank my dedicated lecturers Dr. D. Sigana, Prof N. Gichuki, Dr. C. Gatune, Dr. A. Muohi, and Dr. J. Odhiambo

My special acknowledgement also goes to my classmate Julia Akinyi and Said Hashim. They played a major role in bench marking with their work enabling me to finalize my work too. May God bless and protect her abundantly and grant her success in her work.

I also want to thank the School of Biological Sciences and the entire staff including all the laboratory technicians for their dedicated time and marvelous opportunity I had with them during my studies.

I also thank my dad Prof B. Wanjala for his great support by providing both financial and moral support through my entire course. May the Almighty God protect and guide him through. I wish him God's blessings and good health. I thank my mum Mrs. B. Wafula for her dedicated day to day prayers and encouragement always reminding me how I am going to make it. I also thank my sisters J. Kavata, and C. Wafula, brothers Jimmy and Wilson and friends for their support.

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LIST OF ABBREVIATIONS AND ACRONYMS

cm:	Centimeter
De grise 1:	(99 parts formaline {4% } + 1 part glycerine) solution
De grise 2:	(95 parts ethanol {96% } + 5 part glycerine) solution
De grise 3:	(50 parts ethanol {96% } + 50 part glycerine) solution
G.o.K:	Government of Kenya
IUCN:	International Union for Conservation of Nature
MDS:	Multidimensional Scale
MgSO₄:	Magnesium Sulphate
RPM:	Revolutions per minute
S.O.M	Sediment organic matter
UNEP:	United Nations Environmental Programme

ABSTRACT

Meiofauna is a group of the benthic fauna mostly found in the upper centimeters (cm) of the sediments. They included: copepoda, polychaeta, nematoda among other taxa playing an important role to the environment despite their small size. Their roles are to initiate mineralization of organic matter, support the complex marine food web and many other functions. The meiofauna is however affected by environmental changes and human activities though we cannot tell the extent until we investigate on their distribution, community assemblage, diversity and abundance.

This study was part of a bigger project carried out in Kirepwe, Dabaso, and Mayonda within Mida Creek, Kenya investigating the impact of bait harvesting on benthic invertebrates sampled during the wet season: November, 2013. My study focused entirely on determining the potential of nematodes as bio-indicator of sediments disturbance caused by bait harvesting. This was because bait harvesting was common albeit with different intensity in the different beaches of Mida Creek. Sediments samples were collected along two transect within the mud flat running from the mangrove forest edge to the edge of the subtidal zone. Along the transects, 1m² quadrats were placed at intervals of 20m. A replicate of 2 sediments core (3.4cm diameter, 10cm deep) were taken from each quadrat. Samples were fixed using 5% formalin, stored in plastic bottles and transported to the laboratory for processing and identification. The nematodes were used because they bring out a clear difference in their distribution, community assemblage, diversity and abundance due to sediment disturbance as compared to meiofauna. Out of the total meiofauna, a total of 3988 individual nematodes were identified to the genus level. In addition, out of all other meiofauna taxa, nematoda was the most abundant taxon.

Bait harvesting through digging was more pronounced in Mayonda due to its wider mud flat width. From the result, a clear difference in the distribution, diversity and community assemblage of the nematodes was seen in all the sites. A total of 83 nematode genera were encountered. Kirepwe had 58 genera, Dabaso 46 and Mayonda 35. Mayonda had the highest nematode diversity followed by Kirepwe, and finally Dabaso. On the other hand, Dabaso had the highest nematode density, followed by Mayonda and Kirepwe. Meiofauna had a high community similarity while nematode community similarity was lower at different levels of sediment disturbances. This makes the nematodes better bio-indicators as compared to meiofauna as a group. This study therefore points out that digging out of polychaetes causes sediment disturbance. The disturbance affects the

benthic fauna distribution, community assemblage, diversity and abundance. In the study, *Terschellingia* and *Spirinia* were distributed across all the sites although in disturbed quadrats, the numbers reduced significantly. On the other hand, *Viscosia*, *Pontonema*, *Synochium*, *Haliplectus*, and *Pheronus* increased in numbers in disturbed quadrats. Measures such as educating the fishermen on the effects of digging of polychaete should be emphasized to safe guard the marine biodiversity and its ecosystem.

KEY WORDS: Meiofauna, Polychaete, Nematode, Bait, Sediments disturbance.

CHAPTER ONE

1 INTRODUCTION

1.1 Benthic Community

Benthic communities are organisms living in and /or on the sediments of oceans, lakes and rivers also referred to as benthos (Graf, 1989). They include both flora and fauna (Graf, 1989). Benthic endofauna is divided two: infauna - those living in the sediments and the epifauna - those living on the sediments (Fredrik *et al.*, 2011). Both benthic infauna and epifauna can be classified further into microfauna, meiofauna, macrofauna, and megafauna. Microfauna are organisms that are less than 32 μm while meiofauna range between 32 μm and 1000 μm in size. The macrofauna range in size between 500 μm and 2mm (Eggleston *et al.*, 1999) while megafauna are organisms larger than 2mm in size (Lalli and Persons, 1997; Johnson and Michael, 2009). Sometimes juveniles of macrofauna can be classified as meiofauna whereas some mature adult microfauna can be classified as meiofauna too (Funch *et al.*, 2002).

In the marine ecosystem, the benthic communities are found from the highest intertidal levels to the deepest trenches making the sediment the second largest habitat on earth (Nascimento, 2010). Due to the difference in depth, the organisms found at different depth zones are affected differently by environmental factors such as light, pressure, salinity, temperature, prey and predators' interactions, organic matter, and sediment granulometry (John and Michael, 2009). For instance, shallow water benthic community are bigger and larger in size as compared to the deep water benthic community due to the high input of food in form of decomposed organic matter in the shallow waters as compared to the deep waters (Heip *et al.*, 1985; Van Gaever *et al.*, 1999; Van Gaever *et al.*, 2006). On the other hand, these shallow water benthic fauna that are found near the coastal zone are more prone to human interference as compared to deep communities (National Ocean and Atmospheric Administration Marine Debris Program, 2016). In understanding the benthic community, it is hard to generalise how these communities are structured because of the complexity of the soft aquatic bottom (Wilson 1990). Therefore, to understand the benthic community, the benthic invertebrates are determined by how individuals acquire nutrients. Most of the ocean bottoms are situated below the photic zone meaning they depend on organic matter

for food coming from the phytoplankton bloom (Graf 1989). Determination of organic matter therefore is an important factor in determination of the benthic community (Graf 1992).

1.2 Meiofauna

Meiofauna is a Greek word derived from meio and fauna with meio meaning smaller while fauna means animals therefore, meiofauna are very small animals found both in the fresh and saline ecosystems, tidal and intertidal zones, and in all kind of sediments whether soft or hard including rooted vegetation, sea ice animal structures among others (Finch *et al.*, 1998). Meiofauna include taxa like the nematoda, copepoda, polychaeta among others (Renaud-Debyser, 1963, Huling and Gray, 1971; Heggins and Hjalmar, 1988) and are mostly found in the upper centimeters (0 -50cm) of the sediments in abundance due to food availability, sediment type, and oxygen content (Gray, 1981).

Due to the semi-sessile nature of infauna and their close-association with sediments, benthic fauna, specifically the nematodes can be used as indicators of different parameters affecting the environment such as oxygen deficiency, salinity change, pollution, seabed disturbances among others hence referred to as bio-indicators (Finch *et al.*, 1998).

1.3 Biological indicators

A biological indicator is a function of the ecosystem's chemical, biological, or physical properties that is sufficiently correlated with an endpoint of concern to serve as a surrogate measure of that endpoint (Cairns *et al.*, 1993). A biological indicator can also be defined as a living organism that ecologists and environmentalists use to detect how healthy an ecosystem is when such organisms inhabit the area (Heink and Kowarik, 2010). Such organisms can be terrestrial, marine, or fresh water organisms depending on the ecosystem of interest. For example, different lichen species can be used to determine the quality of air. Dragon fly and water beetles can be used to tell the water quality in an area (Arndt, 2005). Earth worms are also used to determine soil quality (Heink and Kowarik, 2010). In the marine environment, nematoda as a taxon of meiofauna have the potential to be used as bio-indicators.

1.4 Problem statement

Benthic fauna is affected by both environmental and human factors (Finch *et al.*, 1998). At Mida Creek, Kenya, harvesting of polychaetes for bait by the local fisherfolk is steadily on the rise. Harvesting the polychaetes involves digging and churning of the sediments while looking for the large ones. Thus, this is likely to interfere with the sediments and other benthic fauna. So far, no study has been done and documented on the same at Mida Creek. By using the nematode genera vis-à-vis the meiofauna, I will be able to tell whether nematodes are good bio-indicators of sediment disturbance. This study therefore, will report on the distribution, diversity, densities and the community assemblage for both meiofauna and the nematode.

1.5 Project Justification

The most common baits used for fishing by local fishermen around Mida Creek are the hermit crabs, gastropods, and polychaetes (choo). However, they prefer the polychaetes over the hermit crabs and other gastropod. This is because the polychaetes are easily captured causing the sediment disturbances. Several studies have been conducted in the assessment of sediment disturbances, heavy metal contamination, oil and petroleum spillage among others. However, the use of nematodes as bio-indicators can be an alternative method. This alternative method can be used in testing and assessment of contamination due to heavy metal, oil spillage and sediment disturbance. Therefore, this study finding can be used to show that nematodes can be used as bio-indicators as an alternative method of assessment of sediment disturbances. This is because use of nematodes as bio-indicators is cost effective as compared to the different available chemical methods.

1.6 Objectives

1.6.1 Broad objective

To assess the potential value of meiofauna and the nematode community assemblages as indicator of sediment disturbance following polychaete harvesting at Mida Creek, Kenya.

1.6.2 Specific objectives

1. To determine the distribution, of the nematodes genera due to sediment disturbance at Mida creek, Kenya.

2. To determine the diversity of meiofauna and nematodes genera due to sediment disturbance at Mida creek, Kenya.
3. To determine the community assemblage of meiofauna and nematodes genera due to sediment disturbance at Mida creek, Kenya.

1.7 Research Hypothesis

H₀ Digging for polychaetes does not affect the distribution, abundance, densities, and the diversity of meiofauna and nematode community at Mida Creek, Kenya.

H₁ Digging for polychaetes affects the distribution, abundance, densities, and the diversity of meiofauna and nematode community at Mida Creek, Kenya.

CHAPTER TWO

2 LITERATURE REVIEW

2.1 Factors affecting marine meiofauna

Meiofauna play a vital role in the environment around them including; They form part of the simple food chain to the complex food web, and decomposition of organic matter among others (Chinnadurai *et al.*, 2003). There are however, several factors affecting their distribution, abundance, and diversity. For example; Organic matter is needed by meiofauna as food and for secondary production (Arntz *et al.*, 1994). This means that organic matter is critical when it comes to distribution of meiofauna communities (Chinnadurai *et al.*, 2003; Ansari *et al.*, 2012).

Furthermore, organic matter is positively correlated with pH and chlorophyll *a*, and negatively correlated to salinity and depth (Bonaglia *et al.*, 2014; Maciejewska and Pempkowiak, 2015). Increase of sediment organic matter causes a drop in the pH. This is because of the release of weak carbonic acid through complex chemical reactions and anoxic conditions related to decomposition (Bonaglia *et al.*, 2014; Maciejewska and Pempkowiak, 2015). On the other hand, an increase of the sediment organic matter causes an increase of chlorophyll *a*, in the deep depth of the ocean. This is made possible because organic matter during its mineralization, carbon is released and this plays an important role in the formation of chlorophyll *a* in the deep ocean (Bonaglia *et al.*, 2014; Maciejewska and Pempkowiak, 2015).

Organic matter in excess can result to a reduction of species abundance, richness and biomass. This is because of a reduction in oxygen concentration and accumulation of toxic by-products (sulphides and ammonia) which are heavily associated with decomposition of organic material (Chinnadurai *et al.*, 2003). However, organic matter is influenced by grain sizes found in an area. Areas with greater proportion of finer particles tend to have a greater percentage of organic matter (Secieru and Oaie, 2009). Other factors affecting meiofauna include, source of the organic matter, and biotic activities such as respiration, excretion, decomposition, and organic matter transportation (Maciejewska and Pempkowiak, 2015).

Grain size is therefore a major factor affecting the meiofauna. The phi scale is a sediment grain size measurement. Grain sizes more than 1mm are considered as very course sand and the smallest grain which are less than 63 μ m are considered as silt (Krumbein, 1937). Sediment composition

influencing the abundance and the nature of food for meiofauna thus influences the meiofauna composition (Santos and Pires-Vanin, 2004). The composition of meiobenthos from the shelf region off west coast India suggested that harpacticoid – copepods may dominate areas with coarser sand, while nematodes are found across all the sediment sizes (Sajan and Damodaran, 2007). Carnivorous polychaetes prefer areas with coarse sediment due to the large interstices that create space enhancing aeration and mobility of the polychaetes (Santos and Pires-Vanin, 2004). Grain size composition is also important in the recovery of meiofauna communities after natural perturbation where muddy conditions provide the best environment for recovery of meiofauna (Harris, 2012).

In bait digging, tide and wave action causes a continuous churning of the sediments. This causes the exposure of the meiofauna to predators and other harmful environmental factors (McLusky and Anderson, 1981; Anderson and Meyer, 1986; Farrell, 1998). The tide and wave actions tend to transfer the loose sediments, and winnowing of particles to other areas. This may cause both a quick or late recovery of the different meiofauna species depending on how backfilling of the already dug hole is taking place. This may either occur naturally or through human activities such as bait digging (McLusky *et al.*, 1983). McLusky *et al.*, (1983) suggested that recovery of the meiofauna in dug holes is faster. This happens when the holes are backfilled immediately due to weak wave action compared to when it is strong and violent.

Furthermore, at the temperate latitude we expect to find more of the amphipods and isopods which are nocturnal feeders. The tropical sandy beaches areas are mostly inhabited by the ghost crabs which are scavengers (Hagerman *et al.*, 1981). Detritus are mostly washed onshore most of the time. For the case of wave action (due to rotation of the earth and gravitational pull of the moon towards the earth), this will affect water velocity of the oceans and seas. If the water velocity decreases due to weaker wave action, we expect more of settlement of particles to settle. In turn, this will favour colonization of and settlement of meiofauna (Hagerman *et al.*, 1981). This is a clear indication that not environmental condition will impact on the distribution, diversity and abundance of meiofauna but all other factors beyond human activities like wave action, difference in latitude and wave action will differently affect the distribution, diversity and abundance of both flora and fauna living in the intertidal zone (John and Michael 2009). Areas where settlement of

organic and inorganic material occurs as a result of reduced wave action appears to favour settlement of meiofauna due to presence of enough food (Hagerman *et al.*, 1981).

Human activities such as increased fishing pressure, boating activity, tourism, oil exploration, population increase, construction and expansion of ports at the coast line has led to the demand increase for different ocean resources. Such resources include land and fisheries resources which cause an increase in the ocean and sea pollution. This has led to poor conservation and management practices of the ocean and its resources (Hagerman *et al.*, 1981).

Just to mention, population increase according to a report by UNEP, (2006) is expected increase further which is usually observed. This is because of improved health systems, good infrastructure, enough food, and economic development in coastal areas. This increases the chances of marine pollution through runoffs from agricultural practices and products (fertilizers and silt) into the ocean (Snelgrove, 1999) and discharge of domestic sewage. Agricultural runoff and sewage have high amounts of Compound Nitrogen. Nitrogen is a limiting nutrient in the open ocean and increased nitrogen levels automatically increases primary production. This results in increased deposition of organic matter in the benthic zone of the continental shelf resulting in either an increase in benthic standing crop or reduced oxygen levels (hypoxia) in the sediments if deposition exceeds food requirement by the benthos (Voss, 2011). Hypoxia results in low diversity by limiting the abundance of intolerant species at the same time it increases dominance and also leads to a reduction in body size of the benthos. This results in altered trophic structure and energy flow pathways and subsequently affecting the ecosystem services (Levin *et al.*, 2009).

Other factors that affect meiofauna distribution such as digging for bait (McLusky and Anderson, 1981; Anderson and Meyer, 1986; Farrell, 1998) loosens the sediments. It is believed that digging of bait causes much of sediment disturbance that and cause benthic fauna to either migrate away or into the area, or die. At Mayonda, the digging of bait is as shown in below with the collected big polychaete (Figure 1a and 1b).



Figure 1:(1a) Fisherfolk digging out polychaetes;(1b) harvested polychaetes at Mayonda site, Mida Creek-Kenya.

Bait digging to some extent causes a change in chemical composition of sediments. This can be associated with the slow back filling of the accumulation of organic materials such as drifted sea weeds, sea grasses and fine sediments from suspension. This causes the formation of a soft, organically enriched and anoxic layer at the basin bottom holding water permanently that alters the chemical composition of the sediments due to the decomposition processes by either increasing or reducing the pH value (Howell, 1985). Howell, (1985) also recorded during his study that an increase of heavy metal levels following intensive bait harvesting in Budle bay where 50 bait harvesters were estimated to overturn 62.5 metric tons of sediments containing 40g of cadmium and 3kgs of lead on each tide. Exposure and oxidisation of deep sediment particles enabled the heavy metals bound to sediment particles in reduced conditions to become bioavailable.

Bait harvesting affect the marine birds by interfering with their perching, roosting (Evans *et al.*, 1993) and feeding at the shores. This is because bait harvesting digging grounds remain flooded with water even during low tide. Additionally, presence of humans will scare them away because birds naturally are creatures get frightened especially when it comes to human presence (Davidson and Rothwell, 1993).

Bait harvesting also changes the sediment stratigraphy greatly (Davis *et al.*, 2001). In undisturbed areas, bioturbation of sediments, by feeding of the lugworm produces a layer of at least 10cm deep

of well-mixed sand that overlies a bed of stone or shell. Below that, anoxic sediments may persist which also have contaminants. The contaminants may be exposed during bait harvesting which are exposed to tide and wave action and are quickly oxidised releasing pollutants (Davis *et al.*, 2001).

Social environmental conditions like increased population around the coast has led to an increase in demand for different resources such as land, mangrove tress (used for construction, medication, wood fuel among others), fish, coral used as blocks in the construction industry that has led to the increased pressure to the ocean and its resources. The need for fishery resource that has been declining over the years including fishing bait has led to the increase of digging out of baits such as the polychaetes to be used for fishing (Howell, 1985).

Marine pollutants such petroleum and hydrocarbons, plastics, thermal effluents, pesticides like DDT, tributyl tin and untreated sewage have also increased over time due to the ever increasing population. Currently, plastics is one of the major ocean pollutant that has impacted not only the distribution, diversity and assemblage of meiofauna but also other marine organisms (John and Michael 2009). This is seen by the deaths of marine organisms such as the sperm whales, dolphins, sea turtles among others in large numbers.

2.2 Role of marine meiofauna

Meiofauna plays various roles in the environment, such as being part of simple food chains to complex food webs despite their small size. Meiofauna not only are fed upon by commercial fishes (flat fishes) (Kennedy and Jacoby, 1999). In addition, the bottom feeding juveniles of fish feed primarily on benthic harpacticoid copepods. This is because they harpacticoid copepods are rich nutritionally to different fishes and animals (Gee 1989; Coull 1990; Feller & Coull 1995). They also feed on diatoms, and detritus and considered primary consumers of micro-algae and tertiary consumers of small metazoans (Carriço *et al.*, 2013). On the other hand, meiofauna are food to the commercial flat fishes and the macrofauna (Kennedy and Jacoby, 1999) and thus important in sustaining food webs.

The benthic fauna both meiofauna and macrofauna plays another vital role in global biogeochemical cycle by influencing how much carbon is sequestered into the geosphere (Cappellen, 2003) and remineralisation of nutrient back into the water column promoting primary

production (Webb and Montagna 1993). Benthic fauna depends on the organic matter from phytoplankton for their food. The phytoplankton material is remineralised back to the water column through microbial decomposition and metazoan grazing and respiration, or permanently buried in the sediments (Sellner 1997). Therefore, animals living in soft sediments have a vital role in the biogeochemical cycles by influencing how much carbon is sequestered into the geosphere (Van Cappellen 2003). Meiofauna take part in the decomposition of organic matter and nutrient cycling too by grazing on the bacteria that decompose organic matter and maintaining the bacteria population at the exponential growth phase (Freckman, 1997). The bacterial feeding nematodes help in dispersing microbes in the water and sediment (Freckman, 1997). They feed on saprophytic and plant pathogenic bacteria influencing composition of the microbial community (Freckman, 1997).

Meiofauna influences the structure of sediments creating a link between the water column, surface and sediment depth (John and Michael, 2009). This is termed as benthic-pelagic coupling (Lalli and Persons, 1997). The interaction between water surface, water column, and sediments is enhanced when the meiofauna burrows within and through the sediments. This allows not only for the penetration of water into the sediments but also dissolution of gases promoting existence of life. Furthermore, benthic communities receive limited food in the better part of the year (Rudnick 1989). Hence, the settling of organic matter affects greatly the dynamics of the population and their metabolism (Elmgren 1978; Graf 1992; Gullberg *et al.*, 1997) and quite a number of assemblages of the benthic species exhibit life history characteristics adapted to seasonal inputs of settling organic matter (Boon 1998 and Olafsson and Elmgren 1997). Therefore, this benthic-pelagic coupling helps in the settlement of organic matter otherwise known as ocean snow that is mineralized by bacterial action and ultimately affects the metabolism and population dynamics of benthic communities (Nascimento *et al.*, 2010).

Meiofauna also can be used to detect estuarine pollution. Most pollutants upon entering the estuarine inform of suspension or solution bind with the different proportion of grain size mostly silt and clay and together with organic particulate are bedded (Kennedy 1984). This is because the affinity of contaminants to sediments is directly proportion to the contaminant hydrophobicity and the sediment organic matter content causing the accumulation of the contaminants in the muddy sediments (McCarthy & Jimenez 1985 and DiToro *et al.*, 1991). Meiofauna interact with the

muddy sediment. (Coull & Chandler 1990) documented that contaminants such as tributyltin find their way into the meiofauna in the aqueous phase. This is also transferred to fish when such fish feed on the meiofauna such as copepods. In Addition, (Marshall & Coull 1996) during their study indicated that fish would avoid eating meiofauna in contaminated sediments. Therefore, from these studies, meiofauna such as copepods can be used to easily detect any contaminants like tributyltin in an estuary.

Meiofauna also can be used to assess the impact of fish farming. When aquaculture is practiced in sea cages, there is a continuous flow of waste including the faecal matter and uneaten pellets that increases organic matter (Mirto *et al.*, 2013). This in turn alter the quantity and the biochemical conditions of the sediments. This will then cause anoxic effects that can be assessed by the help of studying the meiofauna species richness, diversity and abundance (Mirto *et al.*, 2013). The distribution, abundance and diversity of the meiofaunal species in an undisturbed intertidal zone is expected to be high. This is due to the high productivity experienced in this zone due to the availability of high nutrient content for primary producers, other species consumers, organic litter fall from the primary consumers, mangrove and the decomposers (Castro *et al.*, 2008). The organic matter on the other hand, favors enrichment of the sediment which causes a reduction of the meiofaunal abundance (Grego *et al.*, 2009; La Rosa *et al.*, 2001; Mazzola *et al.*, 1999, 2000; Mirto *et al.*, 2000). On the long run, the anoxic effects that can be assessed by the help of studying the meiofauna species richness, diversity and abundance (Mirto *et al.*, 2013).

In addition, continental shelf benthic fauna maintenance of life support processes such as energy flow to higher trophic level, storage of materials, nutrients and degradation of pollutants (Nascimento, 2010; Hyland 2005). They provide a major linkage between primary producers and higher trophic levels since most of the photo-synthetically produced organic matter is lost into greater depths where it initiates microbial and benthic faunal activities (Pratihary *et al.*, 2014; Rowe & Kennicutt, 2001).

2.3 Role of Marine Nematodes as bio-indicators

Nematodes play an important role in the environment. They are the most suitable bio-indicators in the meiofaunal community because they are among the most abundant metazoan organisms that occur in the environment. They do not migrate from stressful conditions, such as oxygen stress

and dehydration (Yingst, 1985; Fleegeer *et al.*, 1995; Vanreusel *et al.*, 1995). They have a permeable cuticle providing a direct contact with their microenvironment, enabling them to closely interact with the environment (Yingst, 1985; Fleegeer *et al.*, 1995; Vanreusel *et al.*, 1995 & Carriço *et al.*, 2013). They penetrate deep into the sediments (Yingst, 1985; Fleegeer *et al.*, 1995; Vanreusel *et al.*, 1995) depending on availability of food. Nematodes also spread out through ocean sediments (Carriço *et al.*, 2013) making them sensitive to any change in their environment (Kennedy and Jacoby, 1999) such as dredge disposal (Carriço *et al.*, 2013). Nematode feeding habits can be easily deduced from the structure of the buccal cavity and the pharynx giving them the ability to occupy key position in the food webs (Bongers and Ferris, 1999). The nematodes too have a very short life cycle, of between one and three months with a direct development stage hence changes in the community structure can easily be observed (Lui, 2009) thus relaying information on substrate disturbances such as pollution, sediment disturbance due to bottom trawling or mining among other human activities.

In a study by Girish *et al.*, (2002), it was discovered that nematodes can be used as a tool to assess the quality of water through their faunal composition to monitor functions of ecosystem and conditions of the environment. The parasitic copepods, acanthocephalan and larval of nematodes dominated in the parasitic indicator role. But the parasitic host relationships involving adult nematodes have been rarely reported (Girish *et al.*, 2002).

Nematodes genera assemblages have been used to detect crude oil (Van Gestel *et al.*, 2001) and diesel pollution (Carman *et al.*, 1997 and Fleegeer *et al.*, 2006). During the study, *Marylynnia* was the only genera to be found to tolerate such kind of pollution and increase in number. *Marylynnia* at such environment is termed as an “opportunistic” species. (Zhang *et al.*, 2011). Nematode too can be used to detect seabed disturbances. Such species will include *Pheronus*, *Viscosia* and *Synochium* due to their opportunistic nature to take over in areas where sediment disturbance has heavily occurred (Sharman and Coull, 1980; Schratzberger and Warwick, 1999). Nematode can be used to detect heavy metal pollution (Mutwakil *et al.*, 1997; Moens *et al.*, 2014). Heavy metal pollution such as Arsenic, Cadmium, Chromium, Mercury, Zinc, Copper, and Lead has been shown to affect nematode community structure and ecological indices. Pollution effects on the structure of the community of nematodes was found to be high near the source of pollution but very low at the source (Mutwakil *et al.*, 1997; Moens *et al.*, 2014). This was enough proof and

evidence that free-living nematodes are useful tools of bio-indicator of contamination. This can be an alternative method to test contamination of heavy metal rather than using chemical method which is relatively costly.

Nematodes genera like the *Desmodoridae* are capable of respiratory reduction of nitrate to nitrite (Hentschel *et al.*, 1999) therefore they can be used to indicate where sediment is exposed to more of nitrate and sulphide. In addition, the *Oncholaimus*, a marine nematode, is adapted to surviving in acidic sediments due to the development of polysulfur chains in the epidermis (Thiermann *et al.*, 2000). This is made possible by assessing both species diversity and trophic diversity (Olafsson *et al.*, 1995; Schirijvers *et al.*, 1997; Netto *et al.*, 1999). Another method of assessment is by using the maturity index (Raffaeli and Mason, 1981). However, Nematode response to disturbance vary differently among species but following the nematode assemblage rule, nematodes are affected by the kind of disturbance that they do not experience naturally (Schratzberger and Warwick, 1999). Such monitoring is important for decision making with respect to the risk caused by different human activities to the benthic fauna (Fisher *et al.*, 2001).

CHAPTER THREE

3 MATERIALS AND METHODS

3.1 Description of the study area

The Kenyan coastline is approximately 536 km long bordering the countries of Somalia and Tanzania to the north and south respectively (Ochieng & Erfemeijer 2003 and UNEP 2009). Towards the North of Mombasa, about 111km, exists the 32km² Mida creek that stretches inland from the Indian Ocean into the Arabuko Sokoke Forest along the Kenyan coastline. It is a broad water tidal creek that is lined with palm trees surrounded by mangrove forest that support about 500 species of birds, different species of crabs, and monkeys (Kennedy, 1990; Dahdouh-Guebas *et al.*, 1999; Kairo *et al.*, 2002; IUCN, 2015) with which the three sampling sites are within the Mida Creek.

Mida Creek is an important conservation site because of the ecological and economic importance it provides to the community living around the area and the country as a whole. The areas support the local communities around by providing food through fishing activities that go on in the area which supplement their daily diet, and help the local earn a living from selling the resources obtained from the ocean (Kennedy, 1990; Dahdouh-Guebas *et al.*, 2000; Kairo *et al.*, 2002 and IUCN, 2015). The mangrove forest help in provision of building material for their homes, leaves and backs act as medicine, fuel wood among other forest resources. In addition, the forest act as a buffer zone between the ocean and the terrestrial region protecting the coastline being hit had with destructive waves and protecting the ocean from silt and other terrestrial materials which may cause coral bleaching from entering the ocean. (Kennedy, 1990). Due to presence of the mangrove forest, the creek is a great spawning site for different fishes including the flat fishes. This is because such areas provide physical protection and food to such fingerlings before they grow to a size that is best for them to migrate to the deep waters of the ocean (Kennedy, 1990; Dahdouh-Guebas *et al.*, 2000 and Kairo *et al.*, 2002) The creek also helps the locals improve their livelihoods through the revenue earned from tourist visiting the area due to its rich biodiversity, wonderful beach, experiencing the local boat rides and warm coastal temperatures (G.o.K, 2013).

At Mida Creek, harvesting of polychaetes happens everywhere especially in all the three mud flat sites but at different intensity due to the width of the sites, from the land to the lowest tide of the

ocean. Three sampling sites within the creek were identified at Kirepwe (Kir), Dabaso (Dab) and Mayonda (May). Kirepwe (S03°27.28': E039°58.490') is an island in the creek, Dabaso is located on the eastern edge of the creek (S 15°03 20.53': E 039°59.23') and Mayonda to the west of the creek. (S03°19.274': E039°59.098') (Figure 2).

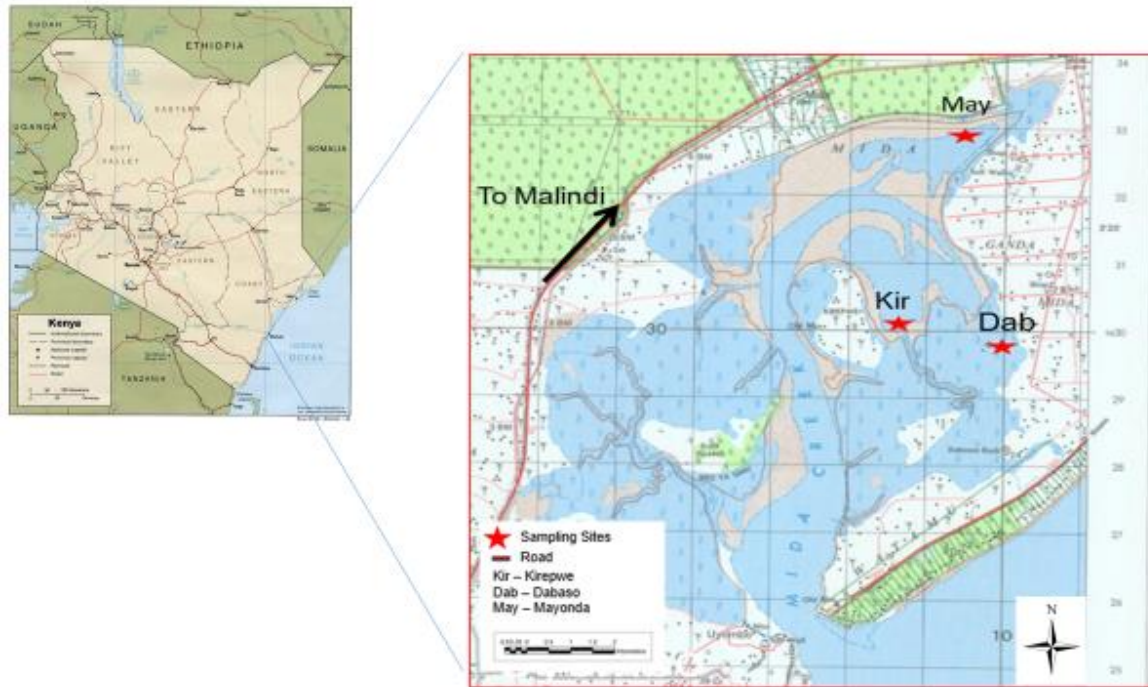


Figure 2: Map of Mida Creek, Kenya showing sampling sites

3.2 Sampling design

This study was part of a larger project that was investigating the impacts of bait harvesting on the benthic invertebrates in the mud flats in the Mida Creek, Kenya. From that study, sediment samples were collected for analysis of sediment organic matter, grain size, and meiofauna from the three sites (Kirepwe, Dabaso, and Mayonda).

At each site, two line transects located 200 m apart were identified within the intertidal zone (from the shoreline to the low water mark). Quadrats of 1m x 1m were laid out at 20m intervals along the line transect, with quadrats A and B being in the mangrove forest zone, quadrat C was at the edge of the forest while the rest of the quadrats D, E, F and G were in the mud flat. The number of quadrats identified along the transect length were dependent on the width of the intertidal zone where Kirepwe is had only 4 quadrats (QA, QB, QC and QD), Dabaso had 6 quadrats (QA, QB, QC, QD, QE, and QF) and Mayonda had 7 quadrats (QA, QB, QC, QD, QE, QF, and QG) (Figure 3).

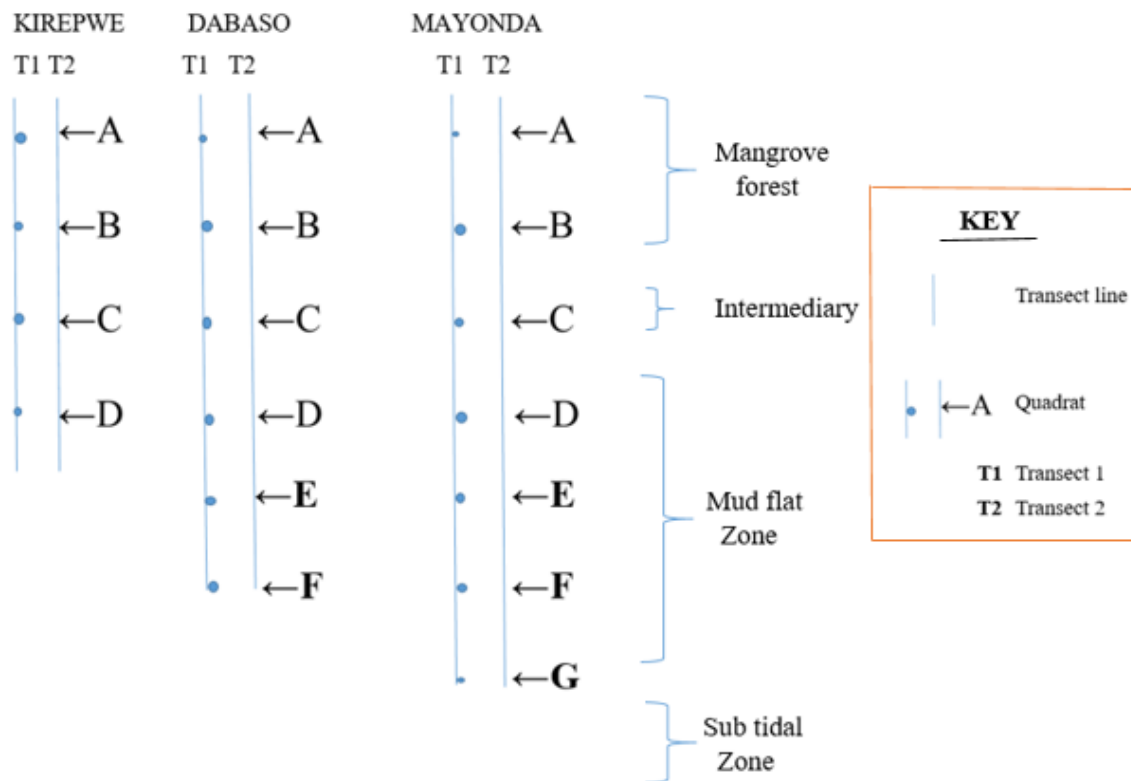


Figure 3: Sketch of the sampling design in relation to sites, transects and quadrats.

3.3 Sample collection

Two replicate sediment samples were collected from the mangrove forest edge (QC) towards the mudflat (QD, QE, QF, QG). A hand corer of 3.4 cm diameter was used to collect the sediment samples for analysis of meiofauna, grain size, and sediment organic matter up to a depth of 10cm. The samples for sediment organic matter analysis were placed in ziplock bags and carried in a cooler box and put in the freezer on arrival at the laboratory. Samples for sediment grain size analysis were carried in plastic bottles without preservation. The samples for meiofauna were immediately fixed in 5% formaldehyde solution for preservation and put in plastic bottles. All samples were well labelled with the date, site, transect and replicate and transported to the University of Nairobi hydrobiology laboratory for processing and analysis.

3.4 Laboratory analysis

3.4.1 Determination of sediment grain Size

In the laboratory a sub-sample of sediment was weighed and dried in the oven at 70°C until there was no change in weight. The dried block sample was then loosened gently not to tamper with the original sediment particles and sieved on different sieve sizes on a mechanical shaker {2.00mm to 63µm i.e. 2.00mm, 1.00mm, 0.5mm, 0.25mm, 0.125mm and 0.063mm (from ASTM D6913-04, 2009)}. The proportion of sediment collected on each of the sieves was weighed and calculated as a percentage of the total sample weight.

For this study, sediment grain size data from one transect (Transect 1) in each site (Kirepwe, Dabaso and Mayonda) was re-calculated. Quadrats QC and QD at Kirepwe, quadrat QC, QD, QE, and QF for Dabaso, and Mayonda quadrat QC, QD, QE, QF, and QG were considered because these were the quadrats considered for nematode identification.

3.4.2 Determination of sediment organic matter

Sediment samples were dried in the oven and weighed before ashing at 600°C using a muffle furnace for six hours. The difference between the dried weight and ash weight was calculated and expressed as percentage proportion of the total sediment weight to represent the sediment organic matter.

For this study, sediment organic matter data from one transect (Transect 1) in each site (Kirepwe, Dabaso and Mayonda) was re-calculated. Quadrats QC and QD at Kirepwe, quadrat QC, QD, QE, and QF for Dabaso, and Mayonda quadrat QC, QD, QE, QF, and QG were considered because this were the quadrats considered for nematode identification.

3.4.3 Meiofauna analysis

The sediment samples for meiofauna analysis were rinsed with normal tap water over 1mm sieve to exclude macrofauna and any other debris, and collected on a 38µm sieve. Magnesium Sulphate (MgSO₄) with a specific density of 1.28g/cm³ was used to wash the fraction retained on the 38µm sieve into a centrifugation tube. MgSO₄ was added to the three quarter mark of each of the centrifugation tubes with different samples and balanced. The samples were centrifuged 3 times for 10 minutes at 6000 rpm. After each centrifugation, the supernatant was decanted onto a 38µm sieve, rinsed thoroughly with water and put back into well labelled sample bottles using water and 4% formaldehyde solution. 3 drops of Rose Bengal were added to the bottle and left overnight for staining before sorting. Before the analysis of meiofauna was done, the samples were washed through a 38µm sieve with tap water to remove traces of formaldehyde solution.

3.4.4 Enumeration of meiofauna

The sample was shaken well and a small amount was poured into a counting chamber (Counting dish) for enumeration. Using a dissecting microscope at magnification X100, the sample was observed from top left square across to the top right square. In the row below, observation from right to left side of the counting chamber to the end was done. This process was repeated until all samples were analysed. All the meiofauna organisms were picked, identified, enumerated, recorded, and put back in the sample bottles and kept safe in the laboratory.

3.4.5 Nematode analysis

For this study, meiofauna samples from only one transect (Transect 1) in each of the site (Kirepwe, Mayonda and Dabaso). Quadrats QC and QD at Kirepwe, quadrat QC, QD, QE, and QF for Dabaso, and Mayonda quadrat QC, QD, QE, QF, and QG were considered for nematode identification.

Two hundred nematodes were picked from each of the replicate samples and processed to make permanent slides. This was done first by picking the nematodes and placing them in embryo dishes containing De grise 1 (99 parts formaline {4% } + 1-part glycerine) solution while covering it with no time restrictions. In the evening the embryo dishes were uncovered and placed in a desiccator with ethanol in the lower chamber and placed in an oven set at 45°C overnight.

In the morning, the embryo dishes were removed from the desiccator; half covered and returned into the oven set at 45°C. Three drops of De grise 2 (95 parts ethanol {96% } + 5-part glycerine) solution were added using a dropper along the sides of the embryo dish. The process was repeated after every 2-3 hours. In the evening, De grise 3 (50 parts ethanol {96% } + 50-part glycerine) solution was added into the embryo dishes in the oven and set at 45°C overnight. This procedure was done to replace water in the nematode with glycerine. The next morning, the embryo dishes were removed from the oven and placed in another desiccator with blue copper (ii) sulphate crystals to dry the samples overnight. Slides and cover slips were placed in ethanol overnight to clean up any oils. The slides and cover slips were removed from ethanol the next morning and dried using a clean tissue paper.

3.5 Mounting of nematodes onto slides

Clean solid wax was placed in the glass petri dish and left in the oven overnight to liquefy after which it was allowed to solidify. A wax ring was made on the clean slide using a heated brass rod. A small droplet of pure glycerine was placed inside the wax ring using a needle. With a fine needle, at least ten nematodes of nearly same diameter were placed in the glycerine, one at a time ensuring that they did not lie on each other. A cover slip was placed on top of the slide ensuring that no air bubble was trapped in the glycerine. The slides with the nematodes were heated slowly by placing them at one end of a bridge while the burner heated the bridge from the other end until the wax melted slowly. The slides with nematodes were then removed from the bridge and left to cool and labelled appropriately depending on the sample from which the nematodes were picked from.

3.6 Nematode identification

Identification of the nematodes to the genus level was done under the stereo microscope. The immersion oil objective lens was used to watch each nematode and using the key by Platt and Warwick, (1988) and Warwick *et al.*, (1998) identification to the genus level was done. Several

characteristics were used to identify the different nematode genera including type of cuticle; either punctuated or annulated, the type of buccal cavity and size of teeth, reproductive systems, length and size of the nematode, and the tail form.

3.7 Data analysis

The data analysed was from Kirepwe T1: QC and QD, Dabaso T1: QC, QD, QE, and QF while Mayonda T1: QC, QD, QE, QF, and QG. Sediment organic matter and the sediment grain sizes were re-calculated. From the data, genus categories were identified and diversity, abundance, distribution, and densities were calculated and analysed. All the genera of nematodes encountered were tabulated on the MS EXCEL and analysed for relative abundance, and distribution. The multidimensional scaling (MDS) and TWINSpan for community analysis was done using PRIMER 5. The diversity indices, (Dominance, and Shannon diversity) were analysed using the PAST. Bar graphs were drawn using MS EXCEL and SPSS. Significance tests for sediment organic matter, densities, relative abundance, distribution, and diversity between the sites were done using MS EXCEL and PAST.

CHAPTER FOUR

4 RESULTS

4.1 Sediment organic matter (SOM) content

The percentage Sediment organic matter at Kirepwe was 4.1 ± 2.48 . The sediment organic matter percentage mean was highest at Dabaso (8.1 ± 7.01) while Mayonda had the least percentage mean of 2.6 ± 0.64 . One-way ANOVA indicated that sediment organic matter was not significantly different across the sites ($F= 4.00$; $df=2$; $P=0.13$). (Figure 4).

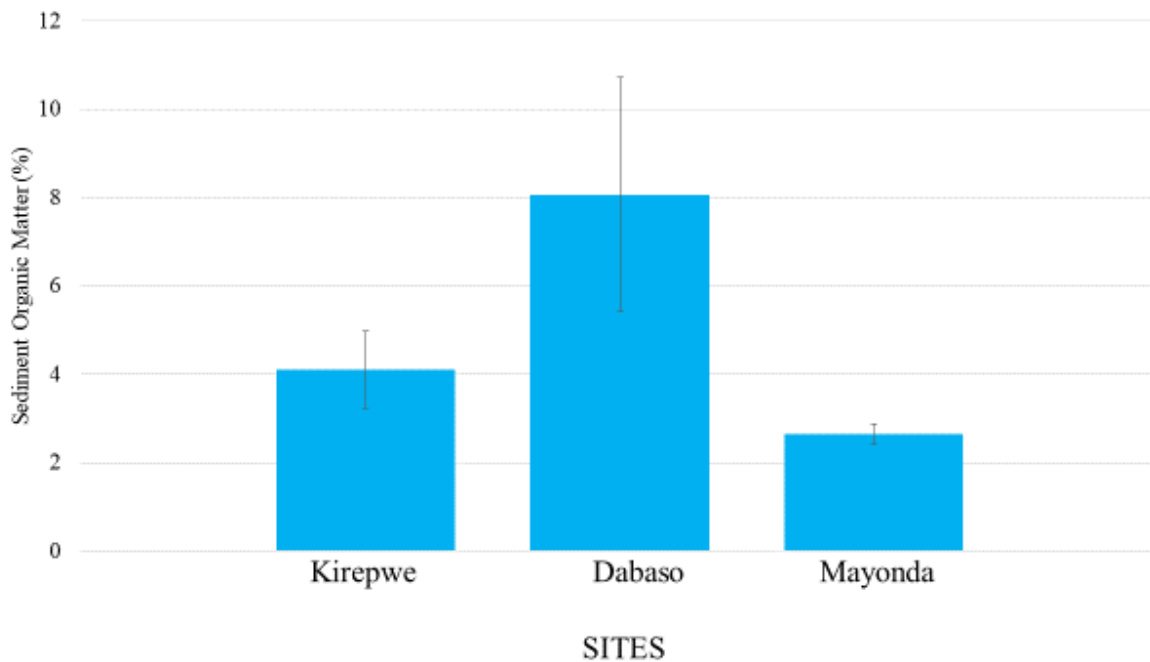


Figure 4: Sediment organic matter percentage mean in Kirepwe, Dabaso, and Mayonda. The error bars represent standard error.

4.2 Sediment grain size distribution

Silt was the least in mean proportion in all the sites. However, Kirepwe had a mean proportion of 4% making it the highest in silt while Dabaso had 3%. Mayonda had only 1%. One-way ANOVA indicated that silt had a significant difference across the sites. This played an important role in the results for meiofauna and nematode diversity, distribution and community assemblages ($F= 14.4$; $df=2$; $P=0.000156$).

Very Fine sand was second least across all the sites. Kirepwe had a mean proportion of 5% while Dabaso had 7% while Mayonda (2%) had the least mean proportion of very fine sand just like silt. The very fine sand also played a key role in the meiofauna and nematode diversity, distribution and community assemblages. However, one-way ANOVA indicated that very fine sand was not significantly different across the sites ($F= 0.69$; $df=2$; $P=0.513$).

Kirepwe had a mean proportion of Medium sand of 29% while Dabaso had the least mean proportion of medium sand of 22%. Mayonda had the highest mean proportion of medium sand of 34%. Medium sand plays an important role in the colonization of other meiofaunal taxa. One-way ANOVA indicated that medium sand was not significantly different across the sites ($F= 1.77$; $df=2$; $P=0.193$) (Figure 5).

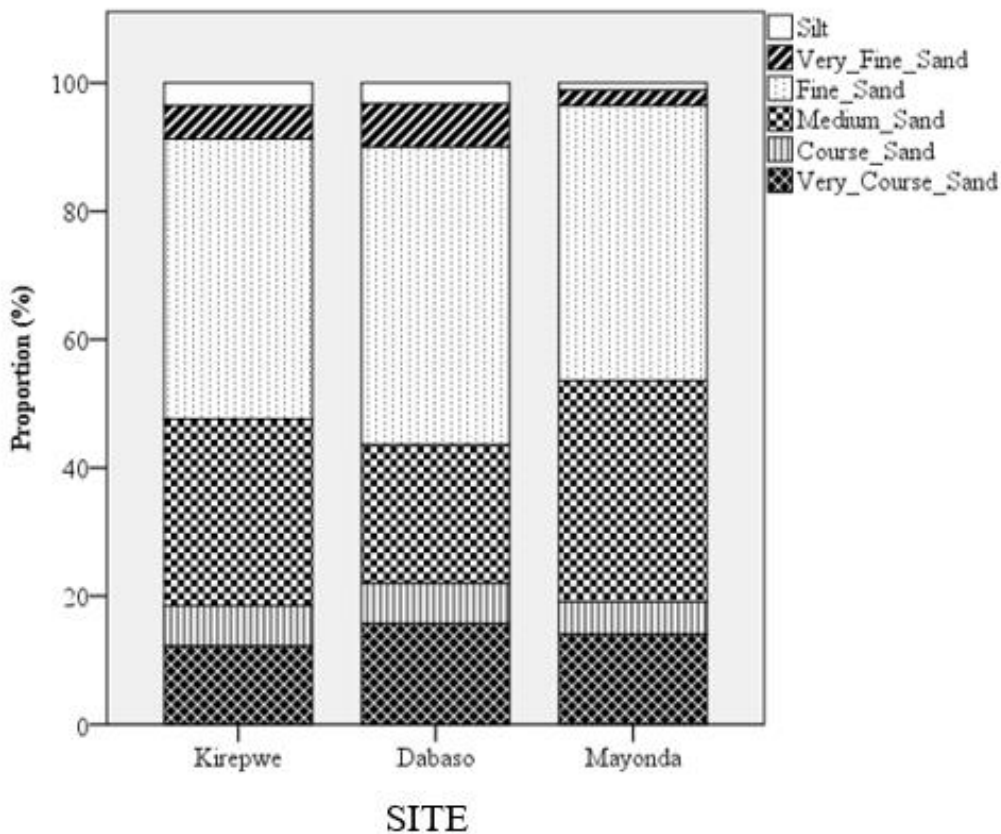


Figure 5: Sediment grain size mean proportion (%) at Kirepwe, Dabaso, and Mayonda

4.3 Meiofauna and nematode density

The mean density of meiofauna ranged between 1183 ± 613.7 - 1429 ± 492 individuals/ 10cm^2 . Mayonda had the lowest mean of meiofaunal densities of 1183 ± 613.7 individuals/ 10cm^2 , Dabaso had the highest meiofaunal density of 1429 ± 492 individuals/ 10cm^2 while Kirepwe's meiofaunal density was 1309 ± 220.9 individuals/ 10cm^2 (Figure 6).

Nematode density ranged between 734 ± 153.9 - 1042 ± 374.1 individuals/ 10cm^2 . Kirepwe had the lowest nematode density of 734 ± 153.9 individuals/ 10cm^2 while Mayonda had a medium density of 782 ± 385.1 individuals/ 10cm^2 . Dabaso had the highest nematode densities of 1042 ± 374.1 individuals/ 10cm^2 .

One-way ANOVA indicated that the mean meiofaunal and nematode densities did not differ significantly across the sites ($F= 0.09$; $df=2$, $P=0.91$) and ($F= 1.14$; $df=2$, $P=0.33$) respectively (Figure 6).

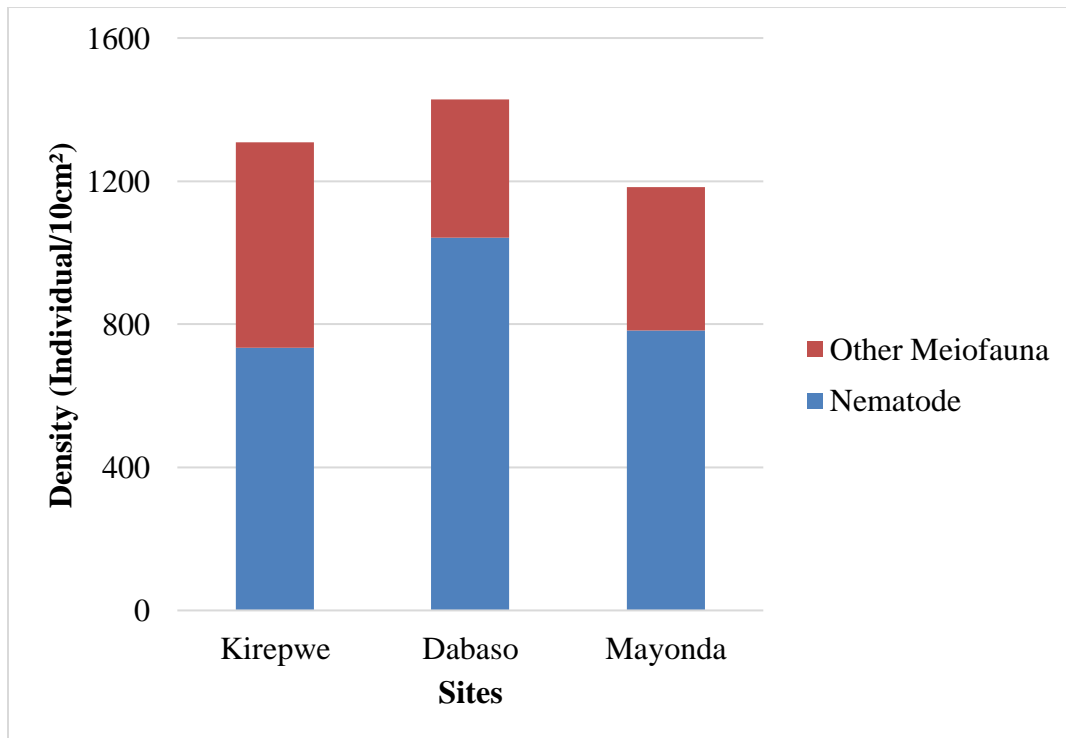


Figure 6: Other meiofauna and nematodes densities (individuals/ 10cm^2) at Kirepwe, Dabaso, and Mayonda.

4.4 Relative abundance of nematodes and the other meiofauna

A total of 12 taxa of meiofauna were observed in the three sites sampled with nematoda taxon being the highest in relative abundance across all the sites. The meiofauna taxa encountered included the nematoda, oligochaeta, isopoda, cladocera, amphipoda, gastrotricha, insecta, rotifera, polychaeta, thermobanaceae, and tardigrada. The nematode relative abundance was lowest at Kirepwe with 56% while the relative abundance of other meiofauna taxa against the nematode was the highest (44%). The highest nematode relative abundance was at Dabaso (71%) while the other meiofaunal relative abundance was the lowest (29%). Mayonda nematode relative abundance was 59% while the other meiofauna taxa relative abundance was 41%. One-way ANOVA indicated that the nematode abundance did not differ significantly across the sites ($F= 1.14$; $Df=2$, $P=0.33$) (Figure 7).

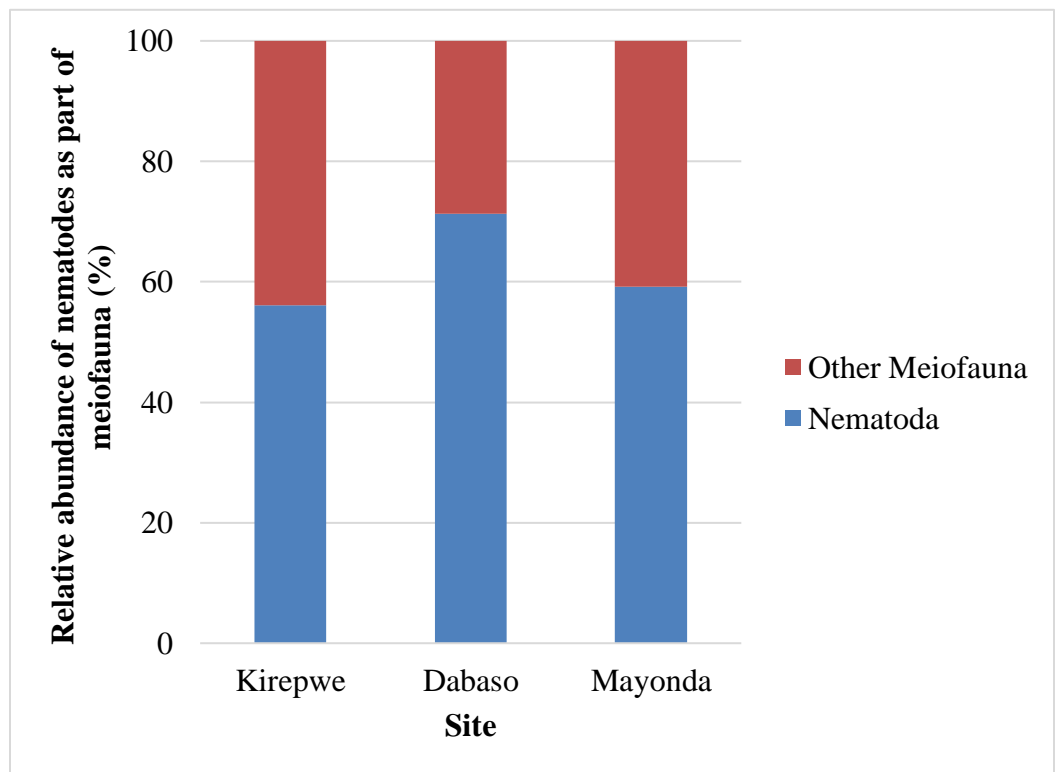


Figure 7: Relative abundance of nematodes and other meiofauna taxa (%) at Kirepwe, Dabaso, and Mayonda.

4.5 Distribution of nematode taxa

A total of 3985 individual nematodes from 83 genera were identified across the three sites, (Kirepwe, Dabaso, and Mayonda). The distribution of nematode genera differed across the sites with Kirepwe having the highest number of genera (58), followed by Dabaso (46) while the least number of genera was at Mayonda (35) (Appendix 1).

However, most genera were thinly distributed (below 6.3%) across all the quadrats. Only 2 genera were above 6.3%, that is, *Spirinia* (18.8%) and *Terschellingia* (13.5%), while 18 genera had an overall distribution of between 1.2% and 6.3% across all the quadrats (Table 1).

Table 1: Distribution of nematode genera across the sites in Mida Creek

GENERA	Kirepwe		Dabaso				Mayonda					MEAN
	QC	QD	QC	QD	QE	QF	QC	QD	QE	QF	QG	
<i>Spirinia</i>	<u>19.8</u>	<u>28.5</u>	<u>7.8</u>	<u>41.1</u>	<u>12.9</u>	<u>43.4</u>	<u>16.3</u>	<u>30.7</u>	<u>2.6</u>	<u>2.7</u>	0.7	18.8
<i>Terschellingia</i>	<u>9.7</u>	<u>22.4</u>	<u>46.5</u>	<u>5.1</u>	<u>21.6</u>	<u>19.1</u>	<u>19.3</u>	<u>3.6</u>	1.0	0.0	0.0	13.5
<i>Pheronus</i>	0.0	0.0	1.7	0.0	0.0	0.0	0.7	0.3	<u>12.9</u>	<u>4.1</u>	<u>49.6</u>	6.3
<i>Daptonema</i>	8.9	11.5	1.9	5.1	3.8	0.5	18.6	12.2	3.6	0.0	0.0	6.0
<i>Dorylaimid</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	<u>4.6</u>	<u>46.6</u>	<u>4.3</u>	5.0
<i>Viscosia</i>	2.5	0.1	1.7	1.5	0.0	0.0	<u>9.0</u>	<u>29.9</u>	<u>4.6</u>	<u>0.0</u>	<u>0.7</u>	4.6
<i>Pontonema</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	<u>42.5</u>	0.0	3.9
<i>Paracomesoma</i>	1.8	0.0	0.0	<u>24.9</u>	<u>6.2</u>	<u>7.5</u>	0.7	0.0	0.0	0.0	0.0	3.7
<i>Synonchium</i>	0.2	0.0	0.8	0.0	0.3	0.0	0.0	0.0	<u>7.7</u>	0.0	<u>29.1</u>	3.5
<i>Dorylaimopsis</i>	0.5	14.7	0.0	2.5	11.6	7.2	0.0	0.0	0.0	0.0	0.0	3.3
<i>Haliplectus</i>	0.2	0.0	0.6	0.0	0.0	0.0	0.0	0.0	<u>28.4</u>	0.0	<u>7.1</u>	3.3
<i>Dichromadora</i>	14.1	1.4	1.9	0.0	0.8	0.3	12.3	0.8	3.1	0.0	0.0	3.2
<i>Paracanthonchus</i>	0.8	0.0	0.3	0.0	0.0	0.0	4.3	19.8	2.6	0.0	0.7	2.6
<i>Gomphonema</i>	6.9	2.7	0.0	7.1	0.3	1.8	7.0	1.0	0.0	0.0	0.0	2.4
<i>Chromadorita</i>	10.7	2.3	0.0	0.0	2.2	1.3	0.3	0.3	7.2	0.0	0.7	2.3
<i>Marylynnia</i>	<u>2.7</u>	<u>4.1</u>	0.0	0.0	<u>4.9</u>	<u>12.4</u>	0.0	0.0	0.0	0.0	0.0	2.2
<i>Longicyatholaimus</i>	0.3	0.0	0.0	0.0	20.8	0.0	0.3	0.0	0.0	0.0	0.0	1.9
<i>Stylotheristus</i>	0.0	0.1	0.3	1.5	6.7	1.8	3.3	1.0	0.0	0.0	0.0	1.3
<i>Spilophorella</i>	1.0	0.8	5.3	0.0	0.5	0.3	5.3	0.0	0.0	0.0	0.7	1.3
<i>Megadesmolaimus</i>	0.0	0.0	12.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	1.2

Nematode genera, *Spirinia*, *Terschellingia*, and *Daptonema* were observed across all the sites, however, they were not recorded in some quadrats in Mayonda. *Pheronus* was restricted to a single quadrat in Dabaso (QC) but was widely distributed in Mayonda. *Dorylaimid* (plant-parasitic

nematode), *Viscosia*, *Pontonema*, *Synonchium*, and *Haliplectus* were widely distributed in the quadrats and restricted at Mayonda. (Table 1).

One-way ANOVA indicated that the nematode distribution did not differ significantly across the sites ($F= 0.9$; $df=2$; $P=0.99$).

4.6 Meiofauna and nematodes diversity

The meiofaunal and nematode diversity H' was highest at Mayonda with 1.3 and 2.7 respectively. The lowest diversity of both meiofauna and nematode was at Dabaso with 0.9 and 2.5 respectively. Meiofauna and nematode diversity at Kirepwe was 1.2 and 2.6 respectively (Figure 8).

The meiofaunal diversity (Shannon Wiener H') in Dabaso and Kirepwe differed significantly from that of Mayonda ($P<0.05$), ($t=-22.501_{(21740)}$) and ($t=9.7601_{(21316)}$) respectively. In addition, the meiofaunal diversity (H') between Dabaso and Kirepwe also differed significantly ($P<0.05$), ($t=-13.14_{(19635)}$). In summary, the meiofaunal diversity H' differed significantly across all sites.

The nematode diversity (Shannon Wiener H') indicated that Kirepwe and Dabaso differed significantly from that of Mayonda. ($P<0.05$), ($t=-3.8212_{(2772.8)}$) and ($P<0.05$), ($t= -4.347_{(2312.3)}$) respectively. On the other hand, the t test indicated that Kirepwe nematode diversity H' did not differ significantly from that of Dabaso ($P>0.05$), ($t=0.8721_{(2777.9)}$).

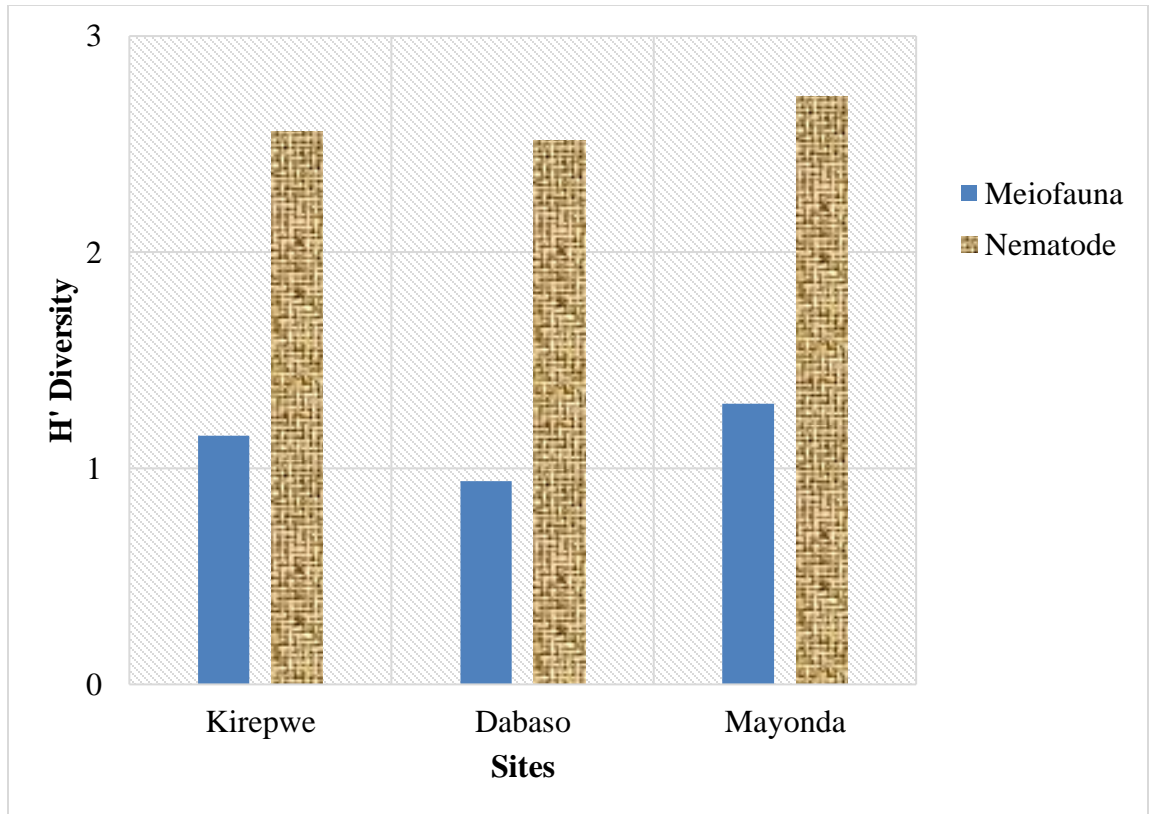


Figure 8: Diversity index H' of meiofauna and nematodes at Kirepwe, Dabaso, and Mayonda.

The highest nematode dominance (d) was in Dabaso (0.14) while nematode evenness was second highest (0.27). Kirepwe's nematode dominance was second highest (0.13) with the least nematode evenness (0.23). Mayonda had the lowest nematode dominance (0.09) and the highest nematode evenness (0.43) (Figure 9).

The calculated probability at 95% confidence interval of both dominance and evenness of nematodes between the three sites was $(0.0765 > 0.05)$ and $(0.27 > 0.05)$ respectively showing no significant difference.

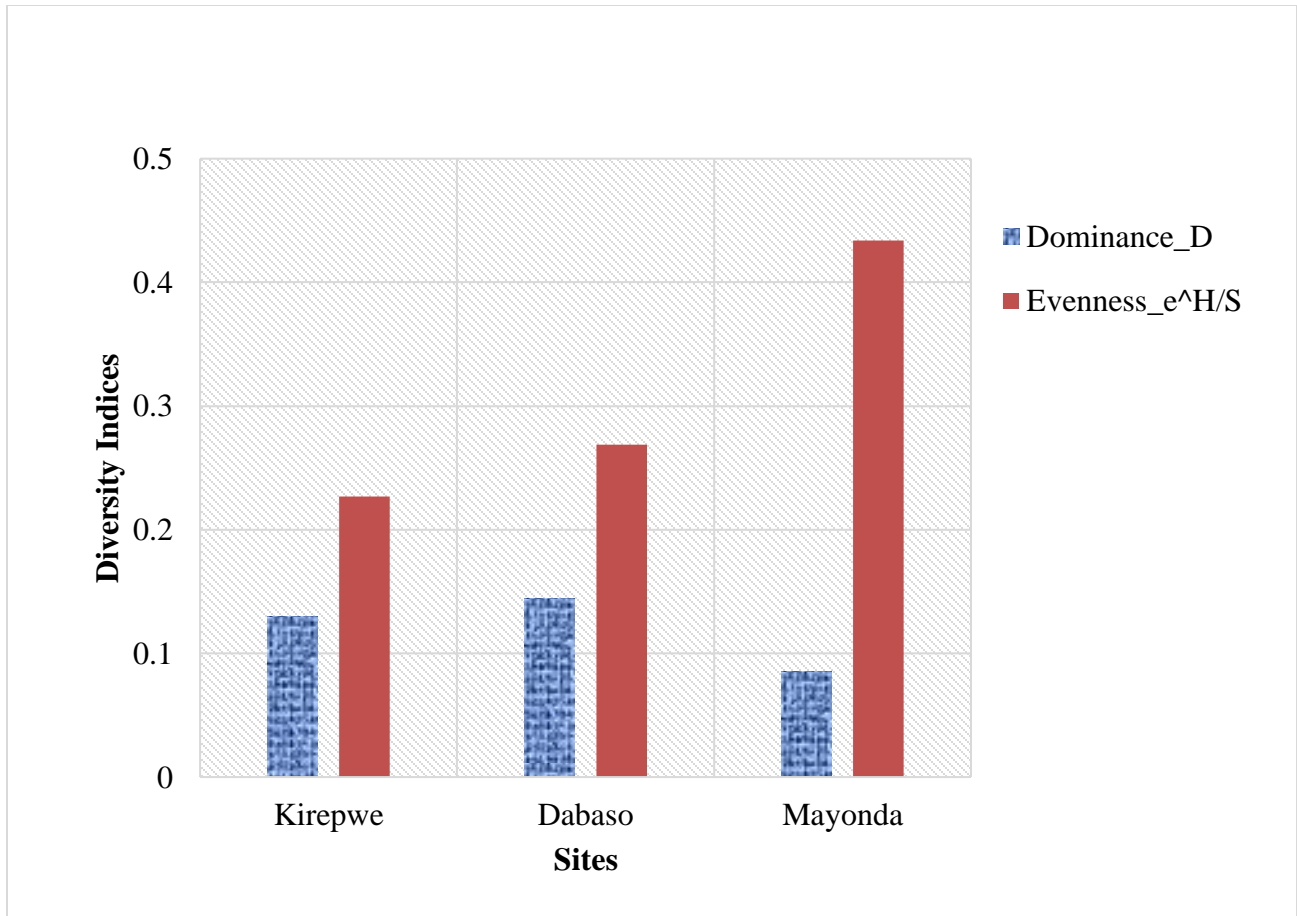


Figure 9: Nematode dominance and evenness at Kirepwe, Dabaso, and Mayonda.

4.7 Meiofauna and Nematodes community assemblage

Generally, the meiofauna communities from the three sites had a very high similarity of at least 75%. The different sites and quadrats were mixed out in the cluster analysis as shown in the dendrogram. The higher the similarity in the community, the lower the chance to conclude whether the community has undergone any kind of disturbances. Therefore, the meiofauna community is not ideal to be used as bio-indicator in this study (Figure 10).

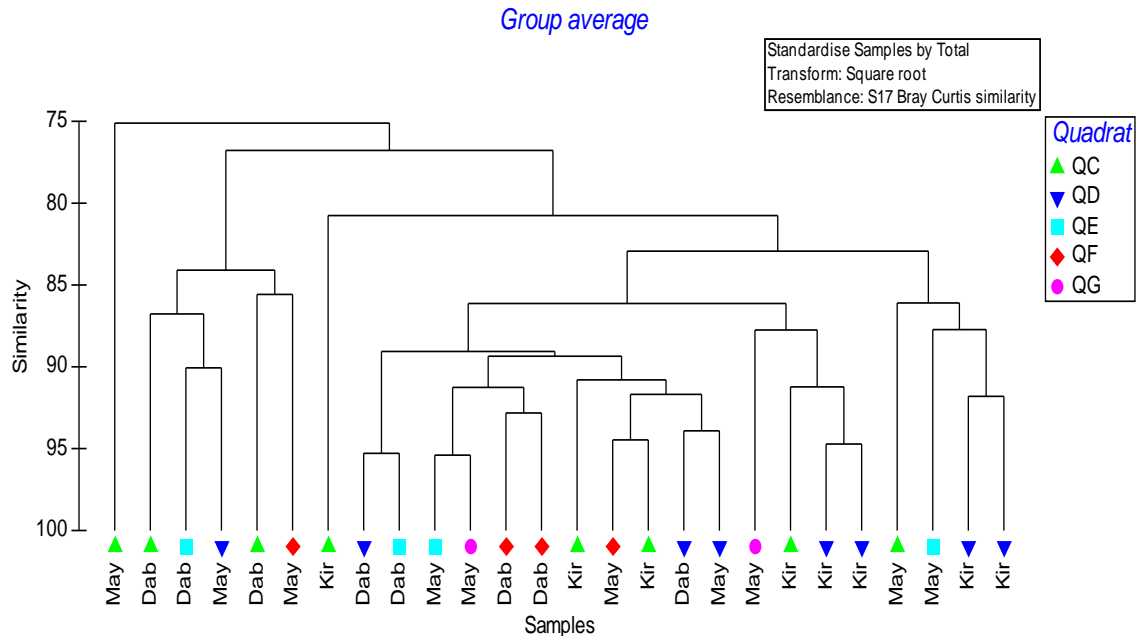


Figure 10: Dendrogram showing the cluster analysis for meiofauna at Mida Creek, Kenya.

On the other hand, the nematode community showed generally low similarity in samples from the different sites and quadrats.

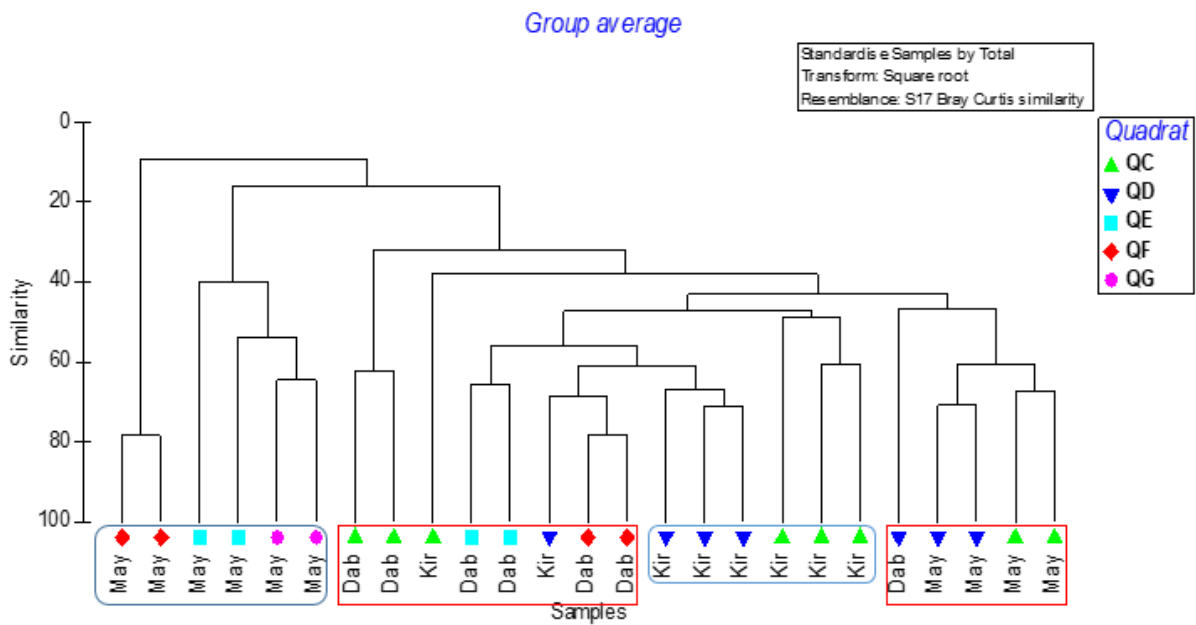


Figure 11: Dendrogram showing the cluster analysis for nematodes in Mida Creek, Kenya.

The above dendrogram shows that nematode community at the quadrat in Mayonda QF, QE and QG were all clustered together. This showed that these quadrats had a higher nematode community similarity. Dabaso QD nematode community was clustered together with Mayonda QC and QD. This also showed that these quadrats had a higher nematode community similarity. On the other hand, Dabaso QC, QE and QF were clustered with Kirepwe QC and QD showing these quadrats had a higher nematode community similarity. However, Kirepwe QC and QD were clustered together showing a high nematode similarity within the quadrats. It is important to note that Mayonda QC and QD nematode community had a close similarity with that of Dabaso QD.

In summary, despite the overall similarity of the nematode community in the three studied sites, there was apparent segregation of Mayonda nematode community from the nematode communities at Dabaso and Kirepwe.

CHAPTER FIVE

5 Discussion, conclusion, and recommendations

5.1 Sediment organic matter and sediment grain size

Mangroves forest contribute a large percentage of organic matter to the sediment through litter fall in the marine ecosystem (Odum and Heald, 1972; Alongi, 1990). In addition, these mangrove forests play an important role in holding and compacting the sediments. This in turn helps in protecting of the shoreline against all kinds of erosion (both wind and waves) (Odum and Heald, 1972; Alongi, 1990). Mayonda had the least amount of the mean sediment organic matter and one-way ANOVA indicated that silt was significantly different across all sites. This could be attributed to the low proportion of silt. Tyson, (2012) in his book sedimentary organic matter and Secieru and Oaie, (2009) during their study on the relation between the grain size composition of the sediment from the new black sea and their total organic carbon reported that sediment organic matter is influenced by the distribution of grain sizes found in an area. They also suggested that small amount of the proportion of finer particles promotes a lower percentage of sediment organic matter as seen at Mayonda as compared to Kirepwe and Dabaso.

There was a lot of sediment disturbance caused by the fisherfolk at Mayonda. The disturbances were caused by the ever digging and churning of the sediment. The main aim was to capture the large polychaetes and this contributed greatly to the disintegration of sediments through mechanical breakdown (Secieru and Oaie, 2009) and (Tyson, 2012). Odum and Heald, (1972) and Alongi, (1990) reported the importance of mangrove forest cover along the coast line. They reported that mangrove forest cover helps in sediment organic matter formation through leaf fall. They also noted during their study that mangrove also protects the sediments against agents of erosion by compacting and holding soil sediments together. In Mayonda, silt and very fine sand were easily eroded since the sediments were exposed to the agents of erosion due to the existence of little mangrove cover as compared to Dabaso and Kirepwe. Apart from the low silt amounts that hindered decomposition of organic matter at Mayonda, the little mangrove forest cover also contributed greatly to the low sediment organic matter. Secieru and Oaie, (2009) during their study on the relation between the grain size composition of the sediment from the new black sea and their total organic carbon and Tyson, (2012) reported that sediment organic matter is influenced by the distribution of grain sizes found in an area when they noted that small amount

of proportion in finer particles promotes a lower percentage of sediment organic matter. This study confirms that Silt in Mayonda was significantly different from other sites that plays a key role in the decomposition and presence of the sediment organic matter in an area (Secrieru and Oaie, 2009) and (Tyson, 2012). Wieser, (1953) during his study on the observation of the feeding habit of estuarine nematode noted that genera such as *Spirinia*, and *Terschellingia* are higher in concentration in areas with high sediment organic matter. This can be used to infer that Mayonda had the least concentration of sediment organic matter due to the drastic drop of existing genera such as *Spirinia*, and *Terschellingia* which are non-selective feeders and selective feeders of sediment organic matter respectively Wieser (1953). Wieser, (1953) and Moens and Vincx, (1997) also noted during their study that a drop in selective and non-selective feeders gives room to an increase of other opportunistic and scavengers genera such as *Viscosia*, *Pontonema*, *Synochium*, and *Pheronus*.

In Kirepwe, the mean sediment organic matter was less as compared to that of Dabaso. It was evident the forest cover at Dabaso was higher as compared to the forest cover at Kirepwe with which forest cover is a major source of sediment organic matter through leaf fall (Odum and Heald, 1972) and (Alongi, 1990). In addition, the same phenomenon of grain size by Secrieru and Oaie, (2009), and Tyson, (2012) comfortably explain the difference in the mean sediment organic matter present in both areas of Kirepwe and Dabaso. The lower mean sediment organic matter at Kirepwe can be attributed to the high proportion of fine and medium sand as compared to Dabaso. High silt at Dabaso as compared to Kirepwe can be used to explain the difference in mean sediment organic matter. Fine and medium sand does not promote the occurrence of sediment organic matter as compared to silt and very fine sand as document by Secrieru and Oaie, (2009) and Tyson, (2012) during their studies. Heip *et al.*, (1985), Nicholas and Hodda (1999), and Lee and Riveros (2012) documented from their study that nematode genera such as *Daptonema* and *Chromadorita* are mostly found on sandy beaches. Due to the presence of *Daptonema* at Kirepwe, this is evident that the area was sandier as compared to Dabaso. Furthermore, there was a high concentration of *Terschellingia* at Kirepwe. Alongi, (1987) during his study on the influence of mangrove-derived tannins on intertidal meiobenthos in tropical estuaries recorded that *Terschellingia* survives better at the mangrove forest because it is able to feed not only on the sediment organic matter since it is a selective deposit feeder but also does well in mangrove derived tannin. He also documented that tannin from mangrove is more in sandy areas because it binds more easily with sand as compared

to fine sand and very fine sand as observed at Kirepwe. This is enough evidence to show that there was more fine and medium sand at Kirepwe as compared to Dabaso leading to the low sediment organic matter.

Another study by Gheskiere *et al.*, (2005) on meiofauna as descriptor of tourism-induced changes at sandy beaches, and Maria *et al.*, (2012) reported that high amounts of silt with less disturbances, promotes high amount of sediment organic matter. The high mean sediment organic matter in both Kirepwe and Dabaso can be attributed to the less sediment disturbances happening in the area as compared to Mayonda. At the same time, high amounts of sediment organic matter favours presence of nematodes due to presence of great amounts of food (Wieser 1953).

Less amount of silt and the sediment disturbances caused by fisherfolk contributed greatly to the low sediment organic matter experienced at Mayonda. As Tyson, (2012) observed that sediment organic matter is influenced by the distribution of grain sizes found in an area when he noted that small amount of proportion in finer particles promotes a lower percentage of sediment organic matter. In addition, Giere, (2009) during his study on benthic life in sulfidic zones of the sea-ecology and structural adaptations to a toxic environment observed that low proportions of silt, very fine sand and fine sand, as experienced in Mayonda, favours the existence of other meiofaunal groups. This groups will include oligochaeta, polychaeta, copepoda, thermobanacea, gnathostomulida, cladocera, turbellaria, arachnida, ostracoda, tanaidacea, cnidarian, insecta, and Rotifera. This is clearly demonstrated at Mayonda where different meiofaunal taxa are thriving more across the quadrats as compared to Dabaso and Kirepwe. Therefore, as observed from this study, sediment disturbances as experienced at Mayonda affects the decomposition of organic matter which in turn affects the distribution of nematode genera. Furthermore, sediment grain sizes such as silt plays a major role in the sediment organic matter decomposition, with which the sediment organic matter also influences the distribution and existence of nematode, and other meiofaunal taxa.

5.2 Meiofauna density

Medium sand was higher in proportion at Mayonda as compared to Dabaso, and Kirepwe. From a study done by Giere, (2009) documented that low Silt, very fine sand, and fine sand, with high proportions of medium sand favors the survival of other meiofaunal groups. This information can

be used to explain the high meiofaunal density at Mayonda since the site had lower finer sands and greater proportions of medium sand sizes as compared to Dabaso and Kirepwe that cause the high meiofaunal density. However, we cannot use the meiofauna in general to give conclusive and concrete reason that it is due to the sediment disturbances happening at Mayonda that caused the high meiofaunal densities.

5.3 Nematode density

From the study, there was no significant difference in the population densities of nematodes between Kirepwe, Dabaso, and Mayonda. Gheskiere *et al.*, (2005) on meiofauna as descriptor of tourism-induced changes at sandy beaches. Maria *et al.*, (2012) on the relationship between sandy beach nematodes and environmental characteristics in two Brazilian sandy beaches. These researchers all documented that high amounts of silt, very fine sands caused a high sediment organic matter with less disturbance. These conditions enhance high nematode density because of the high food content provided by availability of high sediment organic matter. This phenomenon is replicated in Dabaso since the site had high amounts of silt, very fine sand, and high sediment organic matter with less disturbance leading to high food content. The area supported the nematode population comfortably leading to high densities. Kirepwe had the least nematode density although it had less disturbances with low sediment organic matter content as compared to Mayonda. This is a rare phenomenon which can be researched further to explain these results.

The silt and very fine sand were relatively higher in proportion in all the sites favouring nematode existence and survival. Similar study done by Renaud-Debyser, (1963) concluded in his study on ecological interstitial fauna that in silt and very fine sandy sediments, the nematodes assemblages reach up to a depth of 50cm. The high amounts of silt and very fine sand played a major role in the high density occurrence of the nematodes (Gheskiere *et al.*, 2005; Maria *et al.*, 2012). This was supported too by Secieru and Oaie, (2009) and Tyson, (2012). Therefore, this phenomenon can be related to the high nematode density at Dabaso. Silt, very fine sand, and fine sand were high in proportion at Dabaso and Kirepwe causing the high nematode densities as compared to Mayonda which had low Silt, very fine sand, and fine sand proportion.

A study by Gheskiere *et al.*, (2005) on meiofauna as descriptor of tourism-induced changes at sandy beaches, and Maria *et al.*, (2012) reported that high amounts of silt with less disturbances, promotes high amount of sediment organic matter. However, at Mayonda, there was major

sediment disturbances that affected greatly organic matter decomposition. This affected greatly the nematode densities as compared to both Kirepwe and Dabaso. This is because high amounts of sediment organic matter favours presence of nematodes due to presence of great amounts of food availability (Wieser 1953).

5.4 Relative abundance of nematode within the meiofauna

A research by Giere, (2009) indicate that high proportion of medium sand promotes the survival of other meiofaunal group. This can be used to explain the high meiofaunal relative abundance at Kirepwe as compared to Dabaso and Mayonda. Such meiofaunal taxa include oligochaeta, cladocera, insecta, rotifera, copepoda, polychaeta, thermobanaceae, turbellaria, ostracoda, and tanaidacea. Similar results of an increase of medium sand causing an increase of other meiofaunal taxa were noted by Maria *et al.*, (2012) during her study on the relationship between sandy beaches nematodes and the environment characteristics in two Brazilian sandy beaches.

The relative abundance of nematode taxon as compared to other meiofauna taxa was very high in all sites. These findings were similar to a research by Giere, (2009) where he recorded that the nematode community dominate any area in relative abundant. This is because they are always among the first living organism to colonize any area. This can be attributed to the presence and availability of silt, very fine sand and fine sand that promotes the decomposition of organic matter which is food to the nematodes (Secrieru and Oaie 2009; Tyson 2012).

Despite nematode dominating all sites in relative abundance as compared to other meiofaunal taxa, Dabaso had highest proportions of silt that enhanced high sediment organic matter which in turn promoted the survival and existence of high relative abundance of nematode as compared to Kirepwe and Mayonda. During their study on observations on the feeding ecology of free-living marine estuarine nematodes, Moens and Vincx, (1997) and Moens *et al.*, (2013) indicated that that high sediment organic matter favors nematode colonization and specialization due to availability of enough food and right physical conditions Witcamp, (1963), Gheskiere *et al.*, (2005) and Maria *et al.*, (2012). This can still be used to explain the high relative abundance of nematode and Dabaso as compared to Kirepwe and Mayonda.

On the other hand, Mayonda had little proportions of silt, very fine sand, and fine sand as compared to Dabaso and Kirepwe that caused a decrease in sediment organic matter decomposition among which usually affects nematode abundance. In addition, Mayonda was the site that experienced a lot of sediment disturbances from the fishfolker through digging and churning. Therefore, it was expected that nematode relative abundance should be way much less as compared to Kirepwe but the relative abundance of nematode in Mayonda (59%) was higher than Kirepwe (56%). This can be attributed to the continuous sediment disturbances happening at Mayonda which does not allow for nematode species specialization. This gives room for more opportunistic and hardy nematode genera that can survive heavy sediment disturbances very well to migrate and occupy the area. Such nematode genera include: *Viscosia*, *Pontonema*, *Synochium*, *Haliplectus*, and *Pheronus* Moens and Vincx, (1997). These genera played a key role in pushing the relative abundance of nematodes at Mayonda as compared to Kirepwe and Dabaso.

5.5 Distribution of nematode taxa at Mida Creek

Feeding in marine nematode play an important role in their distribution Wieser, (1953). Wieser came up with 4 trophic groups including: selective deposit feeder, which are mainly characterised by having a small buccal cavity with no tooth. A few examples are *Tershellinia*, *Paracanthochus*, *Bathylaimus*, *Haliplectus* among others. The second trophic group are non-selective deposit feeders. Their major characteristics is that they possess a large buccal cavity but without teeth too. Some of the deposit non-selective feeders include *Spirinia*, *Daptonema*, *Sabatiera*, *Theristus* among others. The third trophic feeder are known as epistratum feeder which feed basically on diatoms. Some of the example include: *Gomphonema*, *Marylynnia*, *Dichromadora*, *Chromadorita*, *Spilophorella*, *Longicytholaimus*, *Stylotheristus* among others. The final trophic group is the omnivore – predator. Their major characteristic is the possession of a rather big strong tooth. They include *Synochium*, *Pheronus*, *Viscosia*, *Pontonema*, *Paracomesoma* among others. However, this group is not understood much. Lopez *et al.*, (1979), Riemann, (1986), and Moens and Vincx, 1997) reported that *Viscosia* and *Pontonema* can be described as predators that are scavengers too because of their ability to feed on dead foraminiferans.

From this study, One-way ANOVA indicated that the nematode distribution across the quadrats was not significantly different across the sites. However, *Spirinia*, *Terschellingia*, and *Daptonema* were widely distributed across all the sites though reduced in numbers in some quadrats of

Mayonda. This is because, such genera are greatly affected by heavy sediment disturbances. The sediment disturbance affects their feeding grounds since they are all deposit feeders therefore impacting on their distribution. As seen earlier, sediment disturbance affects greatly sediment organic matter decomposition and deposition which is the main source of food of the deposit feeders. Such sediment disturbances were more pronounced at Mayonda as compared to Kirepwe and Dabaso. The disturbances caused a reduced sediment organic matter concentration which in turn affected the distribution of such deposit feeders at Mayonda which *Synochium*, *Pheronus*, *Viscosia*, *Pontonema*, *Viscosia* and *Pontonema* increased in number due to their opportunistic characteristics.

Terschellingia is a selective deposit feeder whereas *Daptonema* and *Spirinia* are non-selective feeders feeding mostly on deposited foods such as organic matter (Wieser 1953; Moens and Vincx 1997; Schratzberger *et al.*, 2009). In addition, these genera dominate every habitat (Alongi, 1990). *Spirinia*, was more in quadrats D which was located at the start of the mudflat region across all sites while *Terschellingia* was more in quadrats C where mangrove cover was across all sites. Alongi, (1987) documented that *Terschellingia* survives better at the mangrove forest because it is able to feed not only on the organic matter since it is a deposit feeder but also does well in mangrove derived tannin. On the other hand, *Spirinia* was more in the quadrats located at the mudflats. The mudflats have substantial sediment organic matter deposits best situated for its survival (Alongi, 1987). In addition, *Spirinia* is a non-selective deposit feeder hence it is not deprived its feeds (Alongi, 1987). However, with the disturbances happening at Mayonda, both *Spirinia*, and *Terschellingia* drastically reduced especially towards the mudflats. Just to note, polychaetes survive best at the mudflats where there is frequent sea water coming in and moving out (Heip *et al.*, 1985) giving Mayonda a good ground for polychaetes to thrive. The digging of the polychaetes towards the mudflat of Mayonda by the fisherfolk, caused a drastic drop of both *Spirinia*, and *Terschellingia* due to the reduced sediment organic matter which is food for such nematodes.

Heip *et al.*, (1985), Nicholas and Hodda (1999), and Lee and Riveros (2012) noted from their study that genera such as *Daptonema*, and *Chromadorita* (Epistrate feeder) are found on sandy beaches. *Daptonema*, and *Chromadorita* were more in Kirepwe, this is because, fine sand and medium sand was higher in Kirepwe as compared to Dabaso and Mayonda. More of *Terschellingia* was present

in Kirepwe as compared to other sites. Alongi, (1987) recorded that *Terschellingia* survives better at the mangrove forest because it is able to feed not only on the organic matter since it is a deposit feeder but also does well in mangrove derived tannin. He also documented that tannin from mangrove is more in sandier areas because it binds more easily with sand as compared to fine sand and very fine sand as observed at Kirepwe.

Despite *Spirinia* and *Terschellingia* being widely distributed across all the sites, in Mayonda, the genera were low in distribution. This is due to the physical disturbances that destroys their feeding habitat (Alongi, 1990). They are non-selective and selective deposit feeders respectively and the frequent disturbances prevented them from having a specific niche while taxa such as *Viscosia*, *Pontonema*, *Synochium*, and *Pheronus* increased in number (Moens and Vincx, 1997). In addition, the sediment disturbance interfered with the decomposition of sediment organic matter which is main source of food *Spirinia* and *Terschellingia* causing the drastic drop at Mayonda as compared to Kirepwe and Dabaso.

Terschellingia, *Daptonema*, and *Spirinia*, are the genera among the nematode assemblages that are best known to occur in muddy and organically rich sediments (Schratzberger *et al.*, 2006) just like in Dabaso and Kirepwe. These genera are not only found in undisturbed areas that allow the utilization of the dissolved sediment organic matter content by the specific genera of nematodes but also they have the ability to adapt and change during disturbances (Vanreusel, 1990; Vanreusel *et al.*, 2010b), which explains why these three genera were found in Mayonda despite the serious sediment disturbances though in small numbers.

Pheronus, *Viscosia*, *Pontonema*, and *Synonchium* were highly distributed in Mayonda. This is attributed to their predatory feeding habit (Moens and Vincx, 1997). They are also termed as opportunistic nematode that come to colonize disturbed areas just because other nematode genera cannot thrive in disturbed areas such as Mayonda (Moens and Vincx, 1997). It is important to note that *Pontonema* was able to thrive at Mayonda better due to its ability to scavenge for its food. From the general observation, these predators were more in quadrats of Mayonda where oligochaetes were concentrated. This can be used to postulate a relation between such oligochaetes and marine predatory nematode though further research to prove this can be conducted. *Sabatieria* was not present in Mayonda despite its ability to tolerate both hypoxic and anoxic conditions. From the research findings by Jensen, (1987b), Steyaert *et al.*, (2005, and 2007), and Fonseca *et al.*,

(2011), *Sabatieria*, and *Dorylaimopsis* thrive best under reduced sediments as found in Kirepwe and Dabaso.

5.6 Diversity of meiofauna and nematode

Frequent moderate disturbance of sediments reduces dominance and increases evenness and diversity of nematodes Giere, (2009). Communities which are diverse biologically most likely contain resilient species. This is made possible by the ability of these species to adapt to the changing environment because they have a higher chance to get traits that help them survive (Yachi and Loreau, 1999). The meiofauna diversity H' did not differ significantly across all the sites. However, Mayonda had a slightly higher meiofaunal diversity as compared to Kirepwe and Dabaso. This was because the site had very little amounts of silt, same to very fine sand and fine sand from the results. This promoted the existence of other meiofaunal taxa such as oligochaeta, polychaeta, copepoda, thermobanaceae, gnathostomulida, cladocera, turbellaria, arachnida, ostracoda, tanaidacea, cnidaria, insecta, and Rotiferas documented by Giere, (2009). As mentioned, sediment disturbances at Mayonda caused the meiofauna taxa not to occupy a specific niche hence new taxa colonizing the area pushing the meiofauna diversity up (Moens and Vincx, 1997).

Furthermore, in the meiofaunal group, nematoda, oligochaeta and copepoda will always recolonize an area after disturbances though the nematoda taxon recolonization is faster and immediately (Ingolo *et al.*, 2000). Nematodes quickly adapt to any kind of disturbance over a very short period of time (Sherman and Coull, 1980). Thus after the physical sediment disturbance at Mayonda by fisherfolk, nematodes recolonized the area almost immediately pushing the meiofaunal diversity up as compared to Kirepwe and Dabaso. This is because nematode recolonize the disturbed area almost immediately and fast. They also have the ability to easily adapt to the change of environment due to their hardy nature as organisms suggesting that they can be used as indicator organisms in recolonization experiments (Ingolo *et al.*, 2000). Oligochaeta and copepoda recolonized the disturbed area pushing the meiofaunal diversity up (Moens and Vincx, 1997).

Mayonda had the least number of nematode individuals while Kirepwe had the highest whereas Mayonda recorded the highest nematode diversity, followed by Kirepwe while Dabaso had the lowest. The nematode diversity in Dabaso and Kirepwe differed significantly with that of

Mayonda. Yachi and Loreau, (1999) concluded from his research that increasing diversity confer a greater chance to destabilizing the system. This is because there exists a limit to the number of individuals packed in a particular community confirming that when the community species number goes up, the average community population goes down. This means that the smaller population size is, the higher the chances of extinction, so as species richness levels.

Therefore, from the data at Mayonda, diversity is high and this as Yachi and Loreau, (1999) explain can cause species extinction due to the ever increasing disturbances caused by fisherfolk. This can also be attributed to the difference in the intensity of sediment disturbances that affected the sediment organic matter in an area. Grain size proportion also played a big role to the nematode diversity. Lesser proportion of finer particles enhances a lesser percentage of sediment organic matter. The same phenomenon of sediment disturbances affecting the concentration of sediment organic matter by (Secrieru and Oaie, 2009; Tyson, 2012) comfortably explain the difference in the mean total sediment organic matter that affects presence of nematodes in Mayonda. More so, Mayonda had the least proportion of finer sand that played a major role in the slow decomposition and presence of the mean total sediment organic matter in the area. This gave Mayonda a unique nematode diversity. Netto *et al.*, (1994) noted that sediment stability acts as a very important variable in controlling nematode diversity and abundance at the studied sites and this is replicated at Kirpwe, Dabaso, and Mayonda.

On an overall scale, the low diversity observed in Dabaso and Kirepwe was due to nematode species specialization, while Mayonda had the highest diversity due to lack of nematode species specialization. This caused a rise of opportunistic nematode species that came to colonize the area because of the sediment disturbances that occur (Moens *et al.*, 2013). Frequent sediment disturbances do not allow nematode to occupy a specific niche. This is because, as the nematodes try to occupy a niche in the environment, there is sediment disturbance that causes others to migrate or die while providing room for predatory species to colonize the area (Moens and Vincx, 1997; Moens *et al.*, 2013) pushing the nematode diversity up as recorded in Mayonda.

Dabaso diversity and abundance of nematodes was slightly lower as compared to Kirepwe's nematode species diversity and abundance. This can be attributed to the fact that Kirepwe is inhabited by all kind of nematodes, that is, selective and non-selective deposit feeders (*Spirinia* and *Terschellingia*), predators (*Pheronus*, *Viscosia*, *Pontonema* and *Synonchium*) to species that

can also survive extreme (*Daptonema*) physical disturbances, epistratum feeders (*Chromadorita*, *Marylynnia*, *Dorylaimopsis*, *Dichromadora*, *Gomphonema*, and *Longicytholaimus*) (Jensen, 1987). Therefore, special specialization did not exist. Free living nematodes in the marine environment from various studies show that nematode abundance varies greatly among different habitats (Heip *et al.*, 1985). This variability is caused by the complex interactions among different biotic and abiotic factors such as food, and disturbances. For instance, Heip *et al.*, (1985) reported that estuarine muddy sediments are characterised by high densities of more than 3000 individuals/10cm² and a few dominant species per sample.

The results of the diversity indices of Nematode showed significant differences among the three sites; Dabaso, Mayonda and Kirepwe. According to Shannon diversity index and Simpsons diversity index, Mayonda had higher species diversity (richness) compared to Dabaso and Kirepwe. This was brought about majorly by the frequent sediment disturbances that occurs at Mayonda hindering species specialization giving rise to more opportunistic species. In addition, sediment disturbance brought the differences in sediment texture of sampling sites that played an important role in influencing the diversity and distribution pattern of these nematodes as indicated by Bertness *et al.*, (2001) and Nabavi *et al.*, (2008). The high diversity reduces dominance in any ecosystem hence we find species dominance at Mayonda was hindered since no species can come up strongly to dominate the area with the frequent physical sediment disturbances. Low dominance automatically leads to high evenness of nematodes which is seen in Mayonda as compared to Dabaso and Kirepwe therefore nematodes cannot be allowed to occupy a specific niche (Bertness *et al.*, 2001; Nabavi *et al.*, 2008).

5.7 Meiofauna and nematode community assemblage

Despite having different physico-chemical parameters, Kirepwe, Dabaso, and Mayonda meiofaunal community assemblage did have a high percentage similarity from the cluster analysis. Despite Mayonda experiencing a lot of sediment disturbance by the fisherfolk, from the community cluster analysis, the meiofaunal community did not differ with Dabaso and Kirepwe. This shows that meiofaunal community from the studied sites cannot be used as bio-indicators because they do not bring out a clear difference between the sites.

The nematode community assemblage on the other hand at Kirepwe and Dabaso had a close similarity to each other as compared to that of Mayonda nematode community assemblages. This can be attributed to the physical disturbances caused by the fisherfolk during harvesting of polychaetes, sediment sizes sediment organic matter decomposition, and feeding habits of the nematodes. Digging out of the polychaete causes a shift of the nematodes community through death, and migration away or into the area (Shine 2005; Anasari *et al.*, 2012).

Dabaso and Kirepwe had substantial amounts of sediment organic matter content as compared to Mayonda which recorded the least amounts of the mean sediment organic matter. From Heald and Odum, (1972) and Alongi, (1990) studies, they indicated that mangroves forest contribute a large percentage of organic matter to the sediment through litter fall in the marine ecosystem. The low sediment organic matter at Mayonda can be attributed to the existence of very little mangrove forest cover. This sediment organic matter concentration promotes the survival of different nematodes genera as seen in Kirepwe and Dabaso. Apart from the low sediment organic matter caused by the little mangrove cover, Mayonda had low silt and very fine sand concentration which play a key role in sediment organic matter decomposition as reported by (Giere 2009). Furthermore, the sediment disturbances affected greatly the decomposition of the organic matter as indicated by Arntz *et al.*, (1999). This is also seen at Mayonda. These factors played a major role in contributing to the low sediment organic matter at Mayonda. The low sediment organic matter at the same time caused a drastic drop of the selective and non-selective deposit feeders while such as *Spirinia* and *Terschellingia* while more of the opportunistic genera such as *Viscosia*, *Pontonema*, *Synochium*, and *Pheronus* increased in number (Moens and Vincx, 1997).

Similar study was done by Francisco *et al.*, (2012) noted that frequent physical disturbances affects the decomposition of matter to sediment organic matter. This disturbance caused Mayonda to have very little occurrence of sediment organic matter. As mentioned, the sediment organic matter is a major source of food for the nematodes (Arntz *et al.*, 1999). This meant that sediment organic matter is critical when it comes to distribution of nematode communities (Shine 2005; Anasari *et al.*, 2012) just as observed during this study in all sites. Apart from sediment disturbance and sediment organic matter, grain size also affects the community structure of nematodes. Giere, (2009) indicated during his study that very little amounts of silt, very fine sand and fine sand hinders the decomposition of organic matter. Mayonda had very little proportions of silt, very fine

sand and fine sand as compared to Kirepwe and Dabaso. This caused the nematodes community assemblage in Mayonda to greatly differ from that of Dabaso and Kirepwe. This was because of the continuous physical sediment disturbances at Mayonda that caused epistratum, selective and non-selective feeders such as *Spirinia*, *Terschellingia*, *Paracanthochus*, *Bathylaimus*, *Haliplectus* among others to decrease in number while more of the predatory feeders such as *Viscosia*, *Synochium*, *Pheronus*, and *Pontenema* increased.

Due to mechanical weathering of soil sediments, more sand was recorded in Mayonda whereas silt and very fine sand were eroded due to sediment disturbance and the little mangrove forest (root to compact and the soil sediments together) available. Therefore, *Paracanthochus* and *Chromadorita* increased in number due to their ability to survive in areas with sandier conditions (Alongi, 1997) while *Sabateria* and *Dorylaimopsis* were absent (Jensen 1987b; Moens and Vincx 1997; Steyaert *et al.*, 2005; 2007 and Fonseca *et al.*, 2011) as observed during their studies. This was also observed in Mayonda. At the same time, *Dorylaimid* a plant parasite nematode was widely distributed at Mayonda which needs further research to explain these findings.

Spirinia, *Terschellingia*, and *Daptonema* were widely distributed across all the sites though not observed in some quadrats of Mayonda. These nematode genera are all deposit feeders. *Terschellingia* is a selective deposit feeder whereas *Daptonema* and *Spirinia* are non-selective feeders feeding mostly on deposited foods such as organic matter (Wieser 1953; Moens and Vincx 1997; Schratzberger *et al.*, 2009). They also dominate every habitat (Alongi, 1990). *Spirinia*, was more in quadrats D which was located at the start of the mudflat region across all sites while *Terschellingia* was more in quadrats C where the mangrove was across all sites. Alongi, (1987) documented during his study that *Terschellingia* survives better at the mangrove forest because it is able to feed not only on the sediment organic matter since it is a deposit feeder but also does well in mangrove derived tannin. *Spirinia* was more in the quadrats located at the mudflats. The mudflats have substantial sediment organic matter deposits best for its survival as reported by the research done by Alongi, (1987). In addition, Alongi, (1987) reported that *Spirinia* is a non-selective deposit feeder hence it is not deprived its feeds. However, with the sediment disturbances happening at Mayonda, both *Spirinia* and *Terschellingia* drastically reduced especially towards the mudflats. This is because the sediment disturbance hindered organic matter decomposition

caused by digging out of the polychaetes towards at the mudflat of Mayonda. This played a major role in the drastic drop of both *Spirinia*, and *Terschellingia* because they were deprived their food.

Heip *et al.*, (1985), Nicholas and Hodda (1999), and Lee and Riveros (2012) documented from their study that genera such as *Daptonema*, and *Chromadorita* (Epistrate feeder) are found on sandy beaches. *Daptonema*, and *Chromadorita* were more in Kirepwe, this is because, fine sand and medium sand was higher in Kirepwe as compared to Dabaso and Mayonda. More of *Terschellingia* were present in Kirepwe as compared to other sites. Alongi, (1987) noted that *Terschellingia* survives better at the mangrove forest because it is able to feed not only on the organic matter since it is a deposit feeder but also does well in mangrove derived tannin. Alongi, (1987) recorded that tannin from mangrove is more in sandier areas because it binds more easily with sand as compared to fine sand and very fine sand as observed at Kirepwe.

Spirinia, *Terschellingia* and *Daptonema* were not distributed in some quadrats of Mayonda compared to Dabaso and Kirepwe. This is because the genera are among the nematode assemblages that are best known to occur in muddy and organically rich sediments as indicated by Schratzberger *et al.*, (2006) during his study. Furthermore, these genera are not only found in undisturbed sediments in high numbers due to availability of sediment organic matter which acts as food, but also they have the ability to adapt and change during disturbances (Vanreusel, 1990; Vanreusel *et al.*, 2010b). Their ability to quickly adapt to a change in environment can be used to explain why these three genera were found in Mayonda despite the serious sediment disturbances. The reduced number of such genera at Mayonda as compared to Kirepwe and Dabaso played an important role in relaying information about the nematode community during the community analysis.

Pheronus, *Pontonema*, and *Viscosia* were restricted to a single quadrat of Dabaso (QC) while they were widely distributed in Mayonda. This was because of their predatory nature that enabled them to colonize disturbed area (Moens and Vincx, 1997). These genera contributed greatly in relaying important information about the nematode community assemblage during the community analysis between the three sites (Kirepwe, Dabaso, and Mayonda). *Dorylaimopsis*, *Marylynnia*, *Sabatiera*, and *Pontonema* were absent at Mayonda completely. *Dorylaimopsis*, *Sabatiera*, and *Pontonema* did not survive in Mayonda mainly because of the difference proportion of the grain size. Such

genera thrive best in areas with high proportion of silt and very fine sand (Jensen 1987b; Steyaert *et al.*, 2005, 2007, Fonseca *et al.*, 2011) as seen in Kirepwe and Dabaso.

Marylynnia is an epistratum feeder that was not seen in Mayonda alone (Wieser 1959). Giere, (2009) and Francisco *et al.*, (2012) confirmed during their study that frequent physical sediment disturbances causes a shift of nematodes community from epistratum and deposit feeding to predatory feeding. This can be used to explain as to why there were more predators at Mayonda as compared to Kirepwe and Dabaso. The presence of more predators and absence of some epistratum such as *Marylynnia* in Mayonda caused the difference in the nematode community during the community analysis. Therefore, the nematodes as compared to the meiofauna from the studied sites can be used as bio-indicators of sediment disturbance to bring out a clear between sites.

Despite *Spirinia* and *Terschellingia* being widely distributed in all the sites, in Mayonda, the genera had a low distribution. This is because of the physical sediment disturbances that destroys their feeding habitat (Alongi, 1990). They are non-selective and selective deposit feeders respectively and the frequent disturbances prevented them from having a specific niche while genera such as *Pheronus*, *Viscosia*, *Pontonema*, and *Synonchium* were widely distributed in Mayonda. This is attributed to their predatory feeding habit (Moens and Vincx, 1997). They also noted that these nematodes are also termed as opportunistic nematodes that come to colonize sediment disturbed areas just because other nematodes genera cannot thrive in sediment disturbed areas such as Mayonda. It is important to note that *Pontonema* was able to thrive at Mayonda better due to its ability to scavenge for its food. *Sabatieria* on the other hand was not present in Mayonda despite its ability to tolerate both hypoxic and anoxic conditions. This is because *Sabatieria*, and *Dorylaimopsis* thrive best under high proportion of finer sediments size such as silt and very fine sand (Jensen 1987b; Steyaert *et al.*, 2005, 2007, Fonseca *et al.*, 2011) as recorded in Kirepwe and Dabaso.

In summary from the findings, sediment disturbance in Mayonda caused affected the distribution and decomposition of sediment organic matter which acts as food to nematodes. This in turn affected the distribution of the epistratum, predators, scavengers, selective and non-selective deposit feeders of the nematodes. In the long run, this affects the community assemblages of the different genera of nematodes making them good bio-indicators not only for sediment disturbance but also sediment environmental change.

5.8 Conclusion

From this study, it is clear that harvesting of polychaetes as bait affects the distribution, diversity and community assemblage of both meiofauna and nematodes. However, a clearly difference of this parameters was not seen in meiofauna as compared to the nematoda taxon. Therefore, based on this research, it was evident that nematodes are good bio-indicators of sediment disturbance. This was made possible by looking at the distribution, diversity and community assemblage of the nematode. Nematode genera such as *Terschellingia*, *Spirinia*, *Viscosia*, *Pontonema*, *Synochium*, and *Pheronus* were helpful as bio-indicators of sediment disturbances. This was made possible by looking at their feeding habits which affect their distribution between different sites. However, Kirepwe had the least nematode density although it had less disturbances as compared to Mayonda. This may need further research to explain such phenomenon. In addition, Dorylaimids, a plant-parasitic nematodes were observed in the mud flats of Mayonda in large numbers while they were not encountered in Dabaso and Kirepwe. This can be researched further to explain its occurrence.

5.9 Recommendations

1. Alternative fishing baits should be highly advocated for which will help to minimize if not stop the frequent sediment disturbances during the harvesting of polychaetes. This can be effected through the Beach Management Units to help safe guard our benthic ecosystems and at large, the marine ecosystem.
2. In filling of holes during bait harvesting will also help to replenishing bait stock, habitat improvement, and also reduce the disturbances of non-target species such as the birds that feed on such shore.
3. Monitoring of such fisherfolk to see that they minimize on bait harvesting.
4. The stakeholders can promote bait farming which will help ease pressure of the wild stocks through carrying out research on how this can be done and provision of related information to the fisherfolk through the constituted beach management units.
5. A rotational basis of the area can be done to allow areas within the sites that have experienced heavy disturbances recover from polychaete bait harvesting.
6. Afforestation and re-afforestation of the mangrove especially at Mayonda should be considered. Furthermore, protecting the existing mangrove forests at the coastline should be

further emphasized. This in the long run will help preserve the coastal environment and at the same time improve the distribution and species richness in the marine ecosystem.

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Appendix 1: Relative abundance of nematode in Mida Creek, Kenya

GENERA	Kirepwe		Dabaso				Mayonda					MEAN
	QC	QD	QC	QD	QE	QF	QC	QD	QE	QF	QG	
<i>Spirinia</i>	<u>19.8</u>	<u>28.5</u>	<u>7.8</u>	<u>41.1</u>	<u>12.9</u>	<u>43.4</u>	<u>16.3</u>	<u>30.7</u>	<u>2.6</u>	<u>2.7</u>	0.7	18.8
<i>Terschellingia</i>	<u>9.7</u>	<u>22.4</u>	<u>46.5</u>	<u>5.1</u>	<u>21.6</u>	<u>19.1</u>	<u>19.3</u>	<u>3.6</u>	1	0	0	13.5
<i>Pheronus</i>	0	0	1.7	0	0	0	0.7	0.3	<u>12.9</u>	<u>4.1</u>	<u>49.6</u>	6.3
<i>Daptonema</i>	8.9	11.5	1.9	5.1	3.8	0.5	18.6	12.2	3.6	0	0	6
Dorylaimid	0	0	0	0	0	0	0	0	<u>4.6</u>	<u>46.6</u>	<u>4.3</u>	5
<i>Viscosia</i>	2.5	0.1	1.7	1.5	0	0	<u>9</u>	<u>29.9</u>	<u>4.6</u>	<u>0</u>	<u>0.7</u>	4.6
<i>Pontonema</i>	0	0	0	0	0	0	0	0	0	<u>42.5</u>	0	3.9
<i>Paracomesoma</i>	1.8	0	0	<u>24.9</u>	<u>6.2</u>	<u>7.5</u>	0.7	0	0	0	0	3.7
<i>Synonchium</i>	0.2	0	0.8	0	0.3	0	0	0	<u>7.7</u>	0	<u>29.1</u>	3.5
<i>Dorylaimopsis</i>	0.5	14.7	0	2.5	11.6	7.2	0	0	0	0	0	3.3
<i>Haliplectus</i>	0.2	0	0.6	0	0	0	0	0	<u>28.4</u>	0	<u>7.1</u>	3.3
<i>Dichromadora</i>	14.1	1.4	1.9	0	0.8	0.3	12.3	0.8	3.1	0	0	3.2
<i>Paracanthonchus</i>	0.8	0	0.3	0	0	0	4.3	19.8	2.6	0	0.7	2.6
<i>Gomphonema</i>	6.9	2.7	0	7.1	0.3	1.8	7	1	0	0	0	2.4
<i>Chromadorita</i>	10.7	2.3	0	0	2.2	1.3	0.3	0.3	7.2	0	0.7	2.3
<i>Marylynna</i>	<u>2.7</u>	<u>4.1</u>	0	0	<u>4.9</u>	<u>12.4</u>	0	0	0	0	0	2.2
<i>Longicyatholaimus</i>	0.3	0	0	0	20.8	0	0.3	0	0	0	0	1.9
<i>Stylotheristus</i>	0	0.1	0.3	1.5	6.7	1.8	3.3	1	0	0	0	1.3
<i>Spilophorella</i>	1	0.8	5.3	0	0.5	0.3	5.3	0	0	0	0.7	1.3
<i>Megadesmolaimus</i>	0	0	12	0	0	0	1	0	0	0	0	1.2
<i>Desmodora</i>	1.2	0	1.9	0	0.3	0	0	0.3	6.2	0	0	0.9
<i>Paralinhomoeus</i>	1.5	0.1	1.1	0	3.8	1.6	0	0	0	0	0.7	0.8
<i>Sabatiera</i>	0	7	1.1	0	0	0.3	0	0	0	0	0	0.8
<i>Anoplostoma</i>	0.2	0.1	1.9	0	0	0	0	0	5.7	0	0	0.7
<i>Promonhystera</i>	1	0	0	6.1	0.3	0	0	0	0	0	0	0.7
<i>Eurystomina</i>	0	0	0	3	0	0	0	0	0	0	4.3	0.7
<i>Chromadorella</i>	0	0	0	0	0	0	0	0	5.7	0	0	0.5
<i>Bathylaimus</i>	0.2	0	4.2	0.5	0	0	0	0	0	0	0	0.4
<i>Tripyloides</i>	0.2	0	3.9	0	0	0	0	0	0	0	0	0.4
<i>Monhystera</i>	3.5	0.1	0	0	0	0	0	0	0	0	0	0.3
<i>Comesoma</i>	0	1.5	0	0	0	0	0.3	0.3	0	1.4	0	0.3
<i>Chromaspirina</i>	0	0	0.3	0	0	0.5	0	0	2.1	0	0	0.3
<i>Pareurystomina</i>	0.2	0.1	0	0	0.8	1	0.3	0	0	0	0	0.2
<i>Paramonhystera</i>	0.2	0	0	1.5	0.3	0	0.3	0	0	0	0	0.2
<i>Pierrickia</i>	1.8	0	0	0	0.3	0	0	0	0	0	0	0.2
<i>Paralongicytholaimus</i>	1.8	0.3	0	0	0	0	0	0	0	0	0	0.2
<i>Metacyatholaimus</i>	0	0.4	0	0	1.1	0.5	0	0	0	0	0	0.2
<i>Theristus</i>	1.7	0	0	0	0.3	0	0	0	0	0	0	0.2
<i>Procamacolaimus</i>	0	0	0	0	0	0	0	0	0	0	1.4	0.1
<i>Desmoscolecidae</i>	0	0	0	0	0	0	0	0	0	1.4	0	0.1

GENERA	Kirepwe		Dabaso				Mayonda					MEAN
	QC	QD	QC	QD	QE	QF	QC	QD	QE	QF	QG	
<i>Draconema</i>	0	0	0	0	0	0	0	0	0	1.4	0	0.1
<i>Microlaimus</i>	0	0	0	0	0	0	0.7	0	0.5	0	0	0.1
<i>Linhystera</i>	0.8	0	0.3	0	0	0	0	0	0	0	0	0.1
<i>Cyatholaimus</i>	0	0	1.1	0	0	0	0	0	0	0	0	0.1
<i>Metacycolaimus</i>	0	0	1.1	0	0	0	0	0	0	0	0	0.1
<i>Comesa</i>	0.8	0	0	0	0	0	0	0	0	0	0	0.1
<i>Metalinhomoeus</i>	0	0.5	0	0	0	0.3	0	0	0	0	0	0.1
<i>Chromadorina</i>	0.7	0	0	0	0	0	0	0	0	0	0	0.1
<i>Crenopharynx</i>	0.3	0	0.3	0	0	0	0	0	0	0	0	0.1
<i>Metacomesoma</i>	0.3	0.3	0	0	0	0	0	0	0	0	0	0.1
<i>Demonema</i>	0	0	0	0	0.5	0	0	0	0	0	0	0
<i>Gammanema</i>	0	0	0	0	0	0	0	0	0.5	0	0	0
<i>Nudora</i>	0	0	0	0	0	0	0	0	0.5	0	0	0
<i>Tarvaia</i>	0	0	0	0	0	0	0	0	0.5	0	0	0
<i>Oxystomina</i>	0.5	0	0	0	0	0	0	0	0	0	0	0
<i>Rhabdocoma</i>	0.5	0	0	0	0	0	0	0	0	0	0	0
<i>Neochromadora</i>	0.2	0.3	0	0	0	0	0	0	0	0	0	0
<i>Paranticoma</i>	0.2	0.1	0	0	0	0	0	0	0	0	0	0
<i>Cricolaimus</i>	0	0	0.3	0	0	0	0	0	0	0	0	0
<i>Desmolaimus</i>	0	0	0.3	0	0	0	0	0	0	0	0	0
<i>Dolicholaimus</i>	0	0	0.3	0	0	0	0	0	0	0	0	0
<i>Eubostrichus</i>	0	0	0.3	0	0	0	0	0	0	0	0	0
<i>Molgolaimus</i>	0	0	0.3	0	0	0	0	0	0	0	0	0
<i>Pandolaimus</i>	0	0	0.3	0	0	0	0	0	0	0	0	0
<i>Rhabdodemia</i>	0	0	0.3	0	0	0	0	0	0	0	0	0
<i>Siphonolaimus</i>	0	0	0	0	0	0.3	0	0	0	0	0	0
<i>Campylaimus</i>	0.2	0	0	0	0	0	0	0	0	0	0	0
<i>Chromadora</i>	0.2	0	0	0	0	0	0	0	0	0	0	0
<i>Didelta</i>	0.2	0	0	0	0	0	0	0	0	0	0	0
<i>Eleutherolaimus</i>	0.2	0	0	0	0	0	0	0	0	0	0	0
<i>Graphonema</i>	0.2	0	0	0	0	0	0	0	0	0	0	0
<i>Hopperia</i>	0.2	0	0	0	0	0	0	0	0	0	0	0
<i>Monoposthia</i>	0.2	0	0	0	0	0	0	0	0	0	0	0
<i>Paracyatholaimus</i>	0.2	0	0	0	0	0	0	0	0	0	0	0
<i>Pomponema</i>	0.2	0	0	0	0	0	0	0	0	0	0	0
<i>Stygodesmodora</i>	0.2	0	0	0	0	0	0	0	0	0	0	0
<i>Trochamus</i>	0.2	0	0	0	0	0	0	0	0	0	0	0
<i>Valvaelaimus</i>	0.2	0	0	0	0	0	0	0	0	0	0	0
<i>Laimella</i>	0	0.1	0	0	0	0	0	0	0	0	0	0
<i>Filoncholimus</i>	0	0.1	0	0	0	0	0	0	0	0	0	0
<i>Halichoanolimus</i>	0	0.1	0	0	0	0	0	0	0	0	0	0
<i>Paramesonchium</i>	0	0.1	0	0	0	0	0	0	0	0	0	0

	Kirepwe		Dabaso				Mayonda					
GENERA	QC	QD	QC	QD	QE	QF	QC	QD	QE	QF	QG	MEAN
<i>Actarjania</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Prorhynchonema</i>	0	0	0	0	0	0	0	0	0	0	0	0
Number of nematode identified	792	776	359	198	371	388	301	395	194	73	141	362.55
Number of genera	27	16	30	12	22	18	18	12	19	7	12	17.55
Nematode Density	219	214	198	217	204	213	166	217	107	40	78	170.27