The distribution of zooplankton in relation to physical parameters along a transect (23°S) off Walvis Bay.

BY:

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Declaration

I hereby declare that this work is the product of my own research efforts, undertaken under the supervision of Dr. S. Mafwila and has not been presented elsewhere for the award of the degree. All the sources have been duly and appropriately acknowledged.

Candidate Signature: ……

Date: ……..

Simon Nkumbwa (200849361)

Certification

This is to certify that this report has been examined and approved for the award of the degree of Bachelor of Science in Fisheries and Aquatic Science of the University of Namibia.

External Examiner…….....

Internal Examiner…….....

Supervisor(s)…….....

Head of Department…….....

Acknowledgement

First of all I would like to thank the Almighty God for giving me the strength to complete this work and secondly the Department of Fisheries and Aquatic Sciences, University of Namibia, for their commitments toward completion of my project. I also would like to thank Mr Richard Haraeb from ministry of fisheries and marine resources who has helped me in collection and analysis data. I extend my handful thanks to my supervisors Dr S. Mafwila for his support and dedication toward the completion of this project. I am appreciative of the support and tremendous help from Lyakonga family in Walvis Bay, NATMIRC stuff, colleagues and all my classmates toward the success of this project.

Dedication

I dedicate this work to my lovely family especially my parents for their support and encouragement throughout my studies. I also like to thank my late cousin Kanyanga who could not see his effort through me. To my supportive and good friend Erika Mokanya, all relatives and other friends for their encouragement and word of strength.

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ABSTRACTS

The study provides the first quantitative analysis of changes in zooplankton abundance and community structure in relation to physical parameters in the Walvis Bay area, off Namibia. Zooplankton was collected July 2012 along 23^{o}S line from 2 to 70-nautical-mile transect. Calanoid copepods were numerically the most abundant mesozooplankton, *Metridia lucens*, *Calanoides carinatus*, *Rhincalanus nasutus* and *Centropages brachiatus* being the most common species, with each exhibiting a specific distribution pattern. However, abundances were exceptionally low inshore and high offshore when upwelling was most intense. transport is believed to be responsible for copepod losses from the area during that period. Abundances of *Am*phipoda were high inshore between 2 and 20, at the onset of the upwelling season, and peaked at 40 t0 70nmi.

Keywords: calanoid copepods, *Calanoides carinatus*, *Metridia lucens*, northern Benguela, upwelling

CHAPTHER ONE

1. INTRODUCTION

The Namibian coast is covered by the cold Benguela current and forms part of the Benguela Current Large Marine Ecosystem (BCLME). The Benguela is one of the four major current systems of the world oceans and it is similar to that of the Canary Current off north-west Africa, the California Current off the west coast of the USA, and the Humboldt Current of Peru and Chile (Shannon and Nelson 1996). They are all characterized by intense upwelling of cold, nutrient-rich waters along the coast due to Ekman transport that transport shore water offshore, a divergence in response to equator ward wind stress (Shannon and Nelson, 1996; Shillington 2006). Upwelling areas are important centre's of plankton (phytoplankton & zooplankton) production and support large biomass of mid-trophic level fish such as sardine and anchovy, as well as seabirds and marine mammals (Lebourges-Dhaussy 2009, Coetzee 2009).

The Benguela Current Large Marine Ecosystem (BCLME) is a complex and highly variable systems for which the evidence of system change and fragmentation. However, important evidence pointing to increasing instability and variability due to climate change as the primary driving forces for large marine Ecosystem (LME) and intensive fishing as the secondary driving force (Shannon *et al* 2003). The Global Environmental Facility (GEF) is supporting ecosystem-based project that three countries (Angola, Namibia & South Africa) government requested. The Program aims to integrating management, sustainable development and environmental protection.

The three countries have addressed trans-boundary issues by preparing a Trans-boundary Diagnostic Analysis (TDA) and implementing a Strategic Action Programme (SAP) through Benguela Current Commission under the ministries of Fisheries and Marine resources.

1.2. ZOOPLANKTON

Zooplankton distinguished from phytoplankton either on the basis of morphology or mode of nutrition (autotrophic or heterotrophic). The mean densities of zooplankton are low across the widest part of the shelf and west of 23^{o}S, but increase towards the coastal areas of the south and east coast of Atlantic Ocean (Lebourges-Dhaussy, 2009). The highest concentration found close inshore are associated with the cool up welled water on the south coast. Integrated biovolume is highest towards the shelf edge on the east coast, but is also elevated in most offshore areas further to the west (Oliver et al, 1990).

Zooplankton can be categorized in different ways using their life-cycles strategy and trophic guild or taxon. There are two most characteristics to consider when grouping zooplankton. Firstly, organisms of a particular size have common physiological rate processes irrespective of taxon. Secondly, the pelagic food web is essentially size based which means big organisms eat small organisms. Gibbon (2007) outlines that the four zooplankton size classes are Micro-zooplankton (2-200µm), Meso-zooplankton (200µm-2mm), Macro-zooplankton (2-200mm), Mega-zooplankton (>200mm).

Zooplankton sampling in the northern Benguela Current region off Namibia has been conducted on a semi-routine basis since the late 1950s (Hansen, 2005). Small planktonic marine copepods (< 1 mm in length) are undoubtedly the most abundant metazoans in the marine water systems. Although small copepods zooplanktons are abundant, they have been historically under sampled due to the use of nets with meshes > 200-333 μm (Turner, 2004). Failure to account for small copepods may cause serious underestimations of zooplankton abundance and biomass, the copepod grazing impact on phytoplankton, zooplankton-mediated fluxes of chemicals and materials and trophic interactions in the sea (Wesmund et al,2005).

Historically, the area around Walvis Bay (23°S) has been studied most intensively owing to its importance to the region's fisheries and because it has been a main spawning area for sardine *Sardines sagax* (Cloete, 2005). These microscopic organisms play a key role in the pelagic food web by controlling phytoplankton production and shaping pelagic ecosystems. Zooplankton are food source for larval and juvenile fish, therefore their population dynamics, reproductive cycles, growth, reproduction and survival rates are all important factors that influencing recruitment of fish stocks (Harris, 1999).

SCOPE OF THE RESEARCH

The study will provide a quantitative analysis of changes in zooplankton abundance and community structure in the Walvis Bay area, off Namibia. Zooplankton transfer organic material and energy to higher trophic levels such as the pelagic fish stocks, commercially exploited. Since zooplankton organisms play a critical role as a food source for larval and juvenile fish, the dynamics of zooplankton populations, their reproductive cycles, growth, reproduction and survival are all important factors influencing recruitment of fish stocks (Ayon *et al.* 2008). Therefore, studying zooplankton abundance is important, as it gives important information on the potential feeding conditions and since marine food webs are size based, a slight but sustained change in zooplankton may lead to an alternation of the balance between species of fish or result in subsequent declines (Gibbons 1997). Furthermore, the distribution of zooplankton biomass and species abundance in relation to physic-chemical and biological parameters is important in understanding the structure and functioning of marine plankton communities in dynamic upwelling regions such as the Benguela.

The position of fish population within ecosystems is influenced by a series of top down and bottom factors (influenced by its predators and its prey). There is no commercial fish species within Benguela ecosystem that is not influenced by zooplankton. Gibbons (1997) outlines that zooplankton provide the food for the adult stages of most small pelagic fishes such as anchovy, sardine, chub mackerel and round herring. They also provide food for the early juveniles of large pelagic (tuna, snoek), meso-pelagic (lightfish, lantern fish, horse mackerel) and demersal fishes (hakes). Studies of zooplankton abundance or growth are very important because they give an indication of potential feeding condition available.

Each fish species feed on zooplankton in different ways that cause in alteration to the size composition of the assembled or change from crustaceans to salps resulting in population decline. However, zooplankton is also predators of fishes during their larval stage and can influence their survival increasing the recruitment rate (Gibbon, 1997).

ESTIMATION ZOOPLANKTON ABUNDANCE

Zooplanktons are very small and it is difficult to rely on estimating the abundance of micro-zooplankton using nets. In general, they are counted directly from water samples and these water samples can be collected by the bucket at the surface or from the rosette of Niskin bottles on the Conductivity Temperature Depth instrument. Most zooplankton has a limited ability to escape plankton nets and can be reliably caught using vertical Bongo nets when vessel is stationary. The nets should be fitted with a 200µmm mesh and have a solid cod-end. Micro- zooplankton can be collected from the bottles, which are used to sample seawater for chemicals. Most macro-zooplankton including fish larvae are not represented in the vertical net samples because they are often able to detect and avoid the nets especially during day times. If nets are to be used to estimate their abundance or biomass they should be large mouth area and wide mesh diameters (500µm) and should be towed (4 knots) at night (Gibbon, 1997)

1.3. LITERATURE REVIEW

Several research programs have been conducted in the tropical Atlantic in the past two decades. The recent programs like the Western Tropical Atlantic Experiment (WESTRAX) and the world Ocean Circulation Experiment (WOCE). The extend and intensity of coastal upwelling throughout the Benguela is primarily determined by the wind/pressure field together with topographic features and orientation of the coast resulting in the formation of upwelling cells (Nelson & Hutchings 1983, Shannon & Nelson 1996). Zooplankton biomass can be determined using either its dry or wet mass. According to Larson (1986), he grouped marine zooplankton based on their elemental content into three groups: the gelatinous plankton (cnidarians, ctenophores, salps) with very low and variable nitrogen and carbon percentages the non-gelatinous group (crustaceans, larvaceans) with high elemental content of low variability and the semi-gelatinous plankton (molluscs, chaetognaths). However, zooplankton ranges over five size classes from nanoplankton to mega plankton based on the mesh sizes (Lenz, 1992).

The zooplankton distribution governed by water depth, trophic status of the area and temperature regime and any other physical parameters of the ocean (Nelson *et al*, 1985). Water depth separates neritic from oceanic plankton. Neritic plankton inhabits inshore waters up to about 200m at the shelf edge. Characteristic of neritic plankton is a high proportion of meroplankton larvae and species with benthic resting eggs. The proximity to the sea bottom favours an exchange between plankton and benthos communities. Oceanic zooplankton on the other hand characterized by a general absence of meroplankton and the presence of distinct vertical migration (Hanse *et al*, 2005). The epipelagic zone (0±200 m) and mesopelagic zones (200±1000 m) is the main domain of zooplankton (Lenz, 1992).

Due to the prevailing currents and advection of new water masses, it is often virtually impossible to follow the same population of organisms every season (Huntley and Niiler, (1995). The growth and metabolism of zooplankton organisms are governed by the interaction of a number of forces, which may be either internal or external. Internal factors are body size and physiological properties, such as range of temperature tolerance, developmental stage and physiological state.

The External factors are food supply and nutritional properties of food, as well as various environmental factors such as temperature, salinity and oxygen saturation, which are the physical parameters of the oceans that determined the zooplankton (Gibbon, 1997). Zooplankton organisms inhabit all regions of the sea, according to their physiological and temperature adaption and tolerance limits (Nielsen 1979). The growth and metabolism of zooplankton organisms are governed by the interaction of a number of forces that may be either internal or external. Internal factors are body size and physiological properties, such as range of temperature tolerance, developmental stage and physiological state. Feeding activity, for instance, depends on the molting cycle in crustaceans. External factors are food supply and nutritional properties of food, as well as various environmental factors such as temperature, salinity and oxygen saturation (Lenz, 1994).

The dynamic, three-dimensional nature of the pelagic environment poses a number of problems for zooplankton and each must have a suit of adaptations that allow their survival. Gibbon (1997) stated the biggest problems facing zooplankton is that of sinking, based on the water property anything, which is denser than water, will sink. It is problem because most zooplankton needs to stay close to surface where their food is found.

In order to stay near surface they either swim all the time, this costs a lot of energy, which could be used for other things. Aquatic organism's posse's gas floats to reduce density (Gibbon, 1997). Another mechanisms that marine organisms is oil and fats found in large concentrations within the body tissues of planktonic organisms and this floatation helps serve a dual function since it can supply food to organisms. Furthermore, small size, spiny or flat is other characteristics, because spiny or flat has relatively large surface area it has a lots of resistance to sinking.

Zooplankton can avoid nets, optical instruments and profiling packages based on previews studies (Wiebe and Benfield, 2003). Avoidance can substantially affect the measurements of biomass, animal size, species composition and behaviour (Ianson *et al*, 2004). Experimental manipulation of the profiler and its instruments revealed that an open-path flow meter was triggering the avoidance and it showed that voidance occurred at an average of 8 m below the profiler with a range between 2 and 13 m (Kelly *et al*, 2009). To know body size, developmental stage and physiological state of a plankton organism and the temperature conditions, it is the only possibilities to calculate the potential growth rate.

In marine copepods, where dominant species often vary comparatively little in body size, temperature has demonstrated as the main factor governing their growth rate (Huntley and Lopez 1992). Physical stress factors such as reduction in salinity and oxygen content limit species distribution and diminish growth and body size in those species that are able to tolerate these adverse environmental conditions (Lenz, 1992).

1.4. AIM

The aim of this study is to investigate distribution of major zooplankton groups in relation to physical parameters off Walvis Bay, transect (23^{o}S).

1.5. OBJECTIVES

The main objectives of this research were to determine the distribution composition, abundance, taxonomy of major crustacean zooplankton along 23^{o}S off Walvis Bay.

The second objectives were to determine how temperature, oxygen and salinity affect the distribution of zooplankton.

1.6. RESEARCH HYPOTHESIS

1.6.1. Zooplankton abundance and community structure differ across the (23^{o}S) transect

1.6.2. Temperature, salinity and oxygen affect zooplankton distribution across the 23^{o}S transect differentially

1.6.3. Horizontal distribution and interaction of zooplankton along Walvis Bay transect (23^{0}S

CHAPTER TWO

MATERIALS AND METHODS

2.1. DATA COLLECTION

2.1. SAMPLE COLLECTION (AT SEA)

The National Marine Information and Research Centre of the Ministry of Fisheries collected zooplankton sample and Marine Resources at Swakopmund, through the regular monthly oceanographic monitoring survey (MOM) of the 23°S transect off Walvis Bay, with the research vessel *RV Welwitchia*.

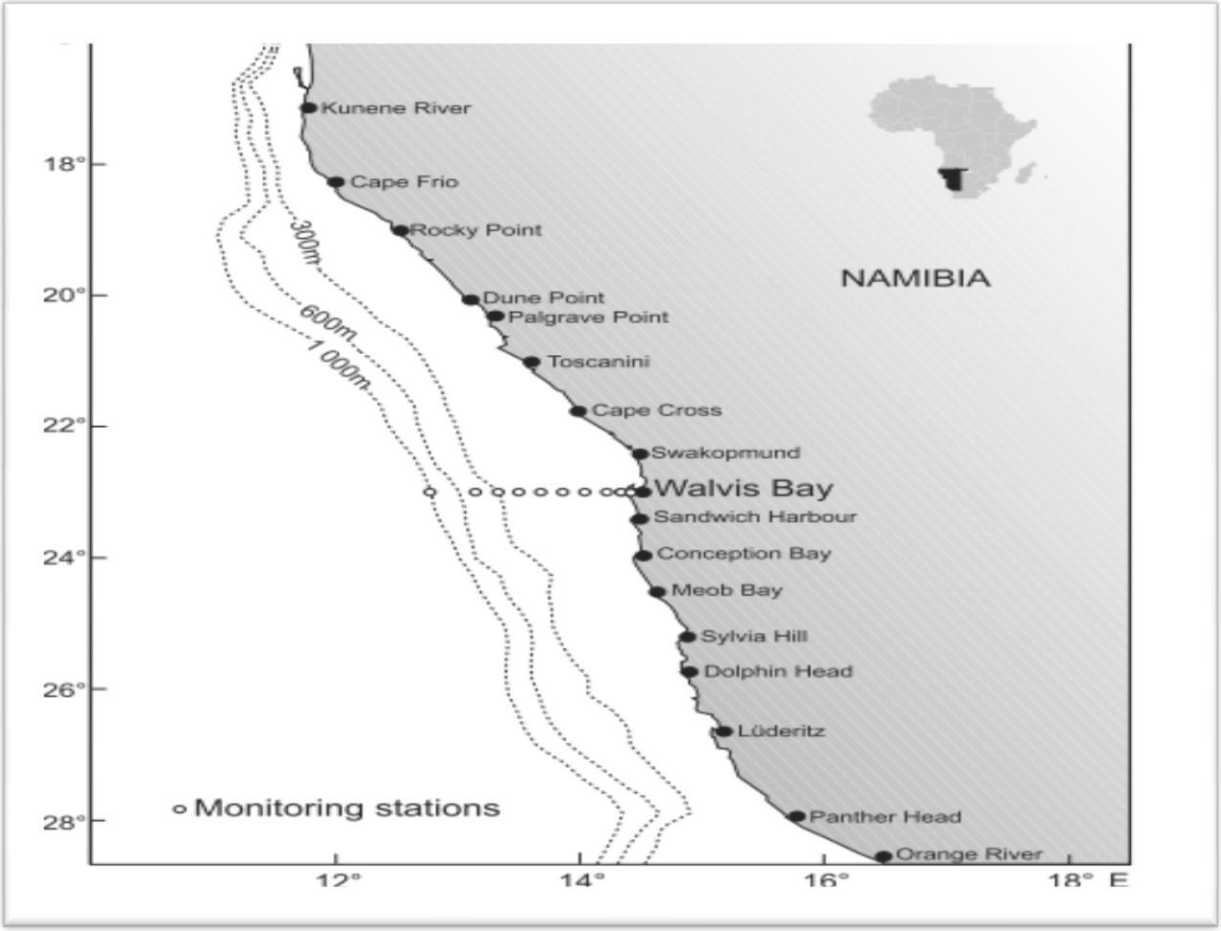


Fig.1.1 *Map of the Namibian coast, showing the monitoring line at 23 °S off Walvis Bay with sampling stations, (modified after Hansen et al. 2005).*

The sampling stations are located at two and 5 nautical miles (nm), and then every 10 nm till 70 nm in an offshore direction on the monitoring line (**Fig.1.1**).

Zooplankton samples were collected during the April survey using the UNESCO WP-2 net (200-μm mesh), hauled vertically at an average towing speed of 0.75m s–1 from 200m (or 10m from the bottom if shallower) to the surface. Flow was measured with a calibrated Hydro Bios digital flow meter oriented eccentrically in the mouth opening of the net. The depth of the net was monitored using a Scanmar acoustic depth sensor, attached to the net frame. All samples were fixed and preserved for taxonomic analyses in 4% formaldehyde-seawater solution buffered prior with sodium tetraborate after removal of jellyfish. It is important that all zooplankton samples be labelled at the time of collection. The labels should contain information on the place of collection, the date and time, as well as the method of collection.

All labels should be clearly written on waterproof papers and inserted inside the samples Jar. It is written in either soft pencil or ink that will not run in chosen fixative/preservative and should be written on top of the sampled jar in labelled form as indicated in (*figue.1.2*).

DATE:.....
TIME: .....
CRUISE NO: .....
STATION NO: .....
GEAR: .....
DEPTH: .....

FIGUE: 1.2. *The format of this label shows typical labelled form added to zooplankton samples at sea.*

In addition to zooplankton, environmental parameters (i.e. temperature, salinity and dissolved oxygen concentration) were also measured concurrently at each station with a CTD. A record of all the samples collected should be written into the daily log sheet at sea as it is shown in (Table: 1.1). The log sheets should contain information on the flow-meter readings, the depth of haul and duration of the haul nets and stations.

Table 1.1. Station protocol data for the sampling period in the local time (GMT +2), showing the sampled stations and time.

Date	Station	Lat degrees	Long degrees	depth	Time in	Time out	Flow-meter start	Flow-meter type
5-Jul-12	WW23002	-23	14	39	12:30	12:32	36140	digital flow-meter
5-Jul-12	WW23005	-23	14	71	13:33	13:36	36230	digital flow-meter
5-Jul-12	WW23010	-23	14	105	14:47	14:51	36371	digital flow-meter
5-Jul-12	WW23020	-23	14	129	16:17	16:21	36602	digital flow-meter
5-Jul-12	WW23030	-23	13	140	17:49	17:55	36893	digital flow-meter
5-Jul-12	WW23040	-23	13	149	19:00	19:20	37238	digital flow-meter
5-Jul-12	WW23050	-23	13	227	21:10	21:16	37592	digital flow-meter
5-Jul-12	WW23060	-23	13	368	23:05	23:10	38124	digital flow-meter
5-Jul-12	WW23070	-23	13	380	1:10	1:20	38894	digital flow-meter

2.2. TAXONOMIC ANALYSIS (LABORATORY)

First thing to do in the laboratory is to let the sample volumes to settle; this is done to provide a crude estimation of total plankton abundance and must be recorded because it allows comparison with historic data sets. When the sampled volumes settled rinse zooplankton sample into a measuring cylinder of appropriate size. Agitate the sample by inverting it a couple of times and leave it for 24 hours. It is very important to tap the cylinder gently every couple of hours in order to ensure the plankton settle properly (Gibbon, 2007).

2.2.1 MESO-ZOOPLANKTON

These are zooplankton (200µm-2mm), the sample should be first filtered through a 200 µm sieve and the preservative replaced with filtered seawater to a volume approximately x10 that of the plankton. Record the volumes of seawater used and keep the preservative. The plankton was maintained in suspension by bubbling air through samples and at least two (preferably three) sub-samples of 2 ml volumes should be removed with a Plunger Sampling Pipette account to Hansen (*figue.1.3*) it is a complete with dilution bottle 250 ml and stopper, ranged 0.1 to 5.0 ml

Figue 1.3. Plunger sampling pipette account to Hansen.

The 2 ml in the Plunger pipette account to Hansen was poured into the Counting Chamber for zooplankton (*figue.1.4*) where individual taxa are counted under a microscope.

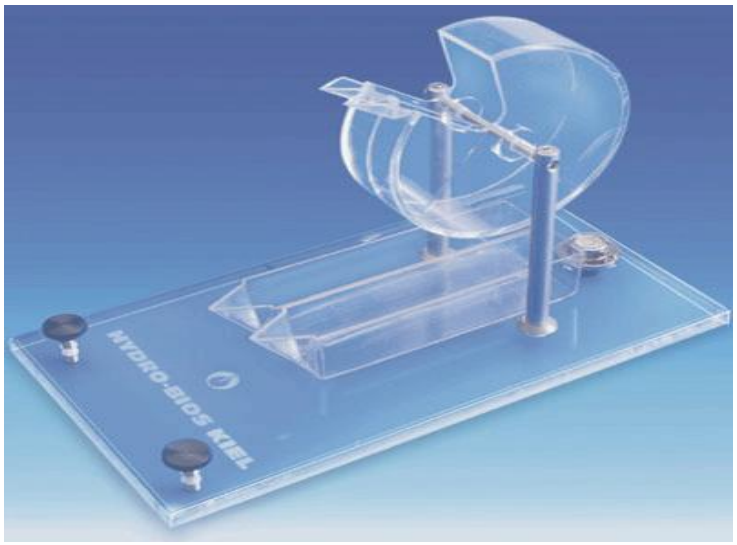
Figue.1.4*.counting chamber for zooplankton*; *made of plexiglass with polished bottom for the best transparency and it has a dimensions 40 ×70 (mm).*

Estimation of zooplankton total abundance in the sample was determined by dividing the volume of seawater used to suspend the samples by two and multiplying by the average abundance per 2ml sub-sample as showed in the formula.

No_m^2= ((((sample volume*average)/subsample volume)/split part)/volume filtered)

2.2.2. MACRO-ZOOPLANKTON

The sample was filtered through a 200µm sieve and the preservative was replaced with filtered seawater. Reverse the preservative, poured the whole sample carefully into a previously labelled Folsom Plankton splitter (*figue.1.5*); ensure that it is poured into the part splitter, which does not have the separation bar. The sample was splitter into two equal parts by rotating the splitter and pouring each part out into appropriately labelled containers. Rinse side of the splitter with filtered seawater using a wash- bottle.



Figue.1.5. *Folsom's plankton sample divider; for dividing large amount of plankton into an amount suitable for examination, dividing the sample into two halves in one operation.*

Two sub-samples each contain half of the original plankton volume. Set one aside, add more seawater to the other container and split it again into half. Repeat the sample splits process to until desired sub-samples of a size that to be counted effectively is reached. Using 5ml Plunger pipette account to Hansen to remove sub-samples and poured into Counting Chamber for zooplankton (*figue.1.4*). Start counting zooplankton under microscope with the smallest sub-samples, for instance if the samples were split 4 times; ½ , ¼, 1/8, 1/16 always starts counting sub-sample 1/16… to ½. All the observed or counted zooplankton is recorded in the tally form using tally mark…

2.3. STATISTICAL ANALYSIS

Surfer and primer software were used to perform different statistical analysis, generate diagram and graphs on physical parameters and Primer to determine the similarity of species diversity. Excel was used in arranging data to generate graphs.

CHAPTER THREE

RESULTS

3.1. Abundance and distribution of major groups of zooplankton

The major groups of zooplankton that were found are Amphipoda, Appedicularia, Bivalvia, Crustacea,calanoida,Copepodes,Cyclopoida,Poecilostomatoida,Cladocera,Cumacea,Echinoderm, Polychaeta, Protozoa, Ostracoda and other zooplankton groups Table1.3. Calanoida, Poecilostomatoida, Amphipoda and Cyclopoida were the most abundance group foud at each sampling station. Species such as Calanoides carinatus, Metridia, Centropages, Nannocalanus, Rhinchalanus and other zooplankton species belong to calanoida group as indicated in the table.1.2. Nannocalanus were most abundance species at all sampling stations, highest abundance were recorded at 50nm with a peak of 12312, decreasing to 595 at 30nm from the shore. Rhincacalanus species abundance across entire transect 23^{o}S were markedly zero, only 679 were recorded at 60nm table1.2. Cladocera becoming less and less offshore, while copepodes increasing offshore with 380667 at 70nm table1.3.

Table1.2. Calanoida distribution and composition.

Station	Calanoides carinatus	Metridia	Centropages	Nannocalanus	Rhincalanus	Other calanoida
WW23002	70	0	0	5434	0	0
WW23005	111	111	0	1223	0	0
WW23010	0	537	537	4298	0	269
WW23020	0	214	0	1709	0	0
WW23030	99	14583	99	595	0	198
WW23040	0	31864	1738	8690	0	579
WW23050	1071	11776	535	12312	0	535
WW23060	1357	19001	339	11536	679	1357
WW23070	1002	10018	0	5009	0	7012

Table1.3. Major zooplankton group distribution and abundance

Station	Copepods	Cyclopoida	Cladocera	Crustacea	Gelatinous	Other Zooplankton
WW23002	14212	5364	2375	0	0	2856
WW23005	19233	11006	1001	0	445	2779
WW23010	81657	58557	16922	269	537	32233
WW23020	39102	28419	1923	321	214	4915
WW23030	22817	4762	0	397	0	694
WW23040	105440	55038	0	0	0	59672
WW23050	268177	168079	0	8565	535	16059
WW23060	138093	60395	0	0	0	11536
WW23070	380667	193339	0	7012	0	15026

Zooplankton distribution, composition and abundance rely more on the physical parameters. The average temperature at 2nm was 12.879^{o}C while salinity and oxygen is 35.205 and 2.814 respectively table.1.4. There was a low variation in temperature from inshore to offshore and th low temperature was recorded at 60nm with 176.131 depth. Salinity decrease offshore with increasing depth while oxygen was increasing offshore with increasing depth. The species composition at each sampling point was determined in relation to physical parameters. The highest species composition were analysis at 50nm and the abundance at 70nm with a 398 700.

Table.1.4. Physical parameters and zooplankton distribution

station(nm)	Depth(m)	density	temperature	salinity	oxygen	zooplankton	mean	species
23002	16	26.561	12.879	35.205	2.814	16 651	1289	13
23005	30.5	26.577	12.756	35.194	2.34	22567	1075	21
230010	50	26.595	12.589	35.174	1.955	110400	6133	18
230020	61.5	26.577	12.735	35.163	2.606	44449	2339	19
230030	66	26.547	12.729	35.151	2.763	18946	1053	18
230040	70.5	26.527	12.97	35.186	2.537	165112	11007	15
230050	109.5	26.59	12.474	35.144	2.437	293334	13333	22
230060	176.131	26.706	10.933	34.946	3.334	149629	8313	18
230070	153.078	26.667	11.315	34.978	3.508	398700	19935	20

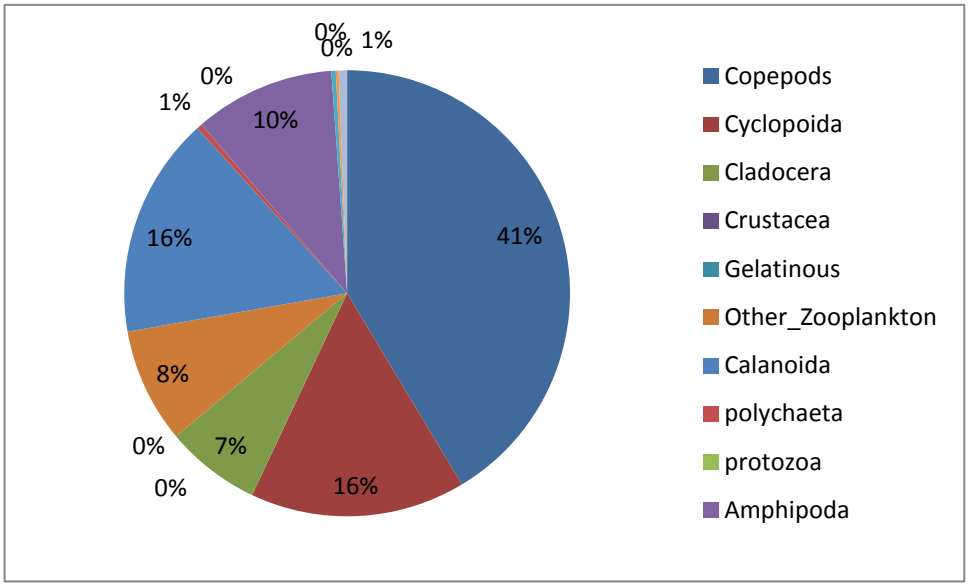


Figure.1.6. Zooplankton distribution along 23^{0}S line off Walvis Bay, copepods was the most abundance on the areas. Calanoida and Cyclopoida both have 16% equal distributed in the area.

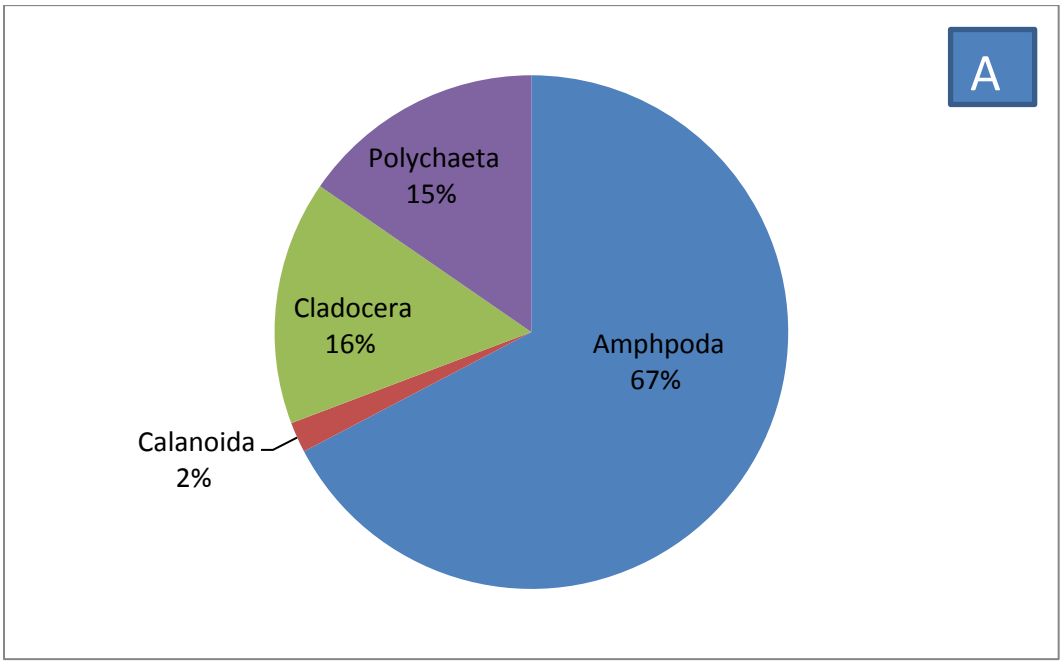


Figure.1.7. Zooplankton distribution 2nmi.

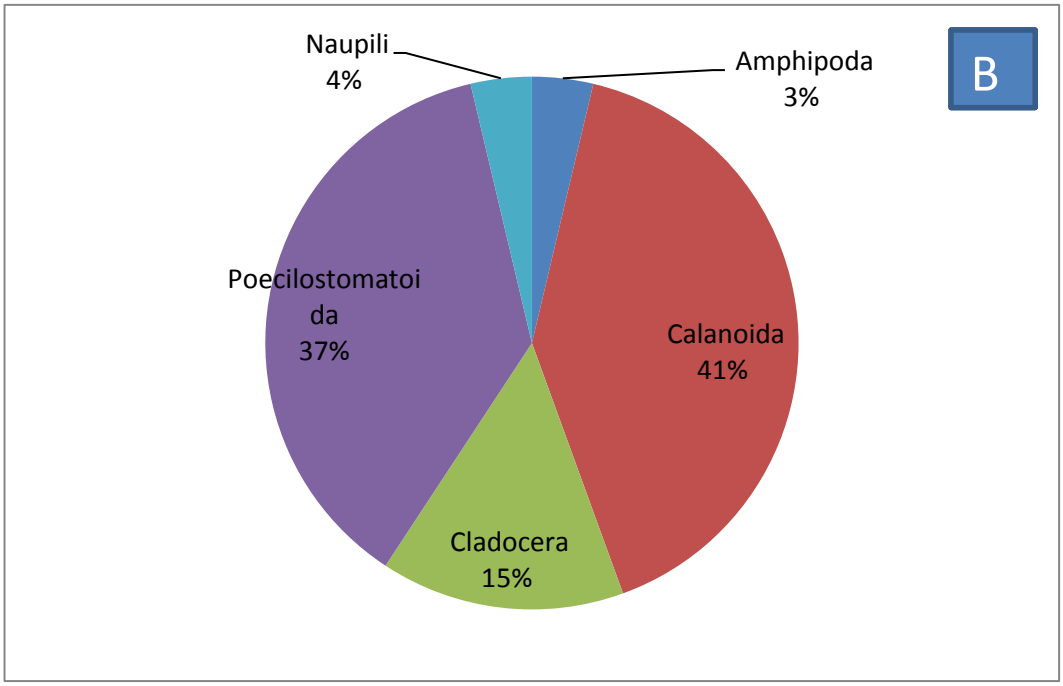


Figure.1.7b. Zooplankton distribution at 20nmi

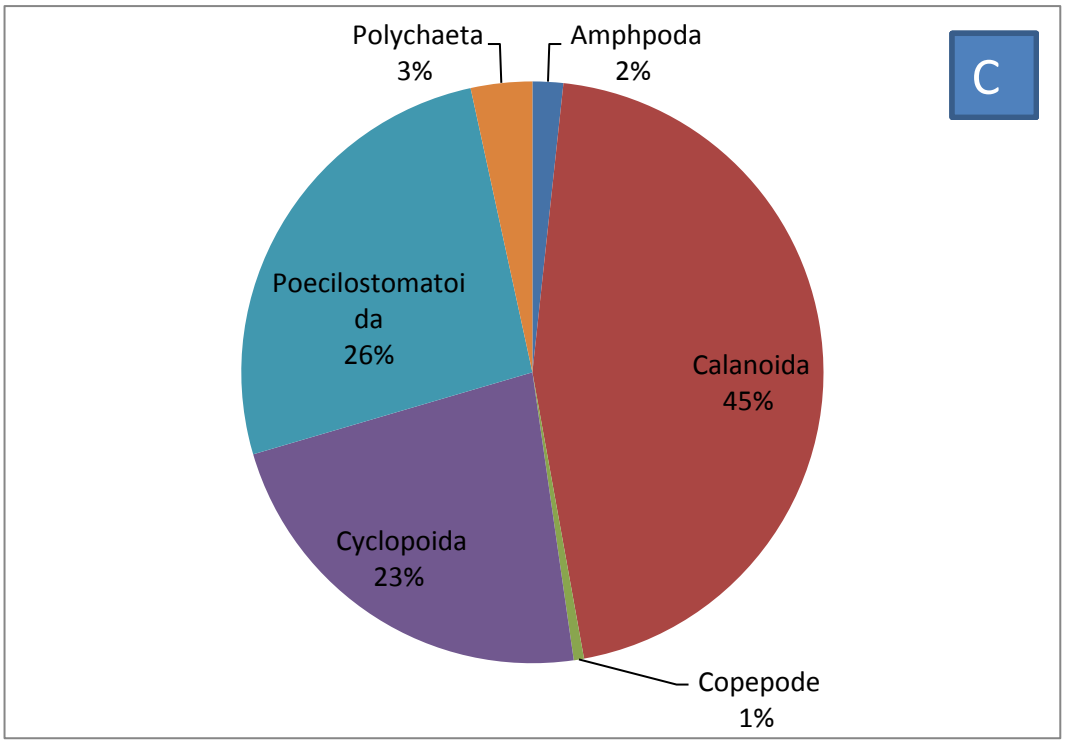


Figure.1.7c. Zooplankton distribution at 40nmi

Inshore at 2nm, Amphipoda was most abundance increasing to 67% and Calanoida were the least with 2% figure.1.7a. However from inshore to offshore Calanoida were dominating, from 2% at 2nm and 41% at 20nm while Amphipoda decreasing to 3% and poecilostomatoi at 37% figure 1.7b. Calanoida steadily increasing from inshore to offshore, at 40nm is 45% leading the zooplankton distribution at the transect 23^{o}S off Walvis Bay. The zooplankton group is not even distribution along the 23oS line due to the facts that some species are increasing toward offshore and others increasing toward inshore. Calanoid showed a complex distribution pattern of multiple peaks, usually in the offshore zone figure.1.8a and copepods approaching 400 000 at 70nm as it indicated in figure.1.8b. Species abundance were increasing with depth, the highest number per m^2 were identified at 70nm with 193339 Oithona, which belong to Calanoida. It is almost 100% distributed offshore as was indicated in figure. 1.8a.

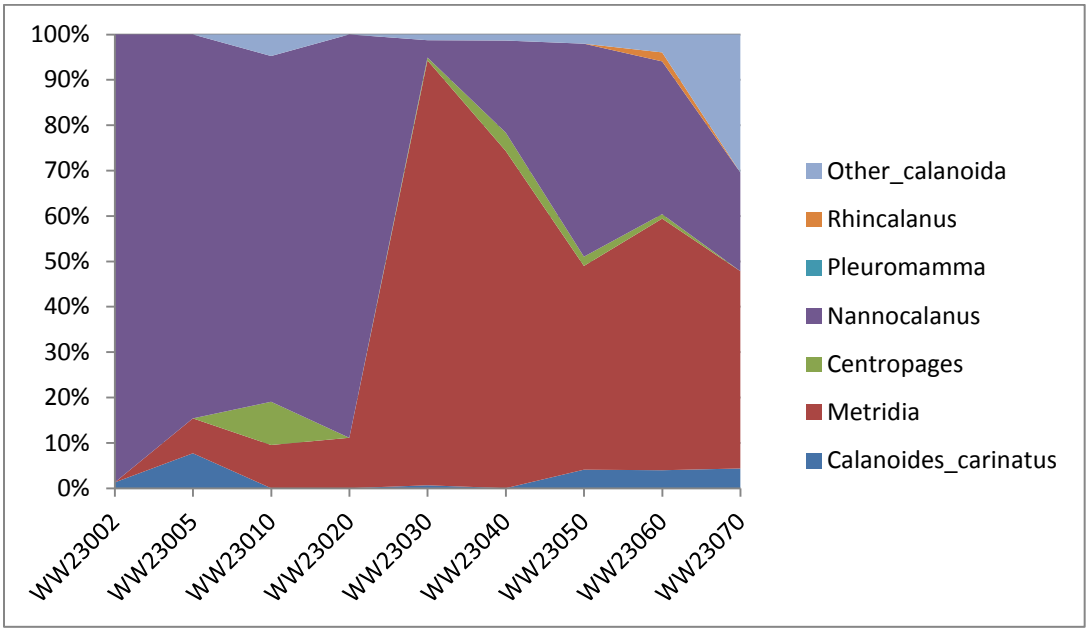


Figure.1.8A. Calanoides distribution along 23^{o}S line.

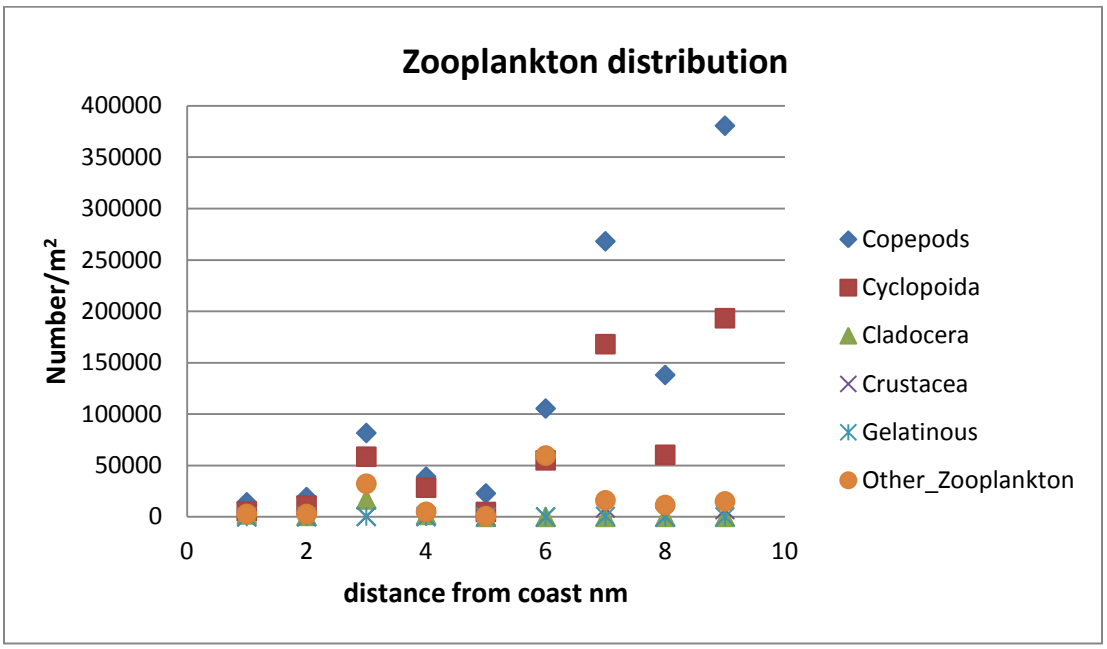


Figure.1.8B. zooplankton groups excluding calanoida

3.2. The relationship between physical parameters and zooplankton

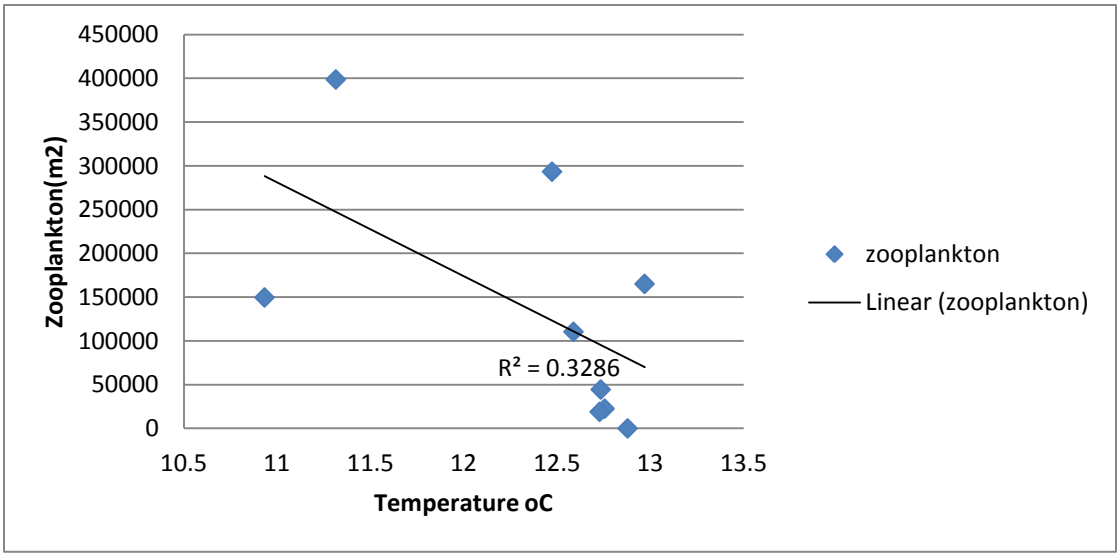
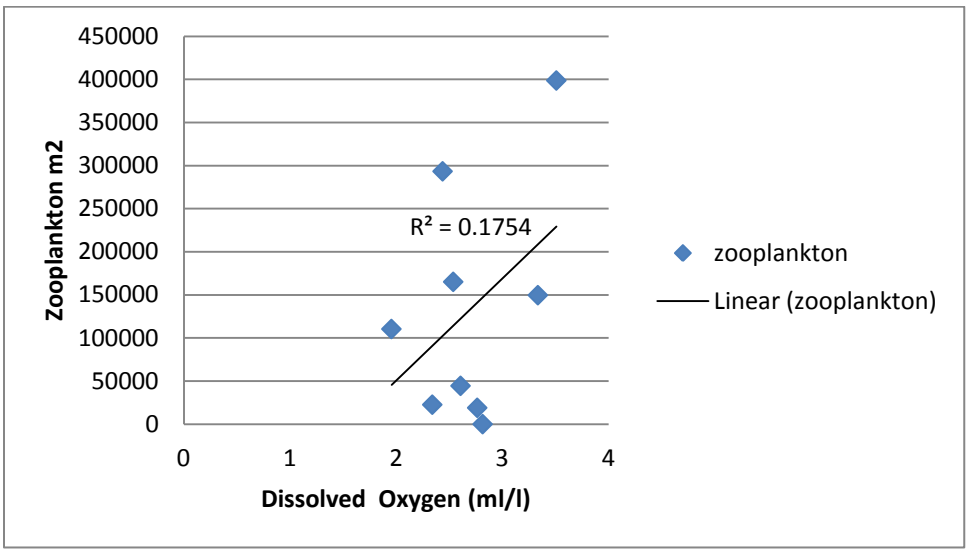


Figure.1.9 show the relationship between temperature and zooplankton, there was a linear relationship based on R2. Decrease in temperature increases zooplankton and vice verse.



Figue.1, 10. A positive relationship between zooplankton and .1, there was a positive relationship between zooplankton and dissolved oxygen. Increase in the DO increases zooplankton distribution and abundance in the water system.

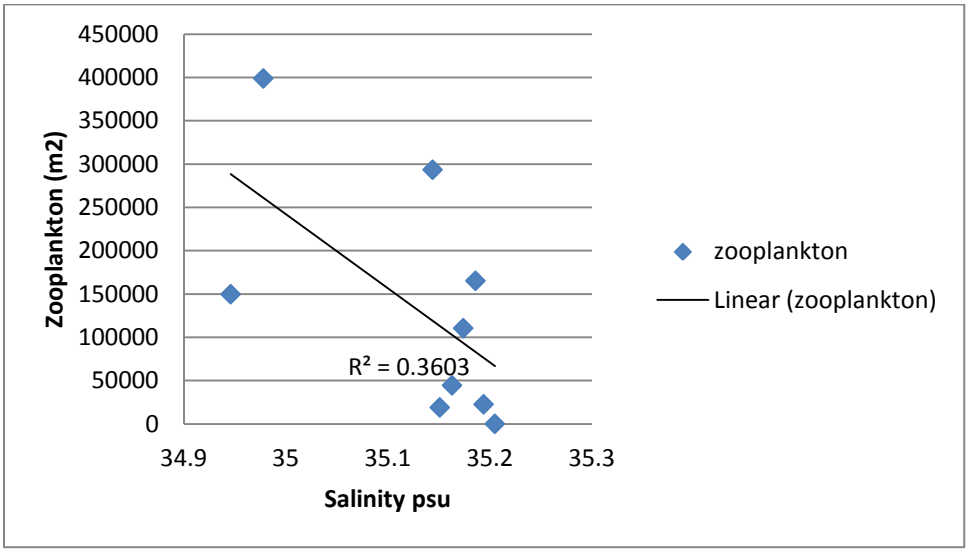
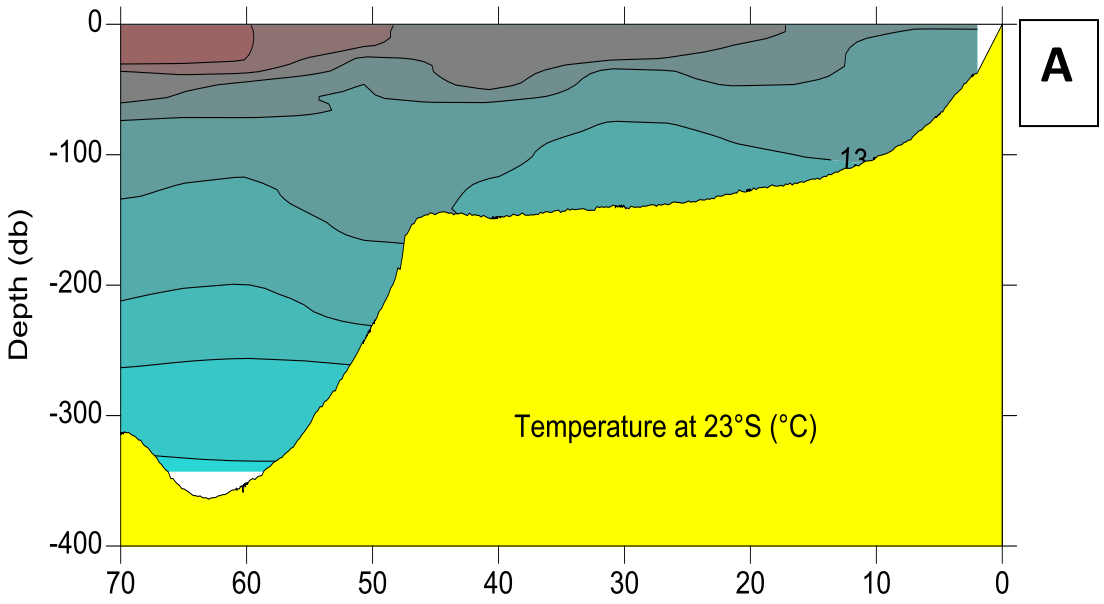
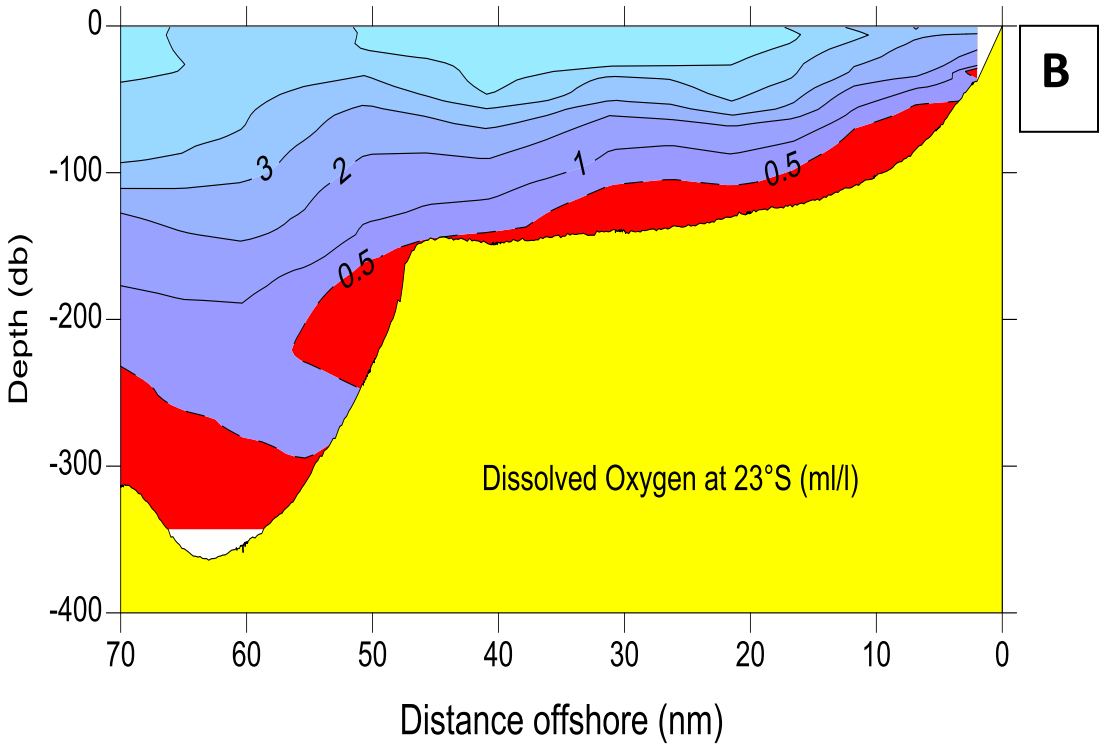


Figure.1.11. show negative linear relationship between zooplaankton and salinity,decrease in salinity increases zooplankton composition and incease in salinity decreases zooplankton composition. Average salinity required by zooplankton was between 35.1psu and 35,2 psu.

3.3. Physical parameters





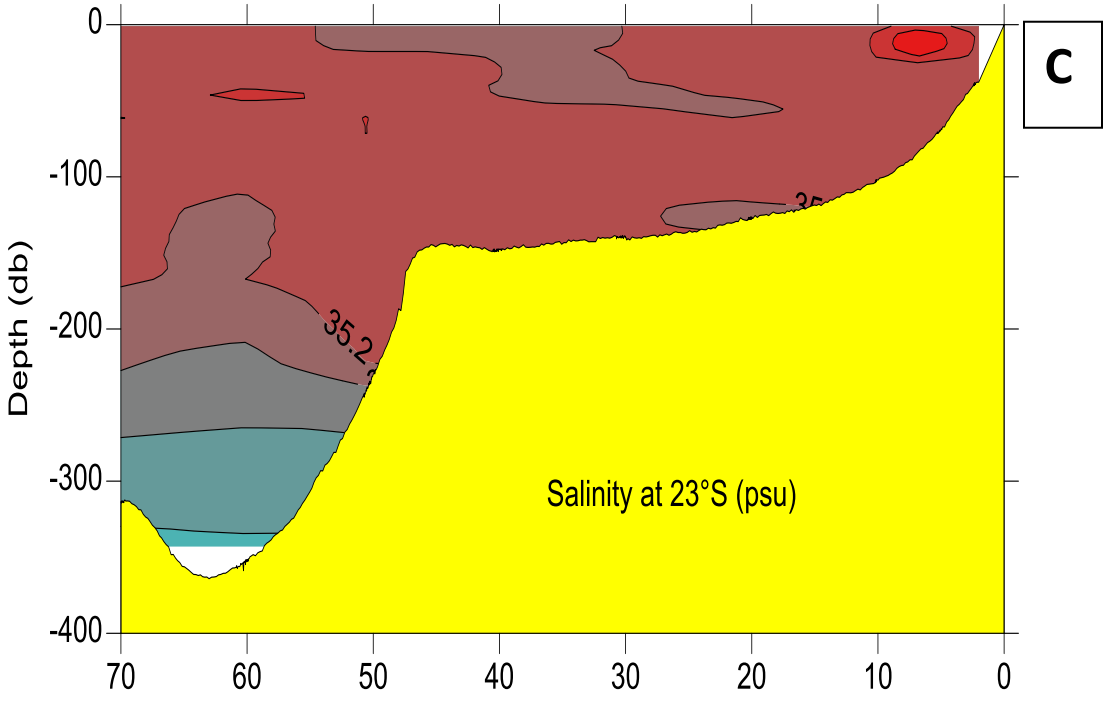


Figure.1.12. Physical parameters (A) Temperature, (B) Oxygen and (C) Salinity.

The temperature decreased with increasing depth that is why in figure 1.12a the surface is brownish. It decreases from inshore to offshore that mean temperature was high at 2nm but low at 70nm. Temperature was 13^{o}C at depth 100 figure.1.12a which mean above 100 it is high than 13^{o}C. Dissolved oxygen was low close to shore about 0.5ml/l and it increase offshore with increasing depth. The dissolved oxygen was 3ml/l at 120m depth and it is increasing from shore to offshore as indicated in figure.1.7b. Dissolved oxygen was associated with zooplankton abundance and distribution, therefore by comparing the species abundance at 60nm, 70nm in table.1.2 and 1.3 with dissolved oxygen at 60nm to 70nm in figure 1.12b and temperature in figure1.12a at 100m depth, showing the 12^{o}C and 3ml/l both in table1.4. Salinity was high at top layer

3.4. Zooplankton species diversity.

The dendrogram indicate two communities of the zooplankton from inshore to offshore figure 1.13. The two communities were separated based on the similarity and species richness at different stations. All the species on the labelled station on the right hand side were zooplankton community found inshore and the community on left are those that live offshore. Species on the 20nm were grouped together with other station close to inshore because of their similarity and species on 10nm grouped together with other species found offshore due to the fact that they all showed similar features. Major groups of zooplankton found on stations inshore are Amphipoda, Appedicularies and Polycheata larvae's. Calanoida, Copepods, Cyclopoida and Protozoa groups dominating offshore communities.

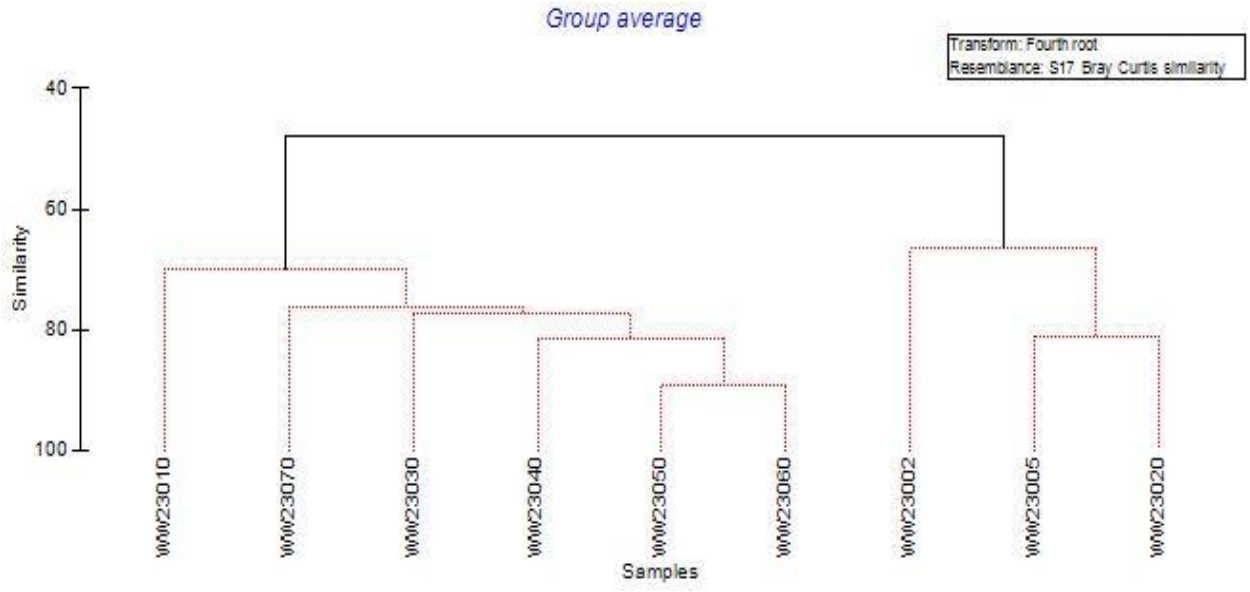


Figure.1.13. Dendrogram showing two community diversities of zooplankton.

Apart from the dendrogram in figure.1.13, multiplies diversity species was used to presenting diversity species community of zooplankton. It indicates clearly two communities that live independently to each other and their distribution, abundance at the 23^0S line off Walvis Bay.

The station 10nm, 30nm, 40nm, 50nm, 60nm and 70nm were all indicating offshore species and 2nm, 5nm and 20nm were species inshore figure 1.14. Inshore species showed that there were big variation in terms of vertical distribution and offshore species indicate less variation and they are close to each other. Offshore species based on sampling station indicate linear distribution especial 30nm, 50nm, 60nm and 40nm, 50nm, 70nm as indicated in figure.1.10. However, horizontal distribution showed that there are relationship between inshore species and offshore species.

Horizontal distribution shower that 2nm and 70nm share similar features; the same species occupied this areas. Species at 5nm, 30nm, 50nm, 60nm have similar characteristics and they shared the same environment. Lastly 10nm, 20nm and 40nm also belong to the same group, utilize resources similarly and all have the same mode of feeding.

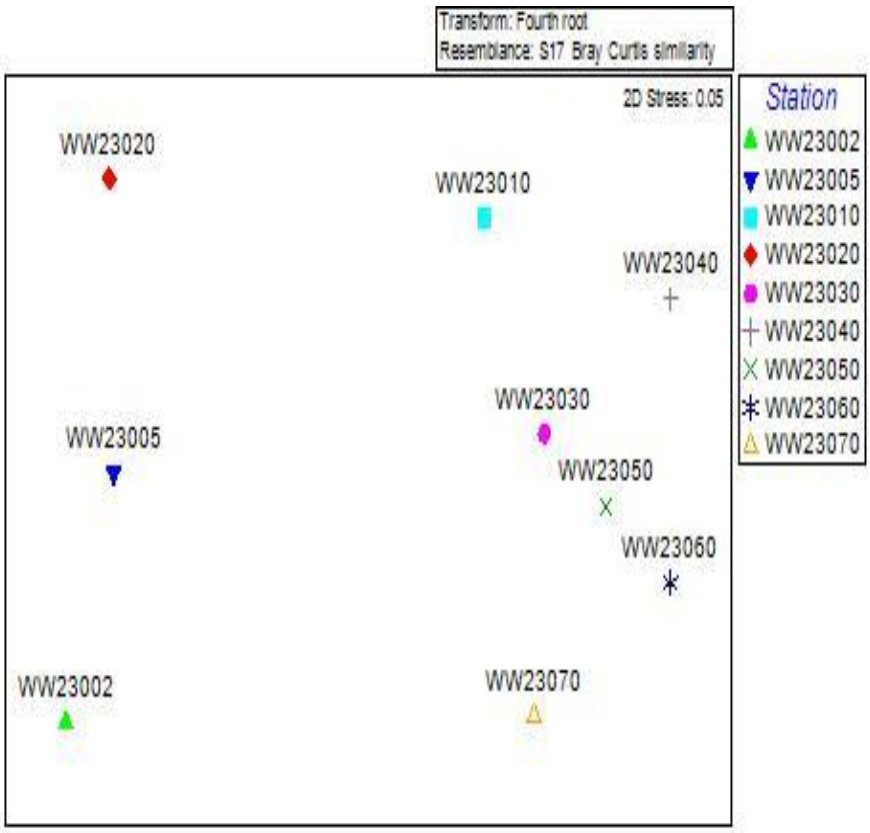


Figure.1.14. Multiplier diversity species horizontal and vertical distribution

Comparing the species richness in all nine stations, it is point out that the highest number of species richness was identified at 60nm with six numbers of species. 50nm and 30nm both have similar number of five, figure1.15a. The lowest species richness was recorded at 2nm that have two numbers of species.

In general species is high offshore than inshore and it also showed that different species occupied different areas therefore species richness will not be the same throughout transect 230S line. However based on figure.1.15b; it indicate that although specie richness is different from each station they are evenly distributed.

Species evenness indicates that not all species in the sampling stations are showing huge variation. The range is from 0.8 to one and it is close to each other that mean there is interaction between species at all stations figure 1.15b. Diversity indices were another example used in determining the species abundance and their distribution in the ocean using Shannon-Wierner model. The indices showed that 2nm has little species with index of 0.5 and 60nm has a highest index of 1.7

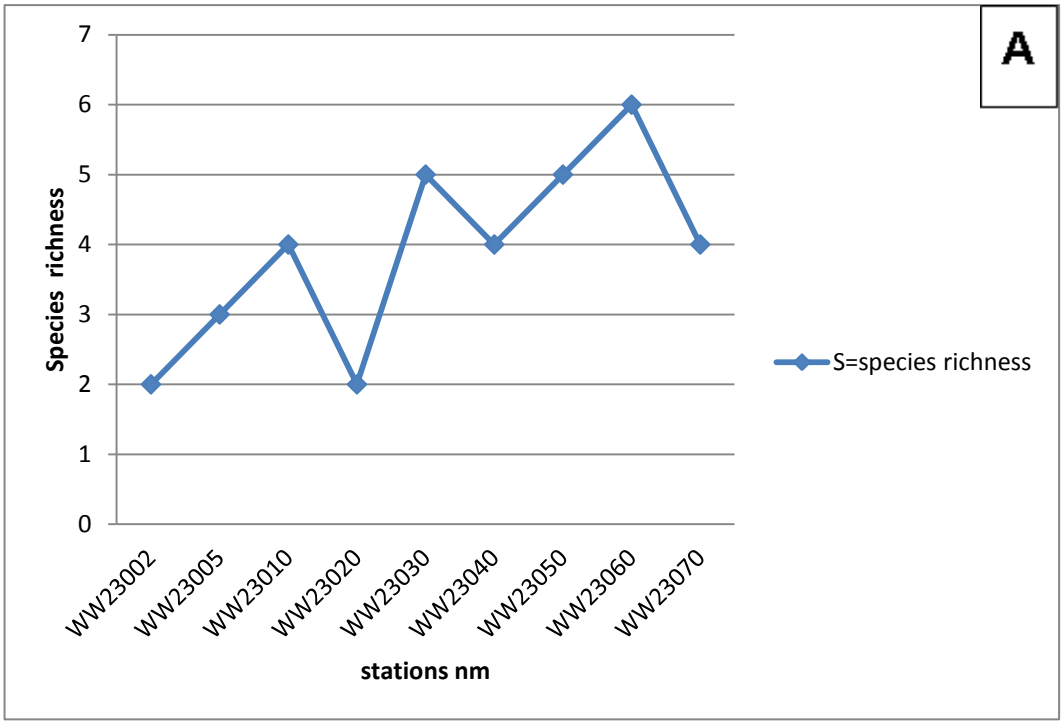


Figure.1.15A. Species richness from inshore to offshore in all sampling area.

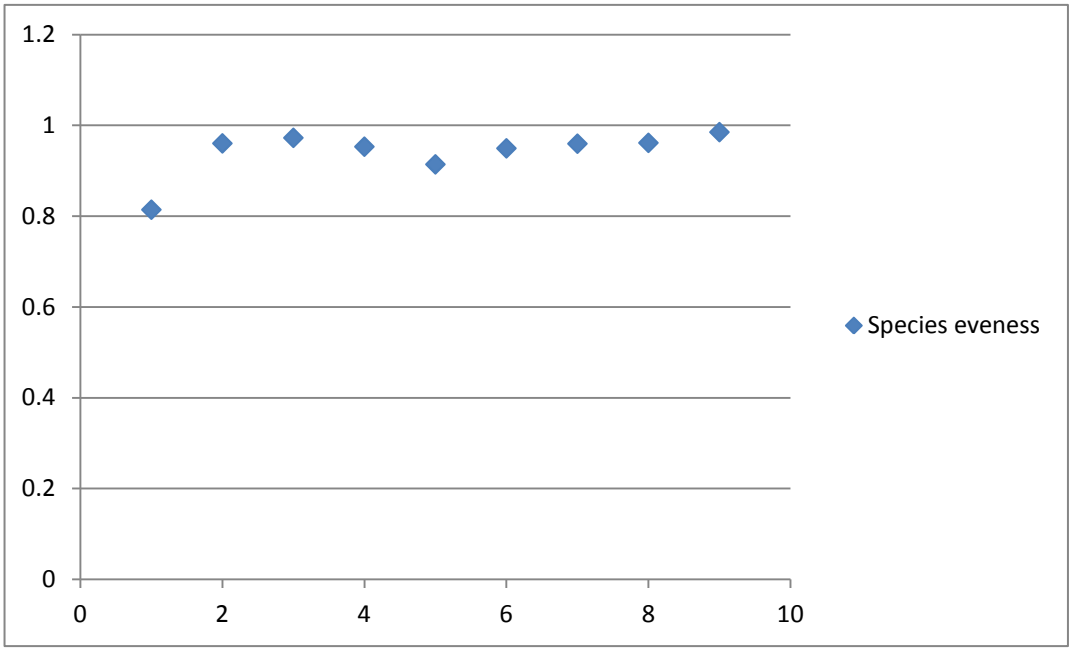


Figure.1.15B. indicate species evenness from inshore to offshore in all sampling area.

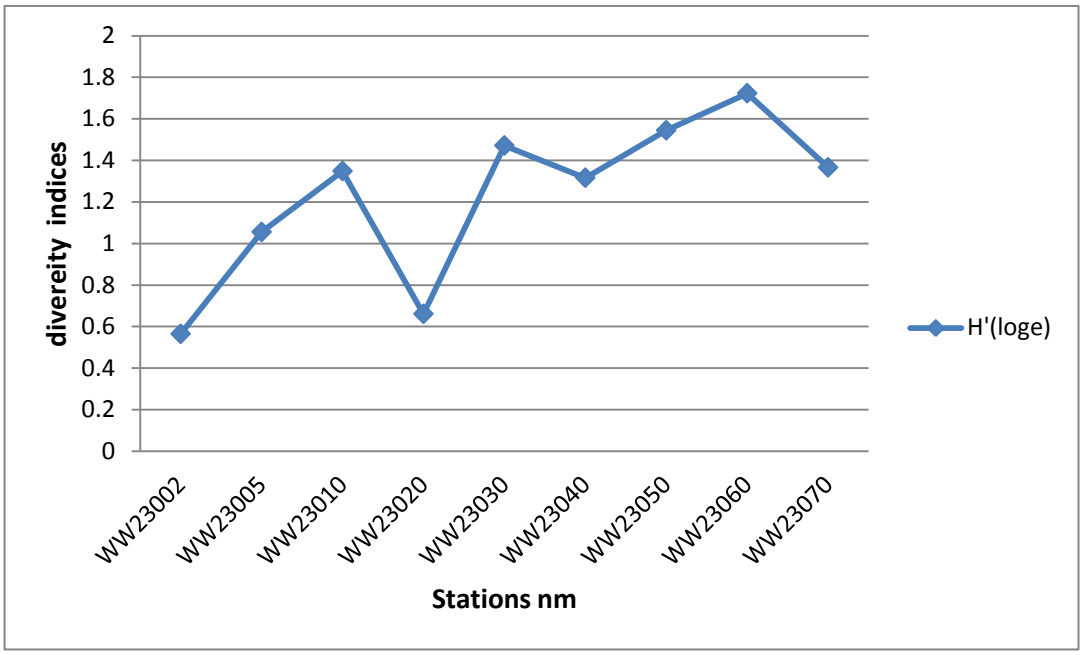


Figure.1.15C. indicate species diversity indices at Shannon-wienner H' (loge).

CHAPTER F0UR

DISCUSSIONS

4.1. Taxonomy of major crustacean zooplankton

The study was undertaken during the month of July 2012 with the aim to determine the main major group of zooplankton. The most abundant groups were Aphipoda (Hyperriidea), Appedicularia (Fritellaria and Oikopleura), Bivalvia (velige), Crustacea (Naupili), Calanoida (C.carinatus, Nannocalanus, Calocalanus, Centropages, and Metridia), Cyclopoida (Oithona), Cladocera (Evadne, Podon, and Penilia), Echinoderm, Protozoa and polycheata. Total copepod abundance in the study area attained up to 1.069 X 10^6 m^2. This value compares well with the few previous records in the Walvis Bay area in which a 200 mm meshed sampler used. Using a WP^2 net, Postal *et al*. (1995) recorded up to around 7.0 X 10^5 m^2 during October 1979, and using a multiple opening-closing net system with a 1-2m^2 mouth opening, Oliver and Barrage (1990) estimated copepod abundances of 3.0–8.0 X 10^3 m^2 during April 1986. In this study, copepods were most abundant within 40nmi from the coast, with peaks at 50nmi and 70nmi. Low abundances were found close inshore, increasing in the midshelf region, and peaking between 10nmi and 70nmi from the coast (**Table.3**).

4.2. Zooplankton distribution, abundance and species composition

Zooplankton distribution and abundance is increasing with distance offshore, which is similar to species composition. Using distribution, abundance and species composition, the transect can be separated into two zones or shelves, with the first one characterized by low distribution, abundance and species composition while the last one marked by high distribution, abundance and species composition. In this study, these zones will be referred to as inshore and offshore shelves. The inshore shelf/zone is comprised of stations 2nm-30nm and offshore zone/shelf of 40-70nm.

In terms of species composition, the inshore shelf is composed of amphipoda and cladocera zooplankton groups. However, Calanoida, Poecilostomatoida and Cyclopoida replaced these groups offshore. The differences in distribution, abundance and composition between inshore and offshore shelves does not suggest isolated zooplankton community but rather a distinct life cycle as nauplii and copepodites (juveniles) inshore recruits into the adult population offshore. The inshore region exhibited low concentrations of fish larvae resulting in high concentrations of chaetognaths and amphipods (Alvarino, 1980). Zooplankton decreases or becoming less inshore because fish larvae such as pilchard feeds on them. Maximum concentrations of fish larvae coincided with the lowest concentrations of hyperiid amphipods. Since some species such as C.carinatus and Metridia are herbivores that feed on phytoplankton, their abundance is high in areas that have high concentration of primary producer. The two herbivores species are main supply of food not only to fish larvae but also to other zooplankton communities.

In this study, similar result was obtained as it is showed in figure.1.6a and it decreases offshore where there is high concentration of fish larvae. Anchovy are size-selective omnivores, capable of ingesting both phytoplankton and zooplankton and they choose the sizes that provide them the highest amount of carbon, therefore, large zooplankton (>1 mm), i.e. calanoid copepods and euphausiids are selected if present in the water body (Coetzee, 2009). Anchovy schools are associated with areas of high levels of chlorophyll*a* and high concentrations of zooplankton. Copepods are highly concentrated offshore because they are not available daytime to anchovy and pilchard to feed on them. Timonin (1995) observed up to 2–2.5 times higher zooplankton biomass in the upper 100 m layer during night times than during daytimes.

This is clearly displayed by two diversity communities of the zooplankton from inshore to offshore in the dendrogram. The two communities were separated based on the similarity and

species richness at different stations. Species found at 10nm and 30-70nm is grouped together share similar features. Another community is found at 2-5nm and 20nm. These similarities prove that there is an interaction between members of zooplanktons in the inshore and offshore areas, which can be related to life history traits like life cycles. Literature has documented that most young stage of zooplankton groups live inshore. The abundance of *C carinatus* and *R. nasutus*, both herbivorous species, increased rapidly in response to the phytoplankton bloom formation following intense upwelling. Increase in abundance of these species provide food for other species that feed on them and creating a long food chain and web in ecosystems.

4.2. Influence of the environment

Increase in zooplankton distribution and abundance with distance to offshore can be explained by the physical environment (i.e. differences in temperature, DO and salinity). Low temperatures could be a sign that upwelling was taking place. Cold waters are rich in nutrients and less saline as indicated in the results, a negative relationship between temperature/salinity and zooplankton abundance implying that zooplankton preferred cold water and avoided warm waters. Similarly cold waters are rich in DO so the relationship between zooplankton and DO is positive, which mean zooplankton preferred more oxygenated waters than less oxygenated waters. The poor correlations between these relationships could mean that there could other factors influencing the distribution of zooplankton. High abundances of *C. carinatus* and *R. nasutus* were associated with cold (<13.0°C), low salinity water, which is characteristic of upwelled water (Hansen, 2000).

The data on table.1.4 indicate low temperature at 60nmi and 70nmi 10.9 and 11.3^{o}C respectively with decrease in salinity to 34.9psu and increases in dissolved oxygen to 3ml/l. Low temperature contained high oxygen level that zooplankton use in their metabolisms.

4.3. Implications to fisheries

Zooplanktons are important food items of pilchard, anchovy and juvenile fish species of horse mackerel and hakes. They also form an important part of the trophic pyramid as secondary producer. Even more important is their interaction within themselves. Their presence and absence has therefore certain implications for fisheries and for the food webs and chain or trophic functioning. Pilchard stocks are currently at their lowest levels ever. The implication of this on zooplankton biomass, their main food items or preys, is not well documented but it is speculated that this has likely to have led to increase of jellyfish and pelagic gobies, which also feed on zooplanktons.

Calanoida is the major group of zooplanktons. Their role is therefore important as they can be used to study and understand other less abundant groups. For example, they can be used as keystone species. Keystones species can be representative of other species, hence can be used to detect changes in ecosystem shifts/perturbations. These can make easier to predict and model such shifts as the Benguela Nino events. Studies focusing on member s of the copepods can be helpful to identify which keystone species recent studies has place emphasis on herbivore species like Metridia and C. Carinatus. Particular Metridia is speculated to associate with upwelling, hence a potential species indicator for good or poor upwelling years. High species richness and diversity were outlines in ***figure.1.11a, b. c***

CONCLUSION

The results were correlating with interpretations of previous studies of the abundances and distribution of zooplankton off Namibia. Highest abundance was generally found within 40nmi from the shore. The dominant groups were Aphipoda (Hyperriidea), Appedicularia (Fritellaria and Oikopleura), Bivalvia (veliger), Crustacea (Naupili), Calanoida (C.carinatus, Nannocalanus, Calocalanus, Centropages, and Metridia), Cyclopoida (Oithona), Cladocera (Evadne, Podon, and Penilia), Echinoderm, Protozoa and polycheata. Amphipoda dominating the inshore community while copepods dominating offshore community. Calanoida is the major group of zooplanktons and species like Metridia and C. Carinatus are herbivores, Particular Metridia is speculated to associate with upwelling, hence a potential species indicator for good or poor upwelling years. Zooplanktons are important food items of pilchard, anchovy and juvenile fish species of horse mackerel and hakes. Their presence and absence has therefore certain implications for fisheries and for the food webs and chain or trophic functioning.

Cold waters are rich in nutrients and less saline and as indicated in figure, the results showed a negative relationship between temperature/salinity and zooplankton abundance implying that zooplankton preferred cold water than warm water. This studies indicate that most young stage of zooplankton groups live inshore where the condition was favourable and fully grown zooplankton live offshore to feeds. Dendrogram indicated the similarities between species inshore and offshore communities. These similarities prove that there is an interaction between members of zooplanktons in the inshore and offshore areas, which can be related to life history traits like life cycles of any other living organism.

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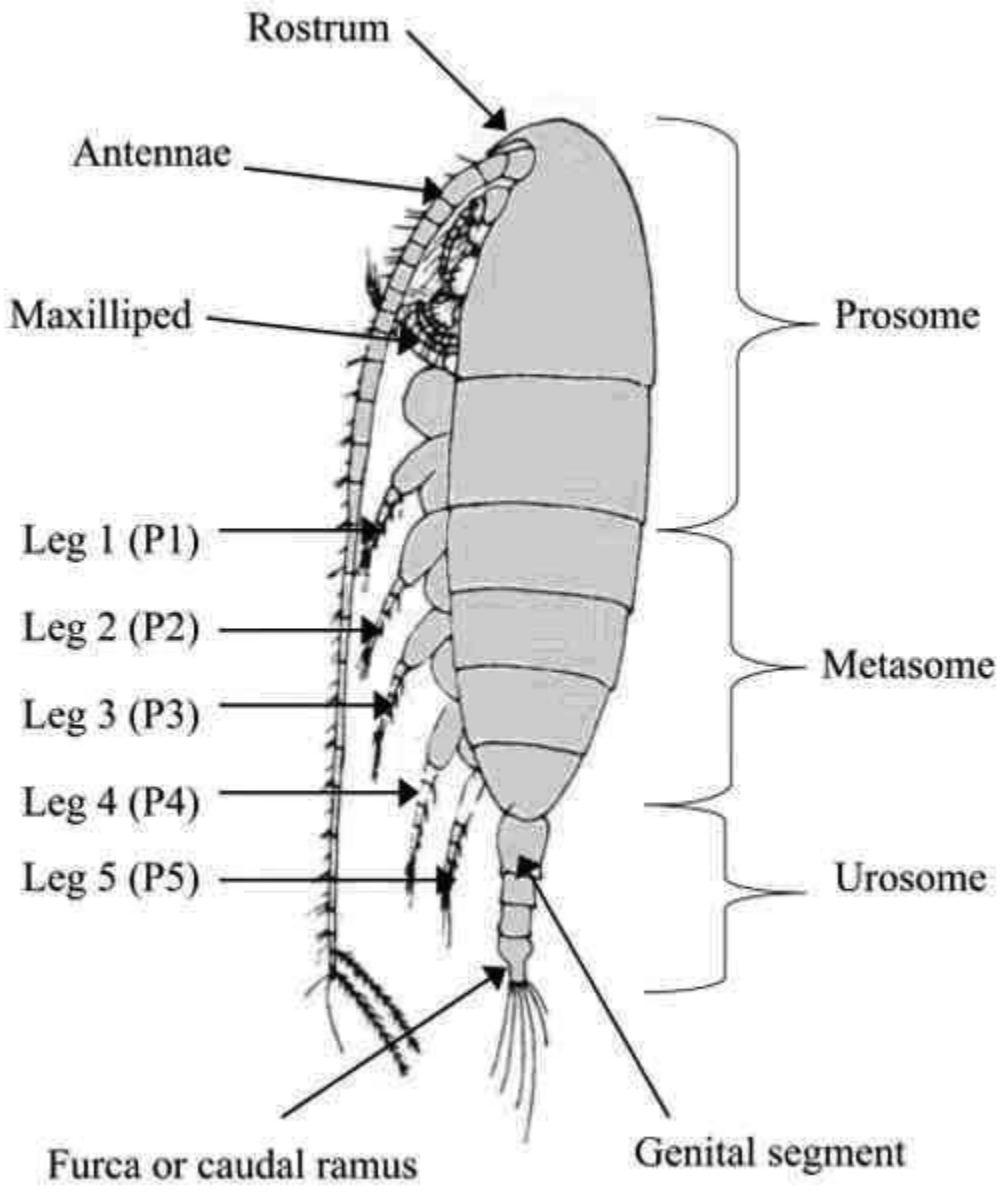
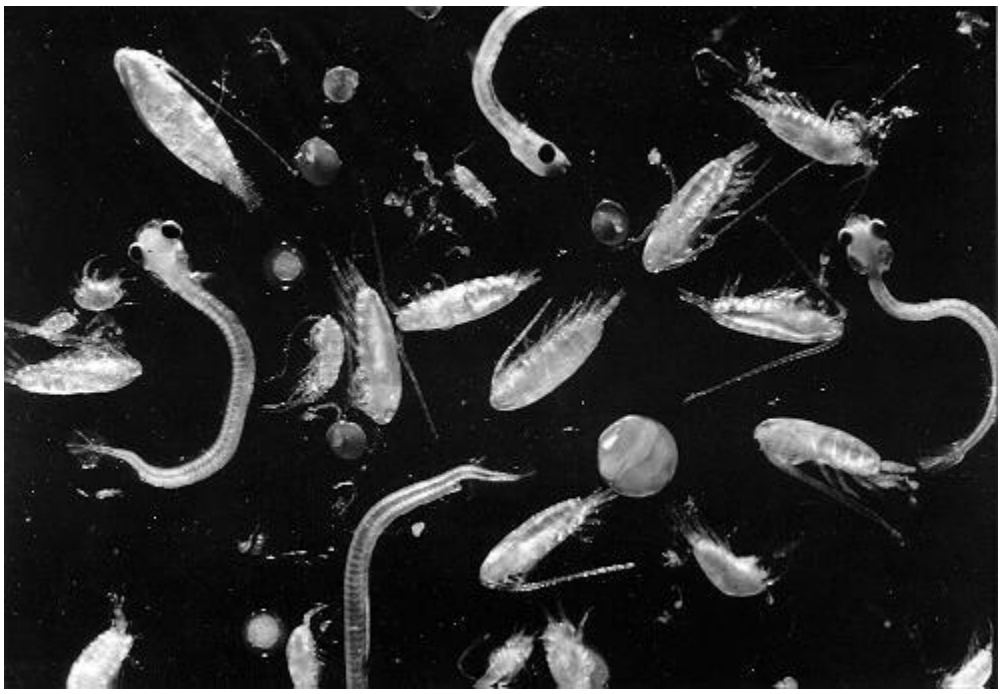
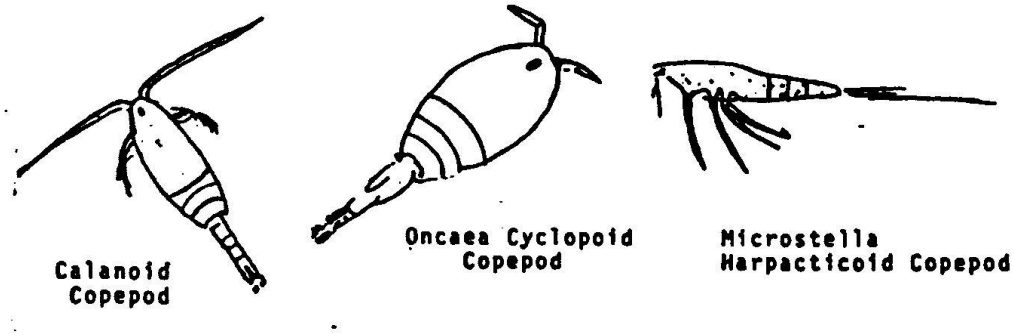
APPENDICES



Appendix 1.2. shows external features of cyclopoida group.



Appendix.1.2. Zooplankton in water samples



Appendix.1.3. Copepods along 23^{o}S line.