

**Initial investigations into dynamics of mesozooplankton community
structure in Algoa Bay, South Africa**

A thesis submitted in fulfilment of the requirements for the degree of

**MASTER OF SCIENCE
at
RHODES UNIVERSITY**

By

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April 2010

ABSTRACT

As part of a long-term monitoring programme initiated by the South African Environmental Observation Network (SAEON) Elwandle Node, the spatio-temporal dynamics of mesozooplankton (200–2000 μm) community structure in Algoa Bay, on the Eastern Cape coastline of southern Africa, was investigated in summer and winter of 2008. Physical-chemical and biological variables were measured at selected sites in the eastern and western sectors of the Bay. During summer, nutrient rich waters upwelling into the eastern sector of the Bay contributed to significant spatial variation in selected physical-chemical variables. During winter, virtually no significant spatial patterns in the physical-chemical variables were observed ($P > 0.05$ in all cases). For the majority of physical-chemical variables, no significant seasonal patterns in values were detected ($P > 0.05$ in all cases). Notable exceptions were water column stability and water temperatures which were highest during summer, and seston, turbidity and ammonium concentrations which attained the highest values in winter. The striking seasonal pattern observed in the water column stability, coupled with the upwelling event, coincided with a strong seasonal pattern in the total surface and integrated chlorophyll-*a* concentrations within the Bay. During summer, the total surface phytoplankton biomass ranged from 1.87–3.11 $\mu\text{g}\cdot\text{L}^{-1}$ and the integrated biomass values between 44.6 and 89.1 $\text{mg chl-}a\text{ m}^{-2}$. In winter, surface chl-*a* concentrations ranged from 0.49 to 0.55 $\mu\text{g}\cdot\text{L}^{-1}$ and integrated biomass from 13.5 to 13.8 $\text{mg chl-}a\text{ m}^{-2}$. During both seasons, the large microphytoplankton ($>20\ \mu\text{m}$) fraction contributed the most ($>80\%$) to the total phytoplankton biomass suggesting that phytoplankton growth is not nutrient limited within the Bay. The total mesozooplankton abundance and biomass values during summer varied between 10088.92 and 28283.21 $\text{ind}\cdot\text{m}^{-3}$ and between 76.59 and 161.94 $\text{mg}\cdot\text{m}^{-3}$, respectively. During winter, total abundance and biomass of mesozooplankton within the Bay were significantly lower, ranging from 2392.49 to 11145.29 $\text{ind}\cdot\text{m}^{-3}$, and from 34.49 to 42.49 $\text{mg}\cdot\text{m}^{-3}$, respectively ($P < 0.05$). During both seasons, cosmopolitan copepod species 200–500 μm in size dominated the total mesozooplankton counts, numerically and in biomass. Hierarchical cluster analyses identified distinct zooplankton groupings within the Bay during both the summer (three groupings) and winter (four

groupings) surveys. The different groupings identified during the two seasons were not associated with any specific geographic region or hydrological feature. Nonetheless, a distinct seasonal pattern in the mesozooplankton community was evident, largely reflecting the increased abundance of mesozooplankton during the summer survey. Canonical Correspondence Analyses (CCA) indicated that the zooplankton community structure within Algoa Bay reflected a complex interaction between physical-chemical (e.g. temperature, water column stability, turbidity, and nitrate, dissolved oxygen and nitrite concentrations) and biological factors (e.g. microphytoplankton and picophytoplankton concentrations). These data provide baseline information towards long-term monitoring programs that will be conducted in Algoa Bay, as part of the South African Environmental Observation Network (SAEON), in the near future.

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LIST OF ABBREVIATIONS AND ACRONYMS

ANOSIM	Analysis of Similarity
ANOVA	Analysis of Variance
CCA	Canonical Correspondence Analysis
Chl- <i>a</i>	Chlorophyll- <i>a</i>
	Commonwealth Scientific and Industrial Research
CSIRO	Organization
GAENP	Greater Addo Elephant National Park
HABs	Harmful Algal Blooms
ISA	Indicator Species Assessment
JGOFS	Joint Global Ocean Flux studies
LTMRP	Long Term Monitoring and Research Programme
MPA	Marine Protected Area
N-MDS	Non-Metric Multidimensional Scaling
NO ₃	Nitrate
NRF	National Research Foundation
PCA	Principal Component Analysis
SAEON	South African Environmental Observation Network
SFC	Size-Fractionated Chlorophyll- <i>a</i>
SST	Sea Surface Temperature
TNPA	Transnet National Ports Authority
WSSD	World Summit on Sustainable Development

ACKNOWLEDGEMENTS

First and foremost I would like to thank God, Our Heavenly Father for providing me with endurance, motivation, electricity, love, warmth and everlasting strength throughout this thesis. I just want to say, “He is worthy of all the Praise, I glorify His Name and I pray that He continues blessing me and providing guidance in everything that I do”.

To the SAEON-Elwandle Node team: Sean Bailey, Shaun Deyzel, Nicola ‘Nikki’ James, Albrecht ‘Ali’ Götz, Anthony Bernard, Ntuthuko ‘Ntuks’ Masikane, Colley ‘Dlalani’ Mpako, Lulama Poni, Lungisile ‘Toyoyo’ Koliti and Lukhanyiso ‘Lukhay’ Vumazonke; you guys are the best team that one could ever wish for and I really enjoyed working with you throughout this thesis. A **very special** dedication and appreciation to Kim Bernard and Angus Paterson for all the extra effort and making this project possible by pushing me beyond the edge when time allowed them to do so in order to make sure that I go all the way with the thesis. God dearly enrich your souls with Heavenly blessings and everlasting devotion.

To my family and friends, my mom and dad, Mr. and Mrs. Snyman, Mr. and Mrs. Fukuzana (my aunt and her husband), my brother and sister Mzukisi Dali and Khanya Snyman and the Zamxaka family, and all of you, whose names I did not mention (especially Lazola Quma). For all the support and motivation, for all the ups and downs that proved to be constructive at the end of it all and made us strong; thank you all very much. May God bless each and every one of you.

To my supervisor, Professor William P. Froneman, and Rhodes University for accepting this research project and believing that something good will transpire from it at the end, thank you. I further extend my gratitude to everyone that offered a helping hand in any way during the course of the project.

Last but not least, to the sponsors of the project, Transnet National Ports Authority (TNPA), South African Environmental Observation Network (SAEON) and National Research Foundation (NRF), I would like to express my gratitude for allowing me a chance to further my studies and develop the knowledge base I had.

DEDICATION

Dedicated to the memory of my grandmother Mrs. Nontsikelelo Betty Dali

CHAPTER 1: INTRODUCTION

1.1 THE SOUTH AFRICAN COASTLINE

The South African coastline extends a distance of ~ 3000 km, between the international borders with Namibia (on the west) and Mozambique (on the east) (Whitfield 1998; Burns et al. 1999). Eighty percent of the coastline is dominated by sandy beaches while the remaining 20 % is comprised of rocky shores, coastal wetlands and estuaries. The coastline includes a few sheltered bays including Algoa Bay and False Bay (Burns et al. 1999). In addition, 343 estuaries stretch between the Orange River Estuary on the Namibian border and the Kosi Estuary on the Mozambique border (Whitfield 1998; Burns et al. 1999), with the majority of these (two thirds) located on the east coast between Cape Padrone (Eastern Cape) and Mtunzini (KwaZulu-Natal). This wide variety of biomes, habitats and ecosystems support diverse populations of flora and fauna (Burns et al. 1999; Attwood et al. 2000).

The South African coastline is shouldered by two oceans. The Atlantic Ocean, with the Benguela Current, lies off the Western/Southern Cape coast, with one of the largest upwelling current systems in the world, the Benguela Upwelling system. The Indian Ocean lies along the Eastern/Southern Cape and KwaZulu-Natal coastlines, with the Agulhas Current as the dominant feature. These two oceans converge south of Africa where the Agulhas Current overshoots the wide tip of the Agulhas Bank (where it leaves the South African coast) into the South Atlantic Ocean and retroflects back into the South Indian Ocean to form the Agulhas Return Current (Figure 1.1) (Lutjeharms 1980; Lutjeharms 2007). At this point, waters from the Indian Ocean are mixed with the South Atlantic Ocean waters via eddies and current rings formed by the Agulhas Current (Lutjeharms 1980). Since the Agulhas Current has an influence on Algoa Bay, it will be discussed in further detail.

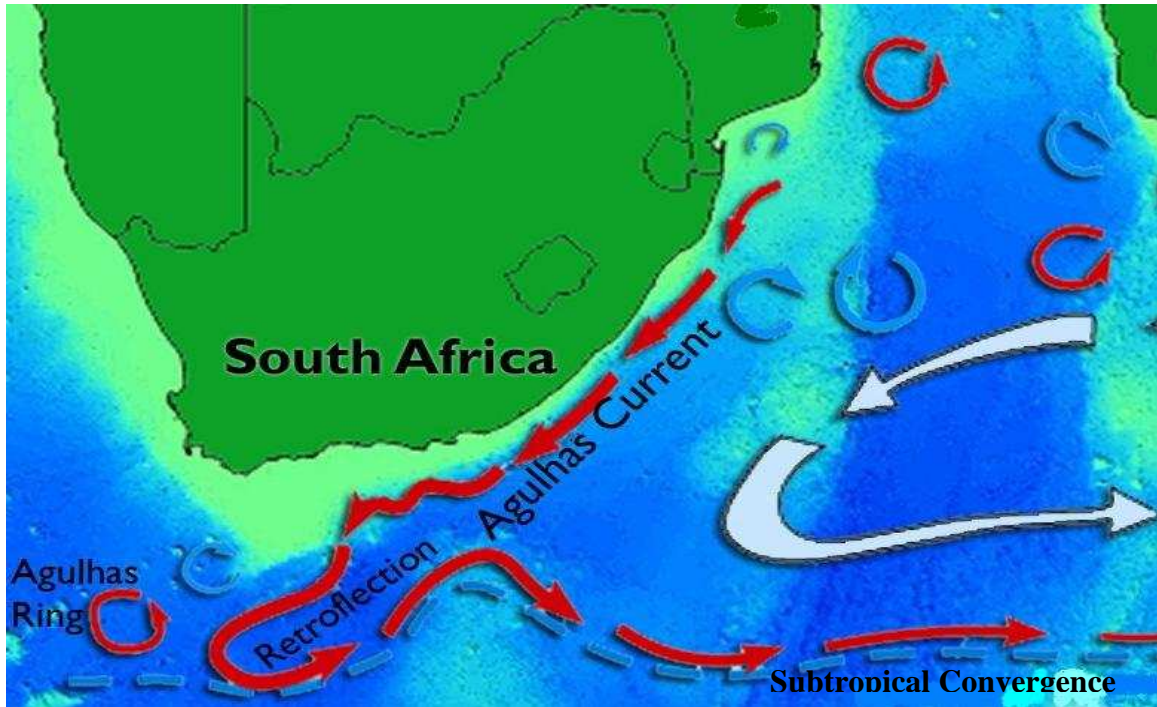


Figure 1.1 The South African coastline showing the Agulhas Currents with the Retroflexion area at the Agulhas Return Current. (Graphic: J. Stapley)

1.1.1 The Agulhas Current system

The Agulhas Current was one of the first western boundary currents to be scientifically described, primarily because its strong southward flow served as an obstruction to commercial vessels sailing between Europe and Asia (Rennell 1832, cited in Lutjeharms 2006). The Agulhas Current flows polewards along the south eastern coast of southern Africa and is diverted offshore by the Agulhas Bank on the south coast of South Africa (Figure 1.1) The Agulhas Current system is largely formed by water derived from the Mozambique Channel and the Mozambique Current (Lutjeharms 2006). Meanders in the Agulhas Current south of Africa generate eddies, which spin off into the Atlantic Ocean (Figure 1.1) (Lutjeharms 1980). South of the Agulhas Bank, the Agulhas Current meets the easterly flowing South Atlantic Current, which forces the Agulhas Current to turn back on itself, forming the Agulhas Return Current (Figure 1.1). The Agulhas Current system has been found to have a distinct upwelling cell at the northern edge of the Natal Bight (near the Cape of St. Lucia), which is a more or less permanent feature (Lutjeharms

2006). Lutjeharms (2007) and Meyer et al. (2002) showed that this upwelling cell was a source of nutrients for the Natal Bight system. Another persistent upwelling cell exists at Port Alfred (Lutjeharms 2007). This upwelling cell is considered as being perennial and is the result of strong easterly component coastal winds blowing alongshore (Meyer et al. 2002; Lutjeharms 2007).

1.1.2 Natural and anthropogenic drivers of the South African coastline

The South African coastline is impacted by both natural and anthropogenic factors, many of which have adverse effects on coastal ecosystems (Burns et al. 1999). Natural forces such as geophysical and climatic processes impact on coastal ecosystems either positively (e.g., through upwelling events that result in increased productivity) or negatively (e.g., through severe erosion that lead to loss of habitat and biodiversity). The uncontrollable increase in coastal development, has had a significant impact on the environment, often resulting in the loss of ecosystem integrity (Burns et al. 1999; Newman and Nel 2002). The reduction in ecosystem integrity includes: (1) habitat loss, degradation and fragmentation as a result of urbanisation and resource utilisation; (2) deterioration in water quality resulting from domestic, industrial and agricultural pollution; (3) altered freshwater input into coastal systems through irrigation and the construction of dams; and (4) a loss of biodiversity through the over exploitation of marine resources (Whitfield 1998; Burns et al. 1999). There is thus an urgent need to establish long-term monitoring of coastal ecosystems in order to detect and predict future changes (Bernard and Paterson, 2009).

1.2 ALGOA BAY

Algoa Bay is the largest and best formed of several log-spiral shaped bays along the Eastern Cape coast of South Africa (Newman and Nel 2002). Two headlands, Cape Recife in the west and Woody Cape in the east, separated by a distance of ~ 90 km (Newman and Nel 2002) enclose the Bay and form a wide mouth which opens onto the eastern Agulhas Bank (Figure 1.2). The maximum depth at the mouth is ~ 73 m. The Bay's wide mouth allows for free exchange of water between it and the Agulhas Bank waters. Offshore of Algoa Bay, the shelf has a width of ~ 55 km where the shelf break is

marked by a sudden increase in bottom depth from <100 m to 200 m (Goschen and Schumann 1994).

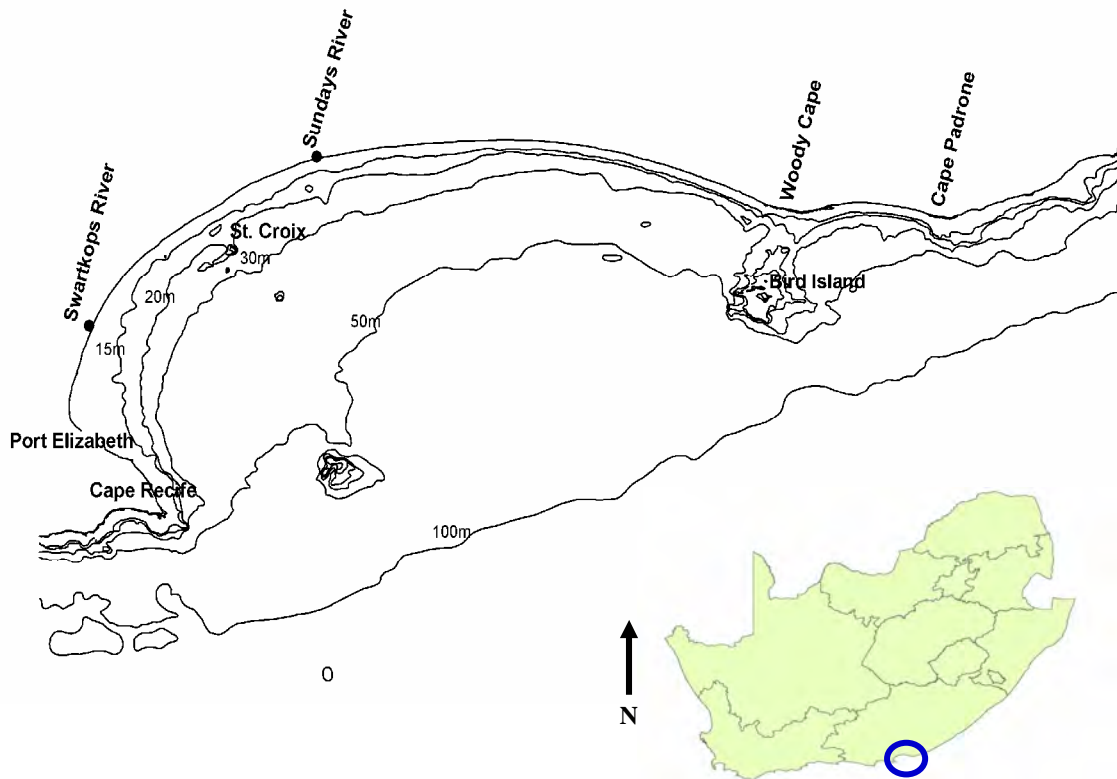


Figure 1.2 A map showing the study site: the log-spiral shaped Algoa Bay (circled on insert picture), located in the Eastern Cape of South Africa. (Graphic: K. Bernard)

Two large perennial rivers that drain extensive catchments areas, the Swartkops and the Sundays Rivers, flow into Algoa Bay. The Islands of the Cross, comprising St Croix, Brenton and Jahleel are located 2–3 km offshore between the Swartkops and Sundays River systems (Newman and Nel 2002). The second island group, the Bird Islands consisting of Bird, Seal, Stag and Black Rocks, are located ~ 8 km offshore from Woody Cape and ~ 65 km from Port Elizabeth harbour (Figure 1.2). Both island groups are situated inside the 30 m depth contour. The large metropolitan area of Port Elizabeth, where more than one million people are resident, abuts the western extremity of the Bay (Newman and Nel 2002). A Marine Protected Area (MPA) has been proposed in Algoa Bay (Figure 1.3), adjoining the terrestrial Greater Addo Elephant National Park (GAENP). The proposed GAENP-MPA will be situated along the north-northeastern

shoreline of Algoa Bay (Newman and Nel 2002). There is currently a smaller MPA around the Bird Island group (Figure 1.3).

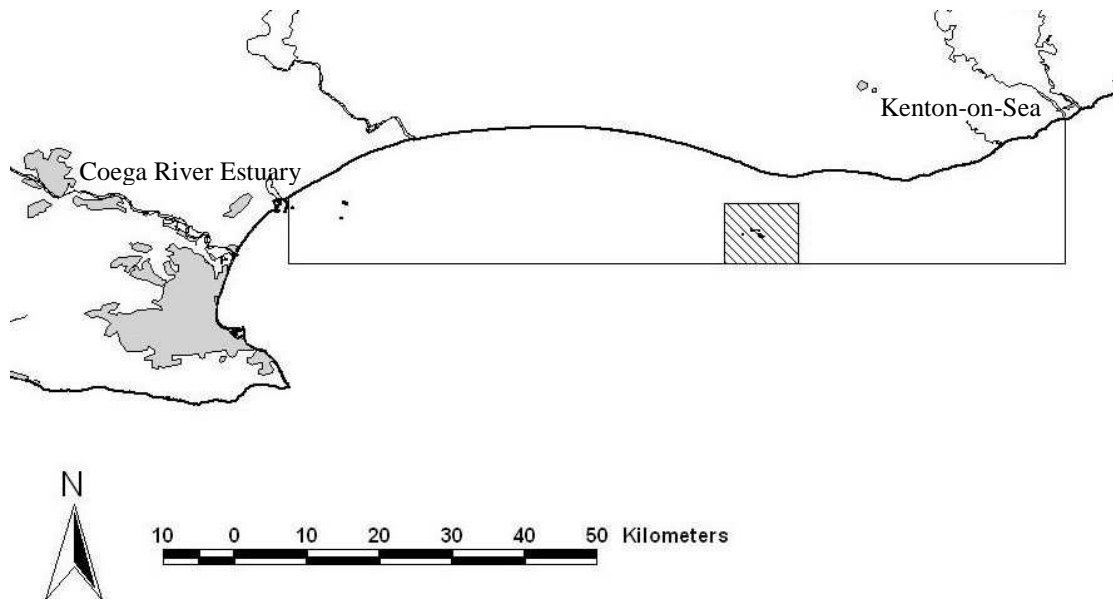


Figure 1.3 Algoa Bay with the GAENP-MPA boundary marked by a border line (between Kenton-on-Sea and Coega River Estuary). The Bird Island MPA is highlighted by the small checked box. (Graphic: R. Chalmers).

1.2.1 Natural drivers of the Algoa Bay marine ecosystem

Hydrology

The hydrology of Algoa Bay has been intensely studied in the western sector (Schumann and Li van Heerden 1988; Schumann et al. 2005). Results of these studies indicate that the hydrology of Algoa Bay demonstrates a high degree of spatial and temporal variability as a result of the complex interaction between wind forcing, tidal and intertidal currents, upwelling and eddies, to mention a few (Schumann et al. 2005). Schumann et al. (2005) reported that variability in currents from nearshore to deeper waters differs in direction and speed as you move offshore. Though the nearshore currents are generally slow and primarily flow in a north-eastward direction (Schumann et al. 2005), further offshore the flow of water is in a predominantly south-westward direction, influenced largely by the Agulhas Current. These patterns, however, may change over space and time (Schumann et al. 2005). In addition, the hydrology of Algoa Bay is influenced by

the intrusion of the Agulhas Current via cyclonic eddies that originate north of the Natal Bight area (Goschen and Schumann 1994; Lutjeharms 2007). This intrusion is seen as warm tongues of Agulhas Current water that enter the Bay from the eastern sector, off Cape Padrone (Goschen and Schumann 1994). Little information is available on the hydrology in the eastern sector of the Bay.

Water Temperature

Seawater temperatures in Algoa Bay are highly variable on both spatial and temporal scales (Beckley 1983; 1988). Generally, there is a net input of heat radiation in summer and a net loss in winter (Schumann et al. 2005). This variability is determined by wind regimes and seasonality, with minimum temperatures recorded in winter (14–15°C) and maximum temperatures in summer (20–22°C) (Schumann et al. 1995; Schumann et al. 2005). During summer the water column is stratified with a thermocline at ~ 11 m depth in the deeper regions of the Bay (Schumann et al. 1988; Goschen 1991; Schumann et al. 2005). During winter, increased wind activity contributes to the formation of a well mixed water column with little or no stratification evident. Research in Algoa Bay has been limited to the western sector in the past; there are thus few studies that provide reference for the eastern sector of Algoa Bay (Goschen 1991, Schumann et al. 1995; Schumann et al. 2005; Patrick and Strydom 2008).

Wind Patterns

South Africa has a predictable climate system with seasonal variability (Newman and Nel 2002). Algoa Bay experiences highly variable winds between the winter and summer seasons with the strongest winds occurring between October and November and relatively weaker winds between May and June (Schumann et al. 1991; Schumann and Martin 1991; Whitfield 1998). Furthermore, the summer season is dominated by strong easterly component winds that induce coastal upwelling (Schumann et al. 1991; Schumann and Martin 1991). The winter season on the contrary, is marked by increased westerly winds, which result in downwelling and water column mixing (Goschen and Schumann 1995). However, westerly component winds have been known to bring upwelled waters back into the western sector of Algoa Bay (Goschen and Schumann

1995). Moderate to strong easterly component winds transport water upwelled off Cape Recife away from Algoa Bay. A shift in wind direction, to a westerly wind, moves the upwelled water back around Cape Recife and into the Bay (Goschen and Schumann 1995). The studies cited in this section were conducted in the western sector of Algoa Bay. There is consequently a paucity of information for the eastern sector of Algoa Bay.

Upwelling

Satellite ocean colour and sea surface temperature data indicate that water upwelled off Port Alfred, to the north of Algoa Bay, intrudes into the Bay resulting in a decrease in sea surface temperature and an increase in phytoplankton biomass (Figure 1.4) (Schumann et al. 2005). Furthermore, the intrusion of cold water around Cape Recife consequential to westerly winds following an easterly wind (as described in the section above), results in increased phytoplankton biomass in the western sector (Goschen and Schumann 1995). It has been suggested that the increase in phytoplankton biomass reflects elevated primary production, which is sustained by the increased availability of macronutrients upwelled into the surface waters. Though coastal upwelling is known to influence Algoa Bay, there is scant data relating to the actual upwelling process and the biological response associated with this process within the Bay.

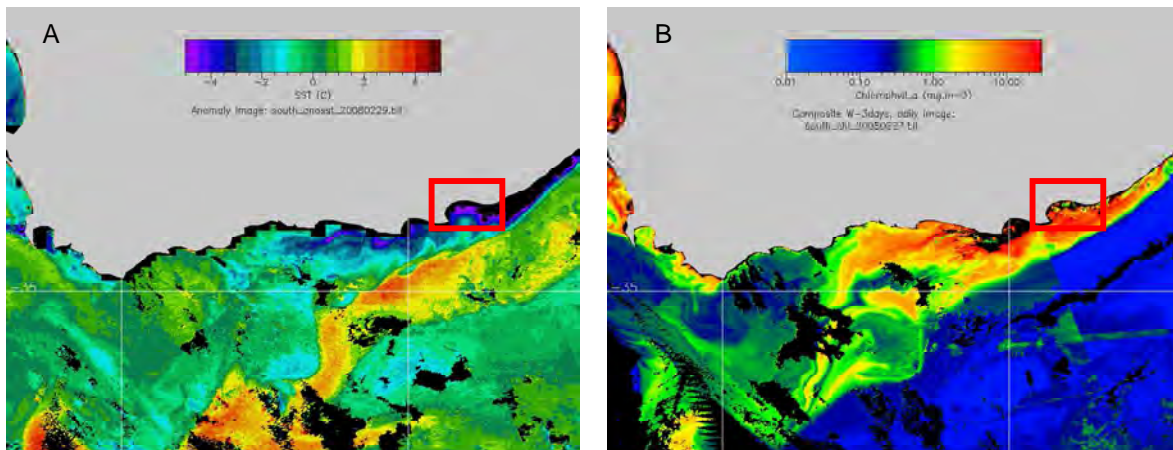


Figure 1.4 Satellite SST (A) and ocean colour (B) images indicating upwelling along the south coast of South Africa. Note the low sea surface temperatures (A) and the corresponding high chlorophyll-*a* concentrations (B). Red box indicates the position of Algoa Bay (Images from www.rsmarinesa.org.za).

Estuaries

A number of studies conducted both locally and internationally have demonstrated that permanently open estuaries play an important role in the nutrient dynamics and energy flow in the near shore marine environment (Okubo 1973; Miller 2004; Lukey et al. 2006; Vorwerk 2006). This was hypothesized to be caused by a unidirectional flow of water in estuaries, which subsequently results in import/export of resources including nutrients and particulate organic matter, to mention a few (Dame and Allen 1996; Roegner and Shanks 2001). This would occur in times of high freshwater input into an estuary, which will subsequently result in plumes of freshwater with low salinities and an influx of nutrients (adjacent to the mouth of the estuary) in the nearshore marine environment. As a consequence of nutrient influx and a large pulse of biomass from the estuary, there will be an increase in both primary and secondary production (Lukey et al. 2006; Vorwerk 2006).

There are four estuaries that enter Algoa Bay. The Swartkops Estuary, situated on the boundary of Port Elizabeth, has been extensively modified and impacted by human activities and is characterised by large intertidal mud and sand banks, salt marshes and salt pans (Baird et al. 1988; Newman and Nel 2002). Freshwater abstraction from the Swartkops Estuary is limited (Scharler and Baird 2003). The Sundays River Estuary, situated further to the east, lacks extensive intertidal habitats and is strongly influenced by agricultural activities, which contribute to reduced freshwater inflow and nutrient loading within the system (Newman and Nel 2002). A third estuary, the Coega (Ngqura) River Estuary, has been considerably modified so that it rarely opens to the sea and, due to reclamation for solar salt works, can be considered as biologically non-functional (Newman and Nel 2002). The fourth estuary, Papkuils Estuary, is canalised and functions as an industrial canal. It has been suggested that, due to their size and varying freshwater and nutrient inputs, the Sundays and Swartkops estuaries will play an important role in the energy and nutrient dynamics of the nearshore coastal ecosystems of Algoa Bay as explained in the previous section (Campbell and Bate 1998; Lukey et al. 2006; Vorwerk 2006).

Islands

Coastal islands form shallow areas and alter the local bathymetry, thereby impacting on the surrounding marine environment (Mann and Lazier 1996; Pakhomov and Froneman 1999; Chown and Froneman 2008). The “island mass effect” is a phenomenon that occurs around coastal and oceanic islands and involves the enhancement of biological productivity through increased water column stratification and the entrainment of plankton communities (Doty and Oguri 1956; Pakhomov et al. 2000; Chown and Froneman 2008). Other factors that enhance productivity in the vicinity of coastal islands include: upwelling, tidal mixing and nutrient rich water run-off (Gran 1912; Doty and Oguri 1956; Mann and Lazier 1996). The elevated productivity and zooplankton biomass associated with islands often supports large populations of top predators, including seals, penguins and seabirds (Williams et al. 2000; Beaugrand 2005; Chown and Froneman 2008). The above studies, however, relate to other oceanic islands.

Improving our understanding of how the islands of Algoa Bay influence local productivity and zooplankton biomass will be important, particularly in terms of the management of the new and existing MPAs. As important functional ecosystems, coastal islands add another integral dimension to the dynamics and functioning of coastal ecosystems (Williams et al. 2000). It has been suggested that plankton communities associated with islands (both coastal and oceanic) may support the top predators living and/or breeding on the islands (Williams et al. 2000; Beaugrand 2005; Chown and Froneman 2008).

1.2.2 Anthropogenic drivers of the Algoa Bay marine ecosystem

The marine ecosystems of Algoa Bay face a variety of challenges as a result of human activities. These include habitat degradation and the loss of ecosystem integrity from an increase in coastal development, urbanisation and agriculture (Levinton 1995; Burns et al. 1999; Newman and Nel 2002). Other important drivers include: (1) changes in sedimentation rates and the deterioration of water quality resulting from domestic, industrial and agricultural pollution; (2) the alteration of freshwater input as a result of the construction of dams; and (3) the alteration of energy dynamics and reduction in

biodiversity through over fishing (commercial, subsistence and recreational) and extensive resource utilisation (Levinton 1995; Burns et al. 1999; Griffiths et al. 2000; Newman and Nel 2002). In addition, ballast waters released by ships in Algoa Bay contribute to the introduction of alien species (Levinton 1995; Griffiths et al. 2000; Newman and Nel 2002). However, there is little evidence of invasive species in the Algoa Bay ecosystem due to a lack of taxonomic database and expertise (Newman and Nel 2002). One study that has been conducted in the southern Cape coast, including Algoa Bay, reflected displacement of endemic species and dominance of rocky intertidal communities by *Mytilus galloprovincialis*. The latter species is said to be non-endemic to this coast but was introduced in this region (Griffiths et al. 1992).

Although not yet evident, point source pollution would significantly impact the integrity of Algoa Bay. For instance, nutrient loading from domestic, agricultural, aquacultural and industrial pollution (from storm drains and the maritime and fishing industries) alters the chemistry of the Bay. This nutrient enrichment may favour the growth of Harmful Algal Blooms (HABs), which can be toxic and/or invasive and compete with non-invasive species for oxygen and nutrients. HABs can develop rapidly and form a dense layer in the surface waters, diffracting light and limiting productivity (Levinton 1995). Toxic HABs can cause mass mortalities in higher trophic levels (Newman and Nel 2002). Toxic (heavy metals, oil spills, etc.) and solid (plastics, broken fishing lines, etc.) waste from a wide variety of sources, including urbanisation, agriculture and so on, significantly impact the coastal flora and fauna, killing fish, birds, turtles and mammals (Levinton 1995; Newman and Nel 2002). Although relatively less well-studied, non-point source pollution carried by offshore winds also plays a significant role in nutrient loading and system alteration.

1.2.3 The plankton of Algoa Bay

Marine organisms can be categorised as benthic, planktonic or nektonic depending on their physical habitat and their mode of motility. Planktonic organisms, the focus of this thesis, are those that live suspended in the water column and are sufficiently small and/or slow so as to be incapable of directed swimming (Diebel 2001). Their distribution is

considered to be controlled by physical processes, such as water currents and turbulent mixing (Steele 1977; Steele and Frost 1977; Miller 2004; Levinton 1995). In addition, plankton can be further divided based on their nutritional modality. Phytoplankton, being autotrophic, depends on light to fix carbon dioxide into organic carbon, whereas zooplankton, being heterotrophic, ultimately depends on the phytoplankton for their dissolved or particulate food source (Levinton 1995; Diebel 2001; Martin 2001; Miller 2004).

Phytoplankton

Phytoplankton biomass in Algoa Bay is documented to vary between 1 and 16 $\mu\text{g/L}$ (Schumann and Campbell 1999; Campbell 2000) with a near surface fluorescence maximum, typical of temperate waters (Schumann and Campbell 1999). The variable nature of phytoplankton biomass in Algoa Bay is the result of localised nutrient and temperature fluctuations. Seasonally, phytoplankton biomass is lowest in winter and highest during spring (Davies et al. 1992; Schumann and Campbell 1999; Campbell 2000). Intermediate values are recorded in summer and autumn, which is a typical situation in temperate areas (Fenchel 1988; Miller 2004). The spring bloom, however, is not as strongly marked as described for other coastal systems that have received much research attention (Schumann and Campbell 1999, Campbell 2000). This might be due to a lack of local research focused on specific features of spring blooms. It was hypothesized that nutrient upload as a result of runoff after rainfall (Campbell 2000) and the occurrence of an upwelling event on the nearshore waters north of Algoa Bay (off Port Alfred, Goschen and Schumann 1995) and its intrusion into the Bay, may influence an increase in primary and secondary production in the eastern sector hence the need to broaden this investigation to the eastern sector as opposed to focusing on the western sector of Algoa Bay.

Three distinct phytoplankton communities are recognisable within Algoa Bay, namely surf zone, neritic (continental shelf) and benthic communities (Newman and Nel 2002). For the purpose of this study only neritic phytoplankton will be considered. Only a few detailed studies of neritic phytoplankton have been undertaken in Algoa Bay (Schumann

and Campbell 1999; Campbell 2000). These studies are primarily based on diatom ecology and accumulations in the surf zone with 80 % contribution to the neritic phytoplankton community (Campbell and Bate 1990; Talbot et al. 1990; Campbell 1996).

Zooplankton

The nearshore zooplankton community of Algoa Bay has been poorly studied, with only sporadic surveys with limited temporal and spatial scale or restricted to specific areas of the Bay (Wooldridge 1981; Newman and Nel 2002; Patrick and Strydom 2008). Newman and Nel (2002) reported several holo-, mero- and facultative planktonic forms from 45 taxa in the surf zone of Algoa Bay. These were dominated by small holoplanktonic forms including cladocerans as well as calanoid and cyclopoid copepods. The remainder of the zooplankton comprised medusae, polychaetae, siphonophora, chaetognaths, ostracods and decapod crustaceans. Abundance and biomass of these zooplankton groups in the surf zone varies from one location to another (Wooldridge 1983, Cockcroft and McLachlan 1986; Cockcroft et al. 1988; Schoeman 1990; Newman 2000). Variability in these communities is influenced by the physical processes such as wind forcing, wave energy and currents activity (Newman and Nel 2002). Diversity, biomass and distribution at spatial and temporal scales, and the ecological relationships and importance of the nearshore holo- and merozooplankton communities of Algoa Bay as a whole are relatively unknown. Furthermore, exact estimates of plankton biomass and abundance in Algoa Bay are not documented. Available data relates to specific planktonic taxa (e.g., Wooldridge 1983; Schoeman 1990; Newman 2000).

1.3 SOUTH AFRICAN ENVIRONMENTAL OBSERVATION NETWORK (SAEON) AND LONG-TERM RESEARCH WITH REFERENCE TO THE SAEON-ELWANDLE NODE LONG-TERM RESEARCH IN ALGOA BAY

The South African Environmental Observation Network (SAEON) was initiated in response to the World Summit on Sustainable Development (WSSD of 2002) as a framework for establishing and managing long-term ecological monitoring and research programmes. The mandate of SAEON is “to develop and sustain a dynamic South African observation and research network that provides the understanding, based on long-term information, needed to address environmental issues” (SAEON Advisory Board 2003). SAEON operates through a chain of nodes located around South Africa focusing on different ecological biomes, including a number of terrestrial biomes and two marine.

The SAEON-Elwandle Node (Elwandle Node from here on) is the coastal inshore node and the Algoa Bay Long Term Monitoring and Research Programme (LTMRP) was established as its first long-term monitoring and research site. There are two aspects to the Algoa Bay LTMRP; these include sustained long-term monitoring of key areas of Algoa Bay and detailed short term research projects. The results of the present study should provide baseline data to allow for an improved understanding of the mesozooplankton dynamics of Algoa Bay (Bernard and Paterson 2008). Furthermore, results from this study will be used to established a suitable zooplankton long-term monitoring programme for Algoa Bay and possibly also other future coastal LTMRPs throughout South Africa.

1.4 AIM AND OBJECTIVES

The aim of this study is to assess the spatial and seasonal patterns of mesozooplankton in relation to selected physical-chemical and biological variables within Algoa Bay. This study will contribute to our understanding of the plankton dynamics within the Bay, particularly in the eastern sector where no previous studies have been conducted. The

main findings of the study will form the baseline on which future monitoring in Algoa Bay will be based upon.

CHAPTER 2: MATERIALS AND METHODS

2.1 STUDY AREA: THE SAMPLING STRATEGY

This study was conducted in Algoa Bay between the two head lands of Cape Recife, in the west, and Cape Padrone, in the east (Fig 2.1). Sampling was conducted during the summer and winter of 2008. The summer survey took place on the 29th of February and 1st of March, and the winter survey on the 4th and 5th of August. A nested sampling strategy was employed from which two regions within Algoa Bay were identified as the eastern and western sectors separated by a distance of ± 30 km. Within these two sectors, six sites were randomly selected ± 10 km apart using the ARC-GIS 9 (ESRI 2006) program. Within these six sites, three stations were randomly selected with distances of ± 100 m apart. During the winter survey, two additional sites (7A and 7B, Fig 2.1) were added to aid in identifying boundaries between the eastern and western sectors of the Bay.

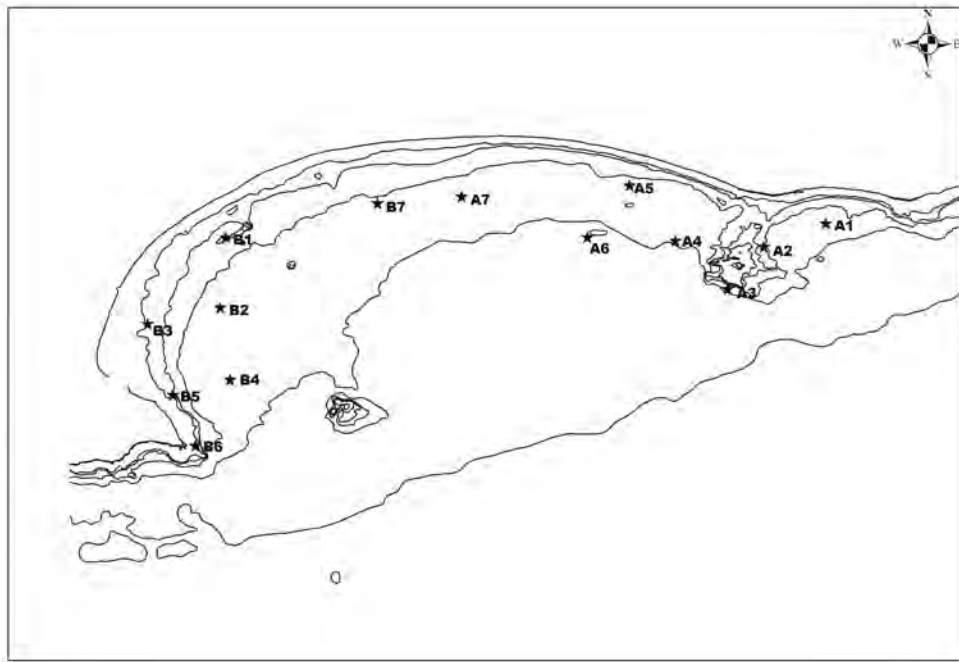


Figure 2.1 Algoa Bay with sampling sites between Cape Recife and Cape Padrone. Note: stations A7 and B7 were only added during winter sampling. A1–A7 are eastern sector sites, while B1–B7 are western sector sites.

2.2 FIELD PROCEDURES

2.2.1 Physical-chemical variables

Physical-chemical variables including seawater temperature (°C), salinity (psu), turbidity (NTU), and dissolved oxygen ($\text{mg}\cdot\text{L}^{-1}$) were measured using a YSI 650 MDS (Multi-parameter Display System) that was calibrated prior to surveys being conducted. Upon reaching a station, the data sensor was slowly deployed vertically through the water column and readings from the surface and bottom layers were taken. For the bottom measurements, variables were recorded 1 m above sea floor (as indicated by the sensor) so that the sensor did not disturb the bottom sediments.

2.2.2 Nutrients

Water samples for nutrients ($n = 3$) were collected using a Niskin bottle from the surface and bottom waters. The seawater samples from each depth were filtered through a Whatman GD/X disposable syringe filter (pore size $0.45\ \mu\text{m}$) to remove organic matter. Filtered seawater was then stored in sterilised 50 mL vials. Due to the high cost of analysis, nutrient samples were collected at one station per site only. The filtered seawater samples were kept cool in the dark by storing the vials in a cooler box with ice bricks. In the laboratory the samples were frozen until later analysis. Nutrients analysed were nitrate, nitrite, ammonia, silicate and phosphate.

2.2.3 Phytoplankton (chlorophyll-*a*) biomass and seston

Water samples for the determination of chlorophyll-*a* and seston concentrations ($n = 3$ for each parameter) were collected using the Niskin bottle from the surface and bottom waters. Samples for chlorophyll-*a* (chl-*a*) and seston concentration determination were collected from all stations at each site. The samples were stored in black bags in a cooler box. In the laboratory the samples were frozen until subsequent analysis.

2.2.4 Mesozooplankton

Mesozooplankton ($n = 3$) were collected by vertically deploying three modified (UNESCO 1968; Harris et al. 2000) WP-2 nets with a mesh size of $90\ \mu\text{m}$ and a ring mouth area of $0.152\ \text{m}^2$. The nets were fitted with $\pm 2 \times 900\ \text{g}$ weights below the cod-

ends to ensure vertical orientation of the net once deployed in the water column. The cod-ends of the nets were fitted with a 90 μm mesh to retain mesozooplankton upon collection. A depth meter was attached to one of the nets to determine whether the net was vertically positioned. Three nets were deployed and retrieved simultaneously at constant speed (UNESCO 1968). Three samples were collected and pooled from each station.

Once on deck, the nets were carefully washed down to the cod-ends, which filtered the water through the 90 μm mesh and retained the mesozooplankton. The contents of each cod-end were then carefully transferred to collection bottles, ensuring that all zooplankton was rinsed into the bottles. Samples were fixed with formalin (~ 6 % of total volume of sample liquid) buffered with hexamine and stored at room temperature until analysis (Harris et al. 2000; UNESCO 1968). For a detailed flow diagram of the sampling design refer to figure 2 in the Appendix.

2.3 LABORATORY PROCEDURES

2.3.1 Nutrient analyses

The water samples for nutrients analyses were sent to the University of Cape Town (UCT) Department of Oceanography. Samples were analysed for Ammonia, Nitrate, Nitrite, Silicate and Phosphate using the procedures outlined in Grasshoff et al.(1983).

2.3.2 Phytoplankton biomass (chl-*a*)

The frozen seawater samples were left in the dark to defrost. In order to determine size fractionated chl-*a* (SFC) concentrations, the samples were gently filtered by serial filtration through a 20 μm Nylon filter, a 2 μm Isopore filter and finally a 0.7 μm Whatman GF/F filter to separate the phytoplankton into microphytoplankton (>20 μm), nanophytoplankton (2–20 μm) and picophytoplankton (<2 μm) size fractions, respectively. After filtration the filter was transferred into a 10 mL polyethylene tube with 8 mL of 90 % acetone and kept frozen at -20 °C for 24 hours for chlorophyll-*a*

extraction. After 24 hours, the tube was removed from the freezer and centrifuged at 5000 rpm for 5 minutes to remove cellular debris (UNESCO 1994; Harris et al. 2000). The sample was then processed by fluorometry (Holm-Hansen et al. 1965) using a calibrated Turner Designs 10AU Fluorometer immediately after centrifugation. A 5–6 mL sample of the supernatant was carefully transferred into a 10 mL glass cuvette for measurement of fluorescence in the fluorometer. Caution was taken to avoid disturbing the particulate matter at the bottom of the centrifuge tubes. An initial fluorescence reading (F_0) was recorded. The sample was then removed and 3 drops of 3M HCl were added and mixed with the supernatant. The final fluorescence reading (F_a) was recorded. Samples with high concentrations (higher than the detectable limit for the fluorometer) of chlorophyll-*a* were diluted by adding a known volume of 90 % acetone ($V_{dil.}$) and the dilution factor was recorded. The process was then repeated for all samples (JGOFS Protocols 1994).

Chl-*a* concentrations were then determined as follows:

$$\text{Chl } (\mu\text{g.L}^{-1}) = (F_m/F_a - 1) \times (F_0 - F_a) \times K_x \times (\text{Vol}_{ex} / \text{Vol}_{filt})$$

Where:

F_m = acidification coefficient (F_0/F_a) for pure chl-*a*

F_0 = reading before acidification

F_a = reading after acidification

K_x = door factor from calibration calculations (0.325)

Vol_{ex} = extraction volume (8ml)

Vol_{filt} = sample volume

For samples with high chl-*a*, the dilution factor ($V_{dil.}$) was multiplied by the final value.

Integrated chl-*a* concentrations at each station were calculated using the formula:

$$IC = [(C_S + C_M) \div 2 \times (D_M - D_S)] + [(C_M + C_B) \div 2 \times (D_B - D_M)]$$

where, IC = Integrated chl-*a* ($\text{mg}\cdot\text{m}^{-2}$); C_S = surface chl-*a* ($\mu\text{g}\cdot\text{L}^{-1}$); C_M = middle chl-*a* ($\mu\text{g}\cdot\text{L}^{-1}$); C_B = bottom chl-*a* ($\mu\text{g}\cdot\text{L}^{-1}$); D_S = surface depth (m); D_M = middle depth (m); D_B = bottom depth (m).

2.3.3 Seston

After seawater samples were defrosted, the exact volume of water ($V_{\text{H}_2\text{O}}$ in L) was determined using a measuring cylinder. The water was then filtered through a pre-weighed (S_0) oven-dried GF/C filter which was then re-dried in a pre-heated oven at 65 °C for 24 hours. After 24 hours filters were re-weighed to obtain the mass of both the filter and seston (S_1). Seston concentration was determined by subtracting S_0 from S_1 and then converted to $\text{mg}\cdot\text{L}^{-1}$ by dividing the value by the volume of seawater in the bottle ($V_{\text{H}_2\text{O}}$).

$$\text{Seston (mg}\cdot\text{L}^{-1}) = S_1 \text{ (mg)} - S_0 \text{ (mg)} / V_{\text{H}_2\text{O}} \text{ (L)}$$

2.3.4 Mesozooplankton

Identification and enumeration

In the laboratory mesozooplankton were removed from the buffered formalin by filtering the samples onto a 90 μm mesh sieve. Samples were then gently separated into the following size fractions: >1000 μm ; 500–1000 μm ; 200–500 μm ; and 90–200 μm by reverse filtration (Harris et al. 2000). Fractionated samples with high zooplankton numbers were sub-sampled to between 1/2 and 1/128, using a Folsom plankton splitter. Individuals were identified to best taxonomic resolution, to species where possible, with others identified to family or genus, using Boltovskoy (1999), Gibbons (1999) and Conway et al. (2003) keys. Mesozooplankton abundances and volume of water filtered during each tow were determined as follows:

Mesozooplankton abundance (ind.m^{-3}) = number of individuals counted (ind) x fraction of sub-sample (no units) \div volume filtered (m^3)

Volume (m^3) = depth of tow (m) x mouth area of the net (m^2)

Biomass

Biomass, measured as dry weight, was determined using the sub-samples used for enumeration and identification. The sub-samples were filtered through pre-weighed dried filters (B_0) and then re-dried in a pre-heated oven at 65 °C for 24 hours. After 24 hours, filters were removed and a final reading (B_1) of the dry weight of both filter and mesozooplankton was recorded. Mesozooplankton dry weight was determined by subtracting the final reading (B_1) from the initial reading (B_0) and calculated as follows:

Biomass (mg.m^{-3}) = [B_0 (mg) – B_1 (mg)] x fraction of sub-sample filtered (no units) \div volume filtered (m^3)

2.4 STATISTICAL ANALYSES

2.4.1 Physical-chemical variables

Water column stability was calculated as the difference between bottom and surface potential density. Potential density was calculated using the MATLAB script referred to as the Seawater Toolbox version 3.2 from the Commonwealth Scientific and Research Organisation (CSIRO) (http://www.cmar.csiro.au/datacentre/ext_docs/seawater.htm) (CSIRO 2006).

The effects of sector (east vs. west), depth (surface vs. bottom) and sector x depth were examined for all environmental variables. All data were tested for normality and/or equal variance. Transformations [$\log_{10}(x + 1)$, square root and rank] were made on those data that failed normality/equal variance tests. Transformed data were again tested for normality and/or equal variance. Parametric tests [including One and Two Way Analysis

of Variance (ANOVA) and t-tests] were run on original or transformed data that passed normality/equal variance tests, while non-parametric tests (including Kruskal-Wallis One Way ANOVA on Ranks and Mann-Whitney U Rank Sum tests) were run on original data that were found to be non-normal or did not exhibit equal variances. Note that there was no non-parametric equivalent of a Two Way ANOVA; in cases where a Two Way ANOVA was to be run on non parametric data, a series of Mann-Whitney U Rank Sum tests and t-tests (if sub-sets of the data proved to be parametric) were run (Quinn and Keough 2002).

2.4.2 Zooplankton community structure

Cluster Analysis

For cluster analysis (Clarke and Gorley 2006), zooplankton size fractions were merged and all site data were used except for copepods that were not identified to species level. First the data were standardised by the total to eliminate the effect of patchiness and differences in sampling volumes. The standardised data were log-transformed to reduce skewness. A correlation matrix was then created based on a Bray-Curtis Similarity (Clarke and Gorley 2006). This matrix was used in the cluster analysis by complete linkage. Complete linkage was chosen as it has been suggested to be a good method for species abundance data (Legendre and Legendre 1983; Dufrêne and Legendre 1997; McGrigal et al. 2000). Sites that were clustered together were tested for significance using ANOSIM.

Margalef's species richness (d) and Shannon diversity ($H' \log_2$) indices for each site and later for each cluster were determined from raw data using PRIMER (Clarke and Gorley 2006). This analysis excluded species that were not identified to species level. These two diversity indices are most frequently used in studies of zooplankton community composition (Legendre and Legendre 1983; Quinn and Keough 2002; Clarke and Gorley 2006).

Indicator Species Assessment (ISA)

ISA was used to identify species (or taxa) responsible for differences between the clusters identified above, following the method described by Dufrêne and Legendre (1997). Indicator values (IndVals) of each species were calculated for each cluster as a combination of group specificity (A_{ij}) and group fidelity (B_{ij}).

$$A_{ij} = N_{\text{individuals}_{ij}} / N_{\text{individuals}_j}$$

$$B_{ij} = N_{\text{samples}_{ij}} / N_{\text{samples}_j}$$

Where $N_{\text{individuals}_{ij}}$ is the mean number of individuals of species i in the samples of cluster j , while $N_{\text{individuals}_j}$ is the sum of the mean numbers of individuals of species i over all clusters. $N_{\text{samples}_{ij}}$ is the number of samples in cluster j where species i is present, while N_{samples_j} is the number of samples in cluster j .

$$\text{IndVal} = A_{ij} \times B_{ij} \times 100$$

Species with IndVals $\geq 50\%$ were considered as indicator species that were responsible for differences between the clusters identified.

Canonical Correspondence Analysis (CCA)

CCA has been referred to as the “best multivariate constrained ordination technique developed to date” (McGarigal et al. 2000). Constrained ordination involves the direct ordination of a first set of variables (such as abundance data) on axes that are combinations of the 2nd set of variables (such as environmental data). CCA has been chosen as it is suitable for species data, which demonstrate a non-monotonic rise and fall of abundances and a large number of zeros. CCA is preferred, therefore, over the ordinations such as Non-Metric Multidimensional Scaling (N-MDS) that assume monotonicity. CCA performs well with data from complex sampling designs. It does not create an arch effect (like PCA does). Unlike BioEnv in PRIMER, CCA is not hampered by multicollinearity or high correlations between either dependent or independent

variables. CCA is also preferred over PCA when the number of variables is more than the number of samples, as is often the case with zooplankton data (the number of species identified far outnumbers the number of sites occupied).

All data were $\log_{10}(x + 1)$ transformed prior to running the CCA in CANOCO for Windows (volume 4.5). Further statistical analyses comparing environmental variables identified as important by the CCA (i.e., those with a correspondence value >0.65) between the clusters identified were then run using Sigma Stats.

Univariate analyses

The effects of cluster (as identified by cluster analysis) on total and size fractionated zooplankton abundance and biomass; dominant zooplankton groups (by size class); and species richness and diversity were examined using One Way ANOVAs (for parametric data) or Kruskal-Wallis One Way ANOVA on Ranks (for non-parametric data). The effects of size fraction (by cluster) on abundance, biomass, species richness and diversity were examined using One Way ANOVAs (for parametric data) or Kruskal-Wallis One Way ANOVA on Ranks (for non-parametric data)(Quinn and Keough 2002).

All data were tested for normality and equal variance. Those that did not pass were transformed [$\log_{10}(x + 1)$ or square root] and re-tested. Parametric tests were run on data that passed normality and/or equal variance tests, while non-parametric tests were run on original data that did not pass normality and/or equal variance tests even after transformation (Quinn and Keough 2002).

CHAPTER 3: RESULTS – SUMMER SURVEY

3.1 PHYSICAL-CHEMICAL ENVIRONMENT

3.1.1 Temperature, salinity and water column stability

Temperature

During summer 2008, surface seawater temperatures were highly variable across Algoa Bay (Figure 3.1A). Surface water temperatures were significantly lower ($P = 0.004$; Table 3.1) in the eastern sector, with an average of $18.29\text{ }^{\circ}\text{C}$ ($SD = 1.65$), than they were in the western sector, where the average was $19.74\text{ }^{\circ}\text{C}$ ($SD = 0.81$) (Figure 3.1B). Bottom seawater temperatures showed a similar trend, with average values in the east (Mean = $11.80\text{ }^{\circ}\text{C}$, $SD = 0.76$) being significantly lower ($P = 0.002$; Table 3.1) than those in the west (Mean $14.18\text{ }^{\circ}\text{C}$, $SD = 2.08$) (Figure 3.1B). In both the eastern and western sectors, seawater temperature was significantly higher in the surface waters than the bottom waters ($P < 0.001$ for both sectors; Table 3.1; Figure 3.1B).

Table 3.1: Results of a series of Two Way Analysis of Variance (F) for rank transformed summer temperature data. For tests where the main effects showed significant variability, a post-hoc Tukey Test (q) was used to conduct pairwise multiple comparison procedure.

Source of Variance	q	P	df	F	Significance
Sector	--	<0.001	1	20.04	**
Depth	--	<0.001	1	236.20	**
Sector x Depth	--	0.838	1	0.04	NS
East: S vs. B	15.57	<0.001	--	--	**
West: S vs. B	15.16	<0.001	--	--	**
Surface: E vs. W	4.27	0.004	--	--	*
Bottom: E vs. W	4.68	0.002	--	--	*

Note: S = Surface; B = Bottom; E = East; W = West; * and ** indicate significant and highly significant P values, respectively; NS= No Significant difference; -- = not tested; df = degrees of freedom.

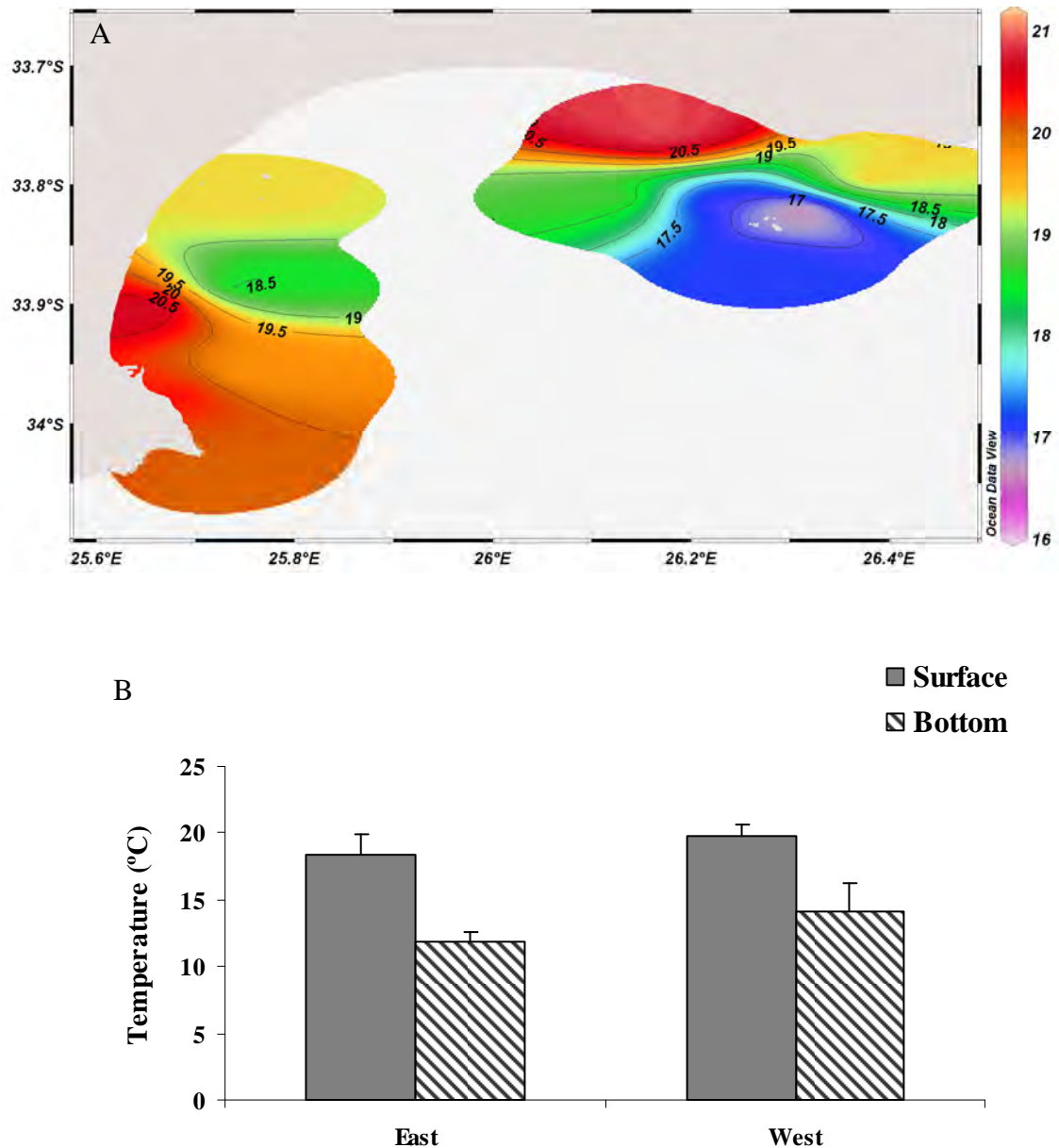


Figure 3.1: A) Surface plot of seawater temperature (°C); B) Average surface and bottom seawater temperatures for each sector, during summer 2008. Error bars are standard deviations.

Salinity

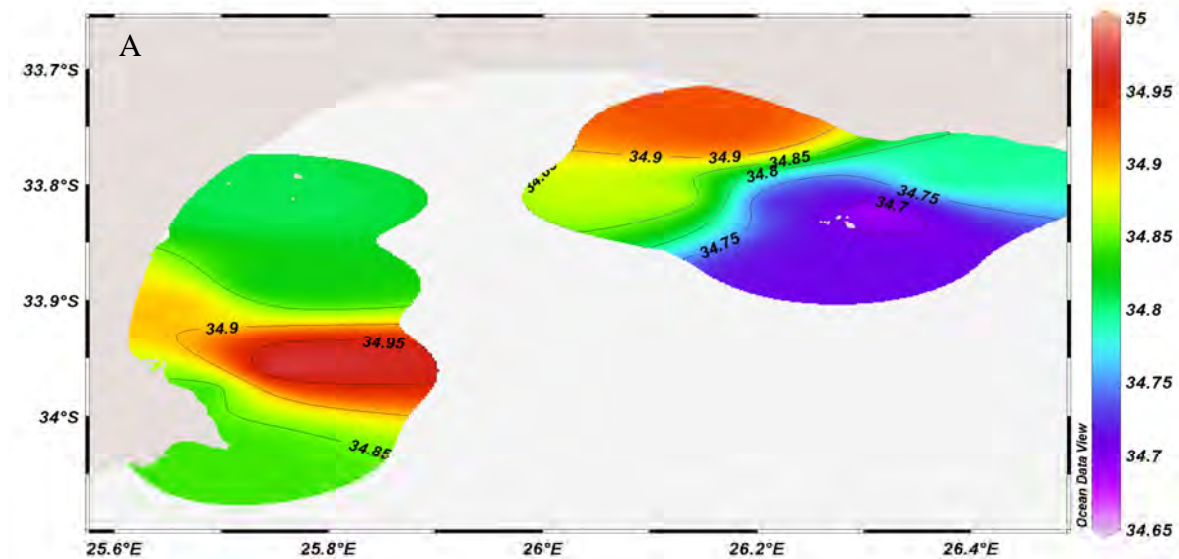
Variability in surface seawater salinity during summer 2008 showed a similar pattern to that of surface temperature (Figure 3.2A). Surface salinities varied significantly between the eastern and western sectors ($P = 0.019$; Table 3.2), where average salinities were 34.78 (SD = 0.09) and 34.86 (SD = 0.06), respectively (Figure 3.2B). Similarly, bottom

water salinities were significantly higher ($P < 0.001$; Table 3.2) in the western sector (Mean = 34.57 SD = 0.15) than they were in the eastern sector (Mean = 34.36 SD = 0.09) (Figure 3.2B). In both sectors salinity was greatest in the surface waters ($P < 0.001$ for both sectors; Table 3.2; Figure 3.2B).

Table 3.2: Results of a series of t-tests and the equivalent non-parametric Mann-Whitney U Rank Sum test for summer salinity data. Note that even after transformation, some salinity data remained non-normal and/or exhibited unequal variances.

Source of Variance	T	df	U	P	Significance
East: S vs. B	12.78	34	--	<0.001	**
West: S vs. B	--	--	15.00	<0.001	**
Surface: E vs. W	--	--	87.50	0.019	*
Bottom: E vs. W	--	--	34.50	<0.001	**

Note: S = Surface; B = Bottom; E = East; W = West; * and ** indicate significant and highly significant P values, respectively; -- = not tested; df = degrees of freedom.



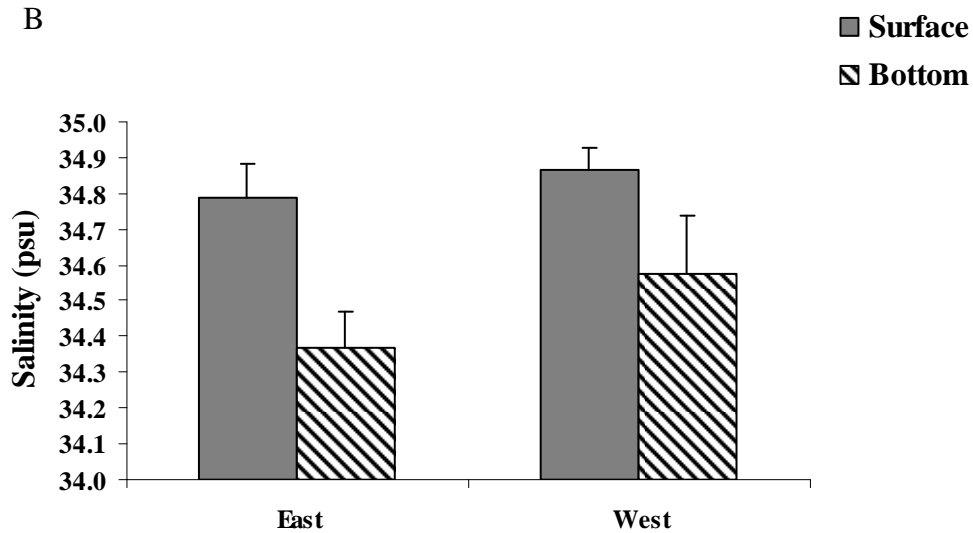


Figure 3.2: A) Surface plot of seawater salinity (Psu); B) Average surface and bottom seawater salinities for each sector, during summer 2008. Error bars on plots are standard deviations.

Water column stability

Water column stability in summer averaged 0.001 (SD = 0.042×10^{-2}) in the eastern sector and 0.001 (SD = 0.024×10^{-2}) in the western sector (Figure 3.3). Water column stability showed no significant spatial variability during the summer survey ($P = 0.739$; Table 3.3).

Table 3.3: Results of a One Way ANOVA for summer water column stability data.

Source of Variance	F	df	P	Significance
East vs. West	0.11	1	0.739	NS

Note: NS = No Significant difference; degrees of freedom.

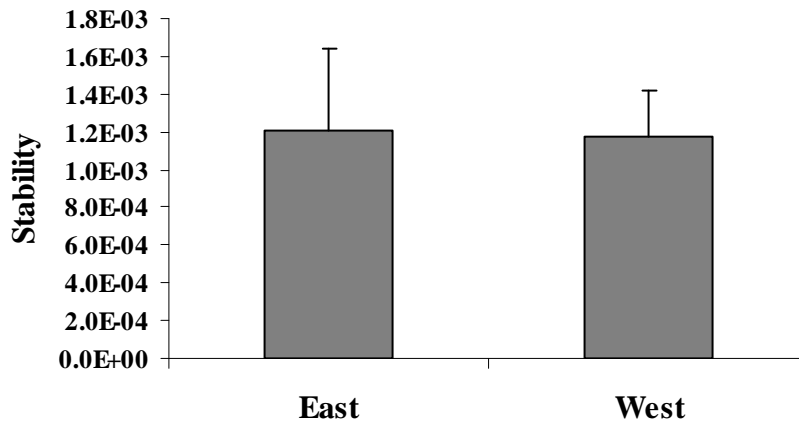


Figure 3.3: Average water column stability for each sector, during summer 2008. Error bars are standard deviations. Note: Scientific notation used for clear differentiation in values.

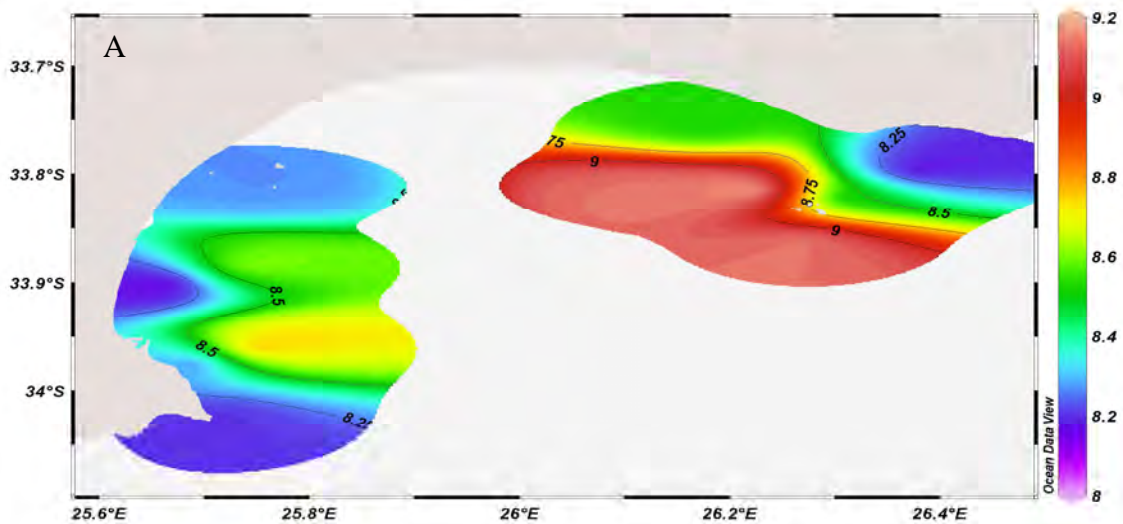
3.1.2 Dissolved oxygen

Surface dissolved oxygen concentrations, during summer 2008, showed significant spatial variability ($P = 0.003$) across Algoa Bay (Table 3.4; Figure 3.4A). Surface dissolved oxygen values were significantly higher in the eastern sector, with an average of 8.77 mg.L^{-1} ($SD = 0.43$), than those recorded in the western sector of the Bay, where the average was 8.37 mg.L^{-1} ($SD = 0.26$) (Figure 3.4B). Bottom water dissolved oxygen concentrations also reflected a similar trend, with the eastern sector exhibiting significantly higher ($P = 0.017$; Table 3.4) average values of 5.54 mg.L^{-1} ($SD = 0.85$) than the western sector average of 4.45 mg.L^{-1} ($SD = 1.700$) (Figure 3.4B). In both the eastern and western sectors, dissolved oxygen concentration was significantly higher in surface waters than in bottom waters ($P < 0.001$ for both sectors; Table 3.4; Figure 3.4B).

Table 3.4: Results of a series of Two Way Analysis of Variance (F) for rank transformed summer dissolved oxygen data. For tests where the main effects showed significant variability, a post-hoc Tukey Test (q) was used to conduct pairwise multiple comparison procedure.

Source of Variance	F	df	q	P	Significance
Sector	15.52	1	--	<0.001	**
Depth	251.53	1	--	<0.001	**
Sector x Depth	0.21	1	--	0.643	NS
East: S vs. B	--	--	16.32	<0.001	**
West: S vs. B	--	--	15.39	<0.001	**
Surface: E vs. W	--	--	4.40	0.003	*
Bottom: E vs. W	--	--	3.47	0.017	*

Note: S = Surface; B = Bottom; E = East; W = West; * and ** indicate significant and highly significant P values, respectively, NS = No significant difference; -- = not tested; df = degrees of freedom.



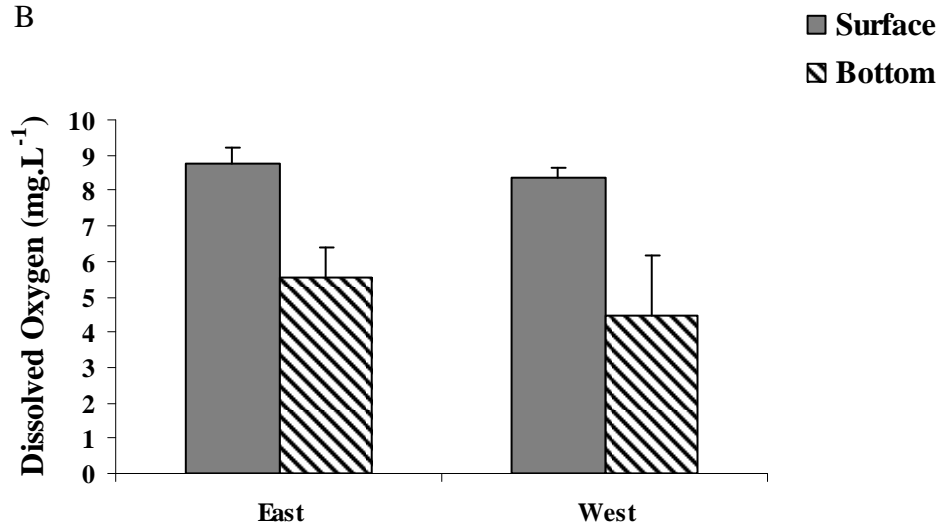


Figure 3.4: A) Surface plot of seawater dissolved oxygen (mg.L⁻¹); B) Average surface and bottom seawater dissolved oxygen for each sector, during summer 2008. Error bars are standard deviations.

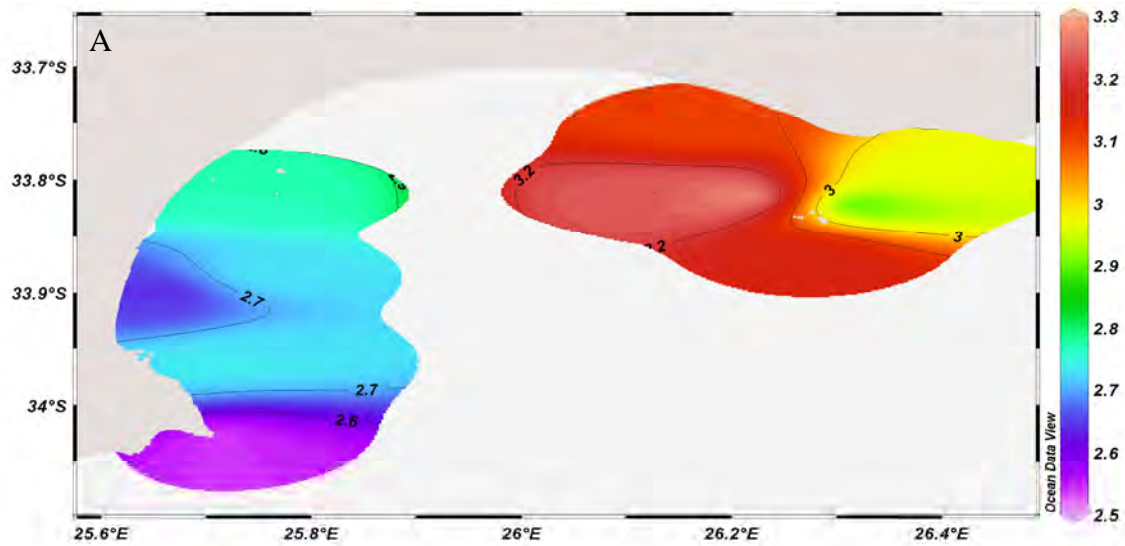
3.1.3 Turbidity

Surface turbidity varied significantly ($P < 0.001$; Table 3.5) between the eastern and western sectors of the Bay (Figure 3.5A and 3.5B). Surface turbidity averaged 3.10 NTU (SD = 0.18) in the east and 2.68 NTU (SD = 0.14) in the west (Figure 3.5B). Bottom water turbidity, in contrast, did not demonstrate any significant spatial variability ($P = 0.949$; Table 3.5). Bottom turbidity averaged 2.84 NTU in the east, and 2.80 NTU (SD = 0.358) in the west (Figure 3.5B). In the eastern sector, turbidity varied significantly with depth ($P < 0.001$; Table 3.5; Figure 3.5B). However, there were no significant differences in turbidity with depth in the western sector of the Bay ($P = 0.244$; Table 3.5).

Table 3.5: Results of a series of t-tests and the non-parametric equivalent, Mann-Whitney U Rank Sum test for summer turbidity data. Note that even after transformation, some turbidity data remained non-normal and/or exhibited unequal variances.

Source of Variance	t	df	U	P	Significance
East: S vs. B	5.12	34	--	<0.001	**
West: S vs. B	--	--	125.00	0.244	NS
Surface: E vs. W	7.56	--	--	<0.001	**
Bottom: E vs. W	--	--	159.50	0.949	NS

Note: S = Surface; B = Bottom; E = East; W = West; * and ** indicate significant and highly significant P values, respectively, and NS = No Significant difference; -- = not tested; df = degrees of freedom.



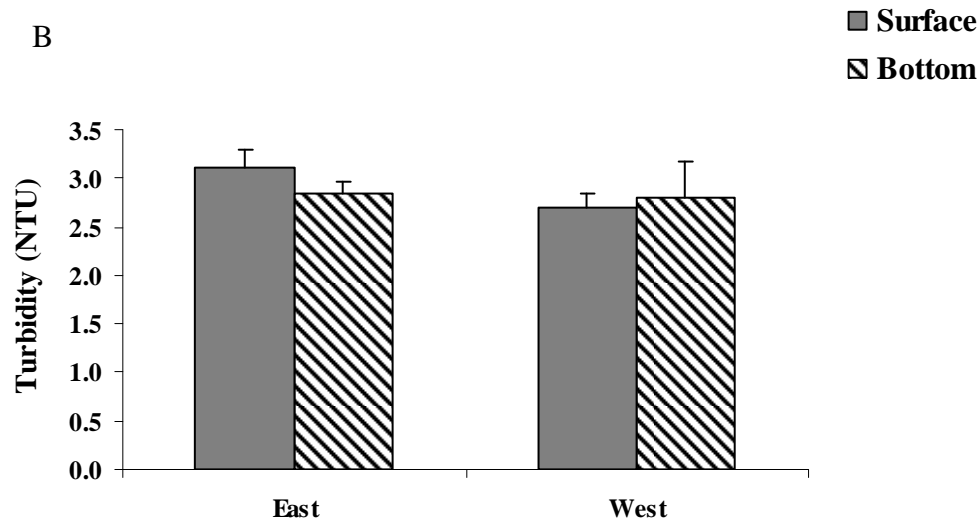


Figure 3.5: A) Surface plot of turbidity (NTU); B) Average surface and bottom turbidity for each sector, during summer 2008. Error bars are standard deviations.

3.1.4 Seston

Surface seston concentrations showed no significant spatial variability ($P = 0.326$; Table 3.6) across Algoa Bay during summer 2008 (Figure 3.6A). Average surface seston concentrations in the eastern sector were relatively higher at 30.37 mg.L^{-1} ($SD = 6.66$), than the 27.27 mg.L^{-1} ($SD = 3.93$) recorded in the western sector. Bottom waters, on the other hand, exhibited higher averages in the western sector, with an average of 28.44 mg.L^{-1} ($SD = 5.32$), than the average of 27.75 mg.L^{-1} ($SD = 4.63$) in the eastern sector (Figure 3.6B). However, none of these differences were significant ($P > 0.050$; Table 3.6). There were no significant differences in seston concentrations between the surface and bottom waters in either the east or west sectors ($P > 0.050$ for all sources of variance in both sectors; Table 3.6).

Table 3.6: Results of a series of Two Way Analysis of Variance (F) for summer seston data. Note that no pairwise comparisons were required as there were no significant differences detected.

Source of Variance	F	df	P	Significance
Sector	0.97	1	0.326	NS
Depth	0.35	1	0.556	NS
Sector x Depth	2.40	1	0.125	NS

Note: NS = No Significant difference; Sector is a comparison between East and West; Depth is a comparison between surface and bottom; df = degrees of freedom.

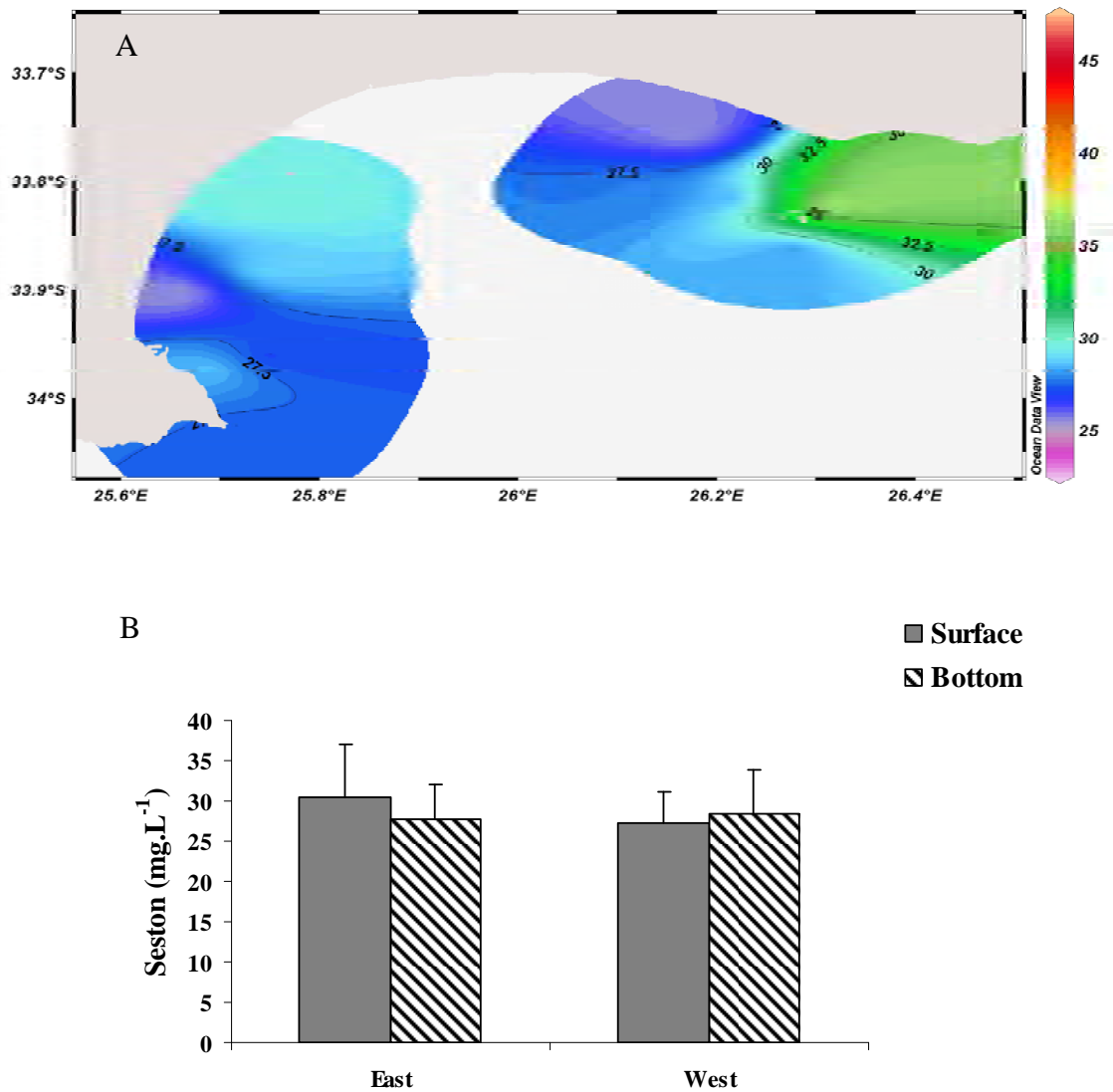


Figure 3.6: A) Surface plot of seston (mg.L⁻¹); B) Average surface and bottom seston for each sector, during summer 2008. Error bars are standard deviations.

3.1.5 Nutrients

Nitrate

Surface nitrate concentrations demonstrated high spatial variability across Algoa Bay during summer 2008 (Figure 3.7A). Surface nitrate concentrations in the western sector were significantly lower (Mean = 0.04 μM ; SD = 0.06; P = 0.042; Table 3.7) than those recorded in the eastern sector, which averaged 0.40 μM (SD = 0.75) (Figure 3.7B). Bottom water nitrate concentrations were higher in the eastern sector with an average of 14.61 μM (SD = 2.22), compared to the average of 7.60 μM (SD = 8.13) in the western sector, but this variability was not significant (P = 0.052; Table 3.7; Figure 3.7B). Surface nitrate concentrations, within both sectors, were significantly lower than bottom water concentrations (P<0.001 for both sectors; Table 3.7; Figure 3.7B).

Table 3.7: Results of a series of Two Way Analysis of Variance (F) for log transformed summer nitrate data. For tests where the main effects showed significant variability, a post-hoc Tukey Test (q) was used to conduct pairwise multiple comparison procedure.

Source of Variance	F	df	q	P	Significance
Sector	9.00	1	--	0.007	*
Depth	48.69	1	--	<0.001	**
Sector x Depth	0.006	1	--	0.939	NS
East: S vs. B	--	--	6.90	<0.001	**
West: S vs. B	--	--	7.05	<0.001	**
Surface: E vs. W	--	--	3.07	0.042	*
Bottom: E vs. W	--	--	2.92	0.052	NS

Note: S = Surface; B = Bottom; E = East; W = West; * and ** indicate significant and highly significant P values respectively, and NS = No Significant difference; -- = not tested; df = degrees of freedom.

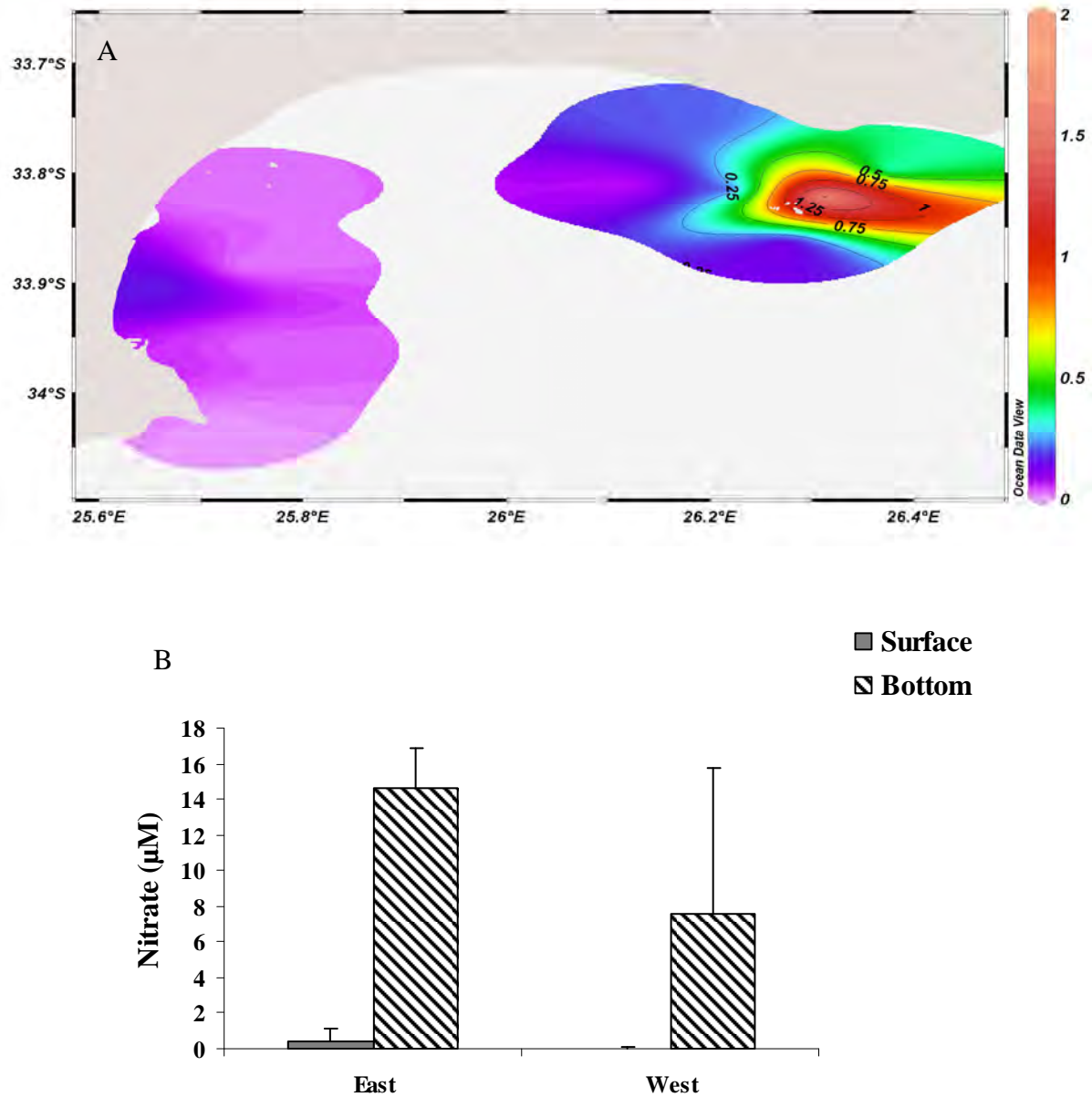


Figure 3.7: A) Surface plot of nitrate concentrations (μM); B) Average surface and bottom nitrate concentrations for each sector, during summer 2008. Error bars are standard deviations.

Nitrite

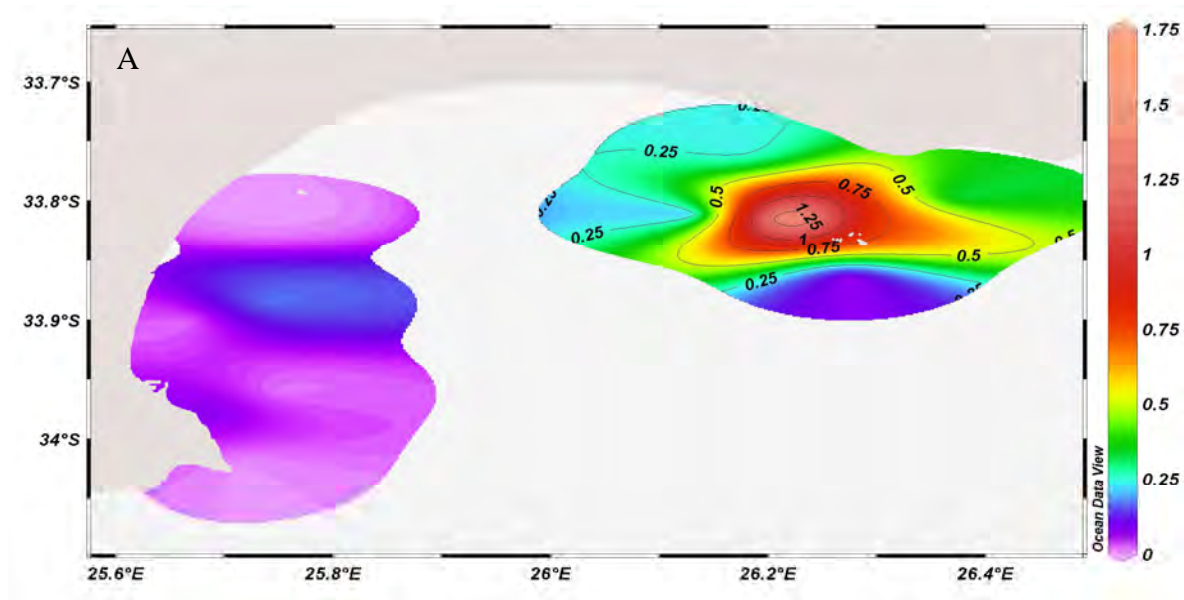
Surface nitrite concentrations demonstrated no significant spatial patterns across Alga Bay during summer 2008 ($P = 0.163$; Table 3.8; Figure 3.8A), although surface nitrite concentrations in the eastern sector were relatively higher (Mean = $0.48 \mu\text{M}$; SD = 0.66)

than those recorded in the western sector (Mean = 0.04 μM ; SD = 0.07) (Figure 3.8A and 3.8B). In contrast, bottom water nitrite concentrations were relatively higher in the western sector (Mean = 1.43 μM ; SD = 0.75) compared to the eastern sector (Mean = 1.33 μM ; SD = 0.32), however this variability was not significant ($P = 0.758$; Table 3.8; Figure 3.8B). In both the eastern and western sectors, surface nitrite concentrations were significantly lower than those in the bottom waters (Table 3.8; Figure 3.8B).

Table 3.8: Results of a series of Two Way Analysis of Variance (F) for summer nitrite data. For tests where the main effects showed significant variability, a post-hoc Tukey Test (q) was used to conduct pairwise multiple comparison procedure.

Source of Variance	F	df	q	P	Significance
Sector	0.64	1	--	0.432	NS
Depth	27.08	1	--	<0.001	**
Bottom	1.54	1	--	0.228	NS
East: S vs. B	--	--	3.96	0.011	*
West: S vs. B	--	--	6.44	<0.001	**
Surface: E vs. W	--	--	2.04	0.163	NS
Bottom: E vs. W	--	--	0.44	0.758	NS

Note: S = Surface; B = Bottom; E = East; W = West; * and ** indicate significant and highly significant P values respectively, and NS = No Significant difference; -- = not tested; df = degrees of freedom.



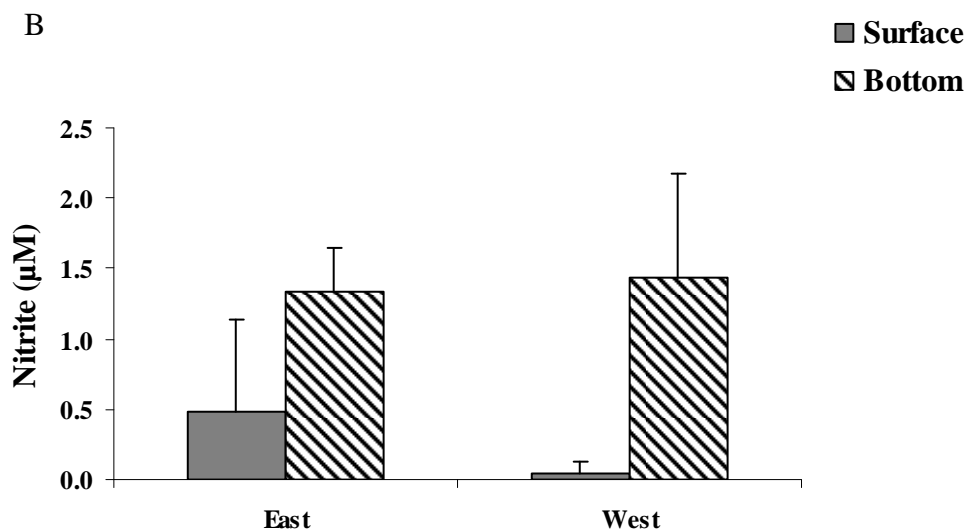


Figure 3.8: A) Surface plot of nitrite concentrations (μM); B) Average surface and bottom nitrite concentrations for each sector, during summer 2008. Error bars are standard deviations.

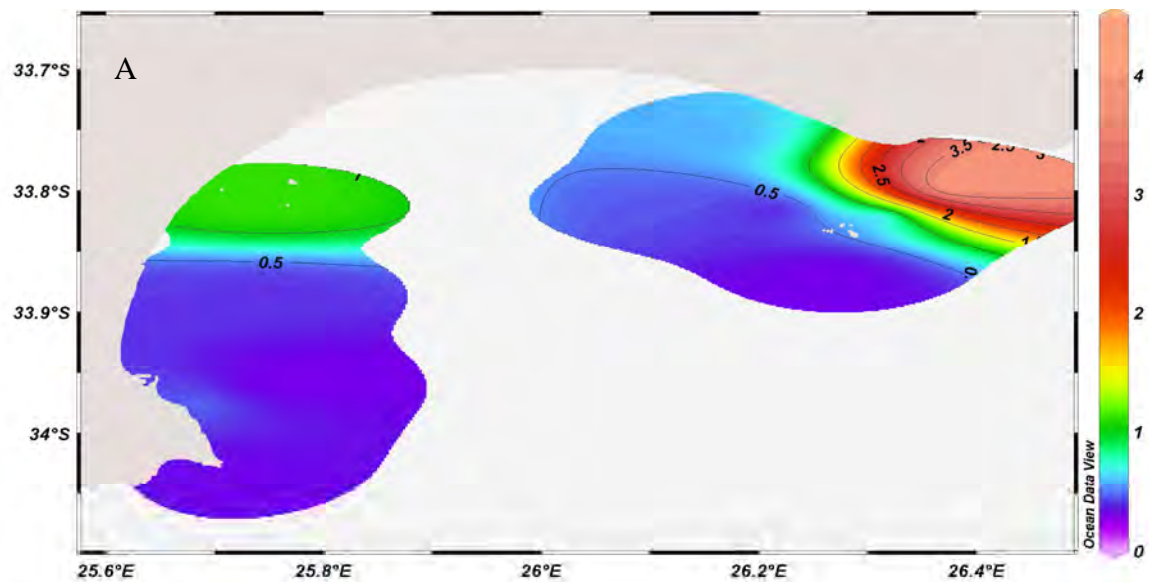
Ammonia

Surface ammonia concentrations did not vary significantly across Algoa Bay during the summer survey ($P = 0.641$; Table 3.9; Figure 3.9A). Higher surface ammonia concentrations were recorded in the eastern sector though, where the average was $1.05 \mu\text{M}$ ($SD = 1.7$). In the western sector, the average surface ammonia concentration was $0.48 \mu\text{M}$ ($SD = 0.33$) (Figure 3.9B). Bottom water ammonia concentrations showed a similar trend, with average values in the east (Mean = $3.64 \mu\text{M}$; $SD = 5.53$) being relatively higher than those in the west (Mean = $2.90 \mu\text{M}$, $SD = 3.26$), but this was not statistically significant either ($P = 0.835$; Table 3.9; Figure 3.9B). In both the eastern and western sectors, there were significant differences in ammonia concentrations between the surface and the bottom waters ($P > 0.050$ for both sectors; Table 3.9).

Table 3.9: Results of a series of Two Way Analysis of Variance (F) for rank transformed summer ammonia data. For tests where main effects showed significant variability, a post-hoc Tukey Test (q) was used to conduct pairwise multiple comparison procedures.

Source of Variance	F	df	q	P	Significance
Sector	0.23	1	--	0.633	NS
Depth	18.05	1	--	<0.001	**
Sector x Depth	0.03	1	--	0.854	NS
East: S vs. B	--	--	4.06	0.010	*
West: S vs. B	--	--	4.43	0.005	*
Surface: E vs. W	--	--	0.67	0.641	NS
Bottom: E vs. W	--	--	0.29	0.835	NS

Note: S = Surface; B = Bottom; E = East; W = West; * indicate significant P values; NS = No Significant difference; NS = No Significant difference; -- = not tested; df = degrees of freedom.



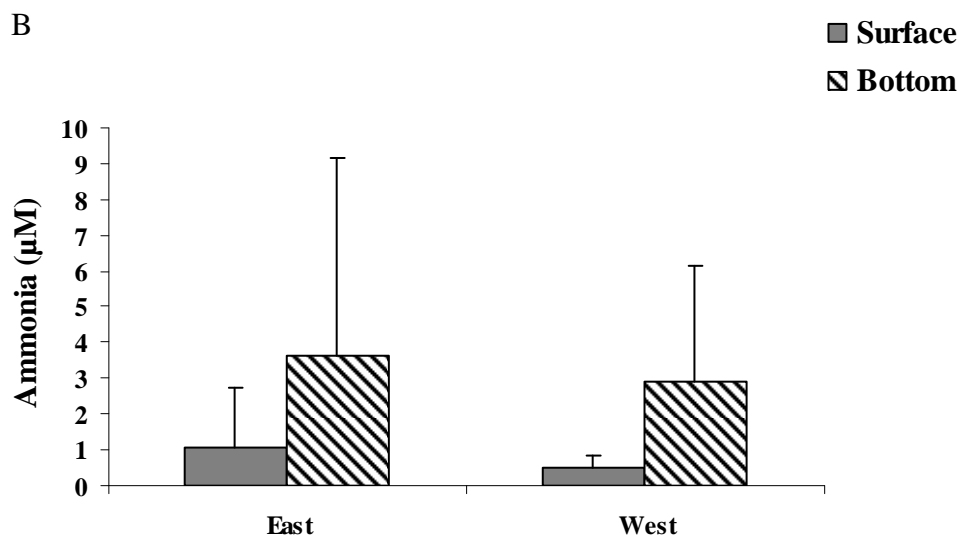


Figure 3.9: A) Surface plot of ammonia concentrations (μM); B) Average surface and bottom ammonia concentrations for each sector, during summer 2008. Error bars are standard deviations.

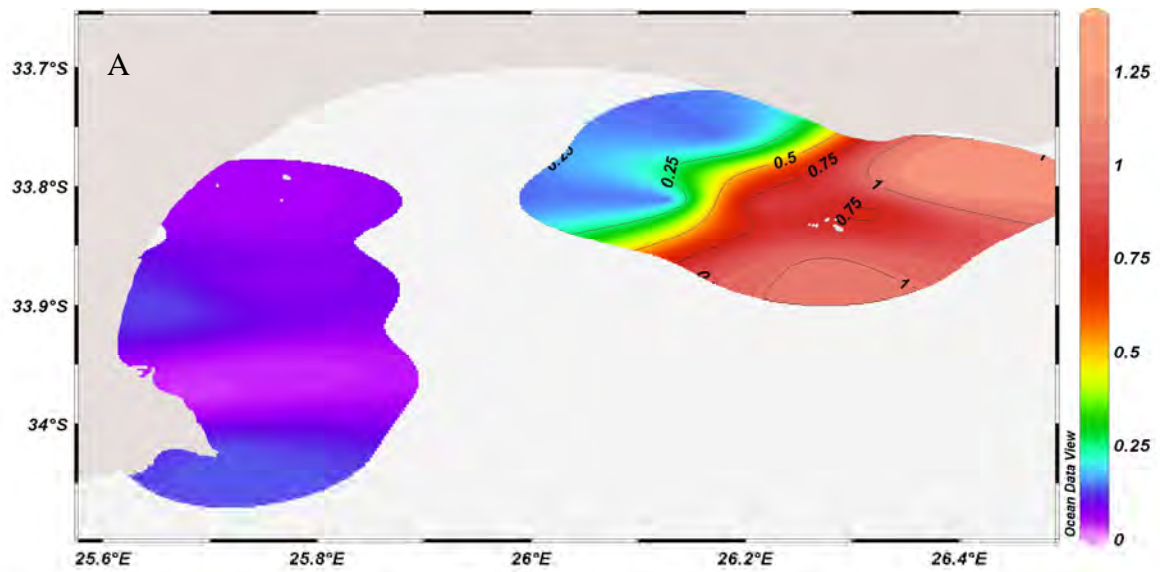
Phosphate

Surface phosphate concentrations demonstrated little spatial variability across Algoa Bay during summer 2008 (Figure 3.10A). Phosphate concentrations reflected no statistically significant variability in either depth or sector ($P > 0.050$ for all tests; Table 3.10). Relatively higher surface phosphate concentrations (Mean = $0.68 \mu\text{M}$; SD = 0.53) were recorded in the eastern sector, while in the western sector the mean surface phosphate concentration was $0.08 \mu\text{M}$ (SD = 0.05) (Figure 3.10B). Similarly, the highest bottom water phosphate concentrations were recorded in the eastern sector, with an average of $1.11 \mu\text{M}$ (SD = 0.720), while those in the western sector averaged $0.69 \mu\text{M}$ (SD = 0.74) (Figure 3.10B).

Table 3.10: Results of a series of Two Way Analysis of Variance for summer phosphate data. For tests where main effects showed significant variability, a post-hoc Tukey Test (q) was used to conduct pairwise multiple comparison procedure.

Source of Variance	F	df	q	P	Significance
Sector	4.53	1	--	0.046	*
Depth	4.71	1	--	0.042	*
Sector x Depth	0.15	1	--	0.703	NS
East: S vs. B	--	--	1.78	0.222	NS
West: S vs. B	--	--	2.55	0.086	NS
Surface: E vs. W	--	--	2.51	0.09	NS
Bottom: E vs. W	--	--	1.74	0.232	NS

Note: S = Surface; B = Bottom; E = East; W = West; NS = No Significant difference; * indicate significant P values; -- = not tested; df = degrees of freedom.



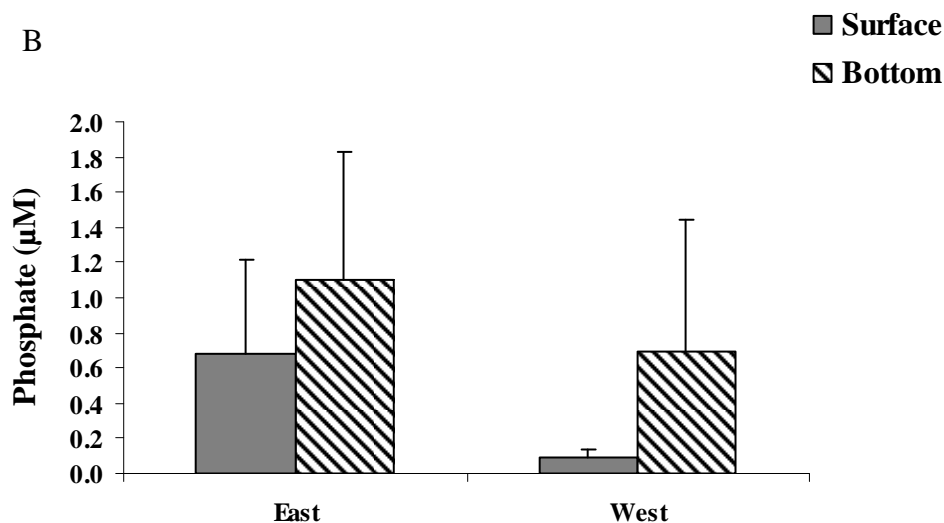


Figure 3.10: A) Surface plots of phosphate concentrations (μM); B) Average surface and bottom phosphate concentrations for each sector, during summer 2008. Error bars are standard deviations.

Silicate

Silicate concentrations showed similar patterns to that of phosphate, with no significant trends in variability with either depth or sector evident across Algoa Bay during the summer survey ($P > 0.050$ for all tests; Figure 3.11A). The surface waters averaged $11.74 \mu\text{M}$ ($\text{SD} = 8.66$) in the eastern sector while the average value in the western sector was lower, at $2.88 \mu\text{M}$ ($\text{SD} = 4.65$) (Figure 3.11B). Similarly, highest bottom water silicate concentrations were also recorded in the eastern sector with an average of $18.25 \mu\text{M}$ ($\text{SD} = 13.67$). In the western sector of the Bay, the average bottom water silicate concentration was $15.19 \mu\text{M}$ ($\text{SD} = 18.54$) (Figure 3.11B).

Table 3.11: Results of a series of Two Way Analysis of Variance (F) for summer silicate concentration data.

Source of Variance	df	F	P	Significance
Sector	1	1.36	0.257	NS
Depth	1	3.39	0.080	NS
Sector x Depth	1	0.32	0.576	NS

Note: NS = No Significant difference; df = degrees of freedom.

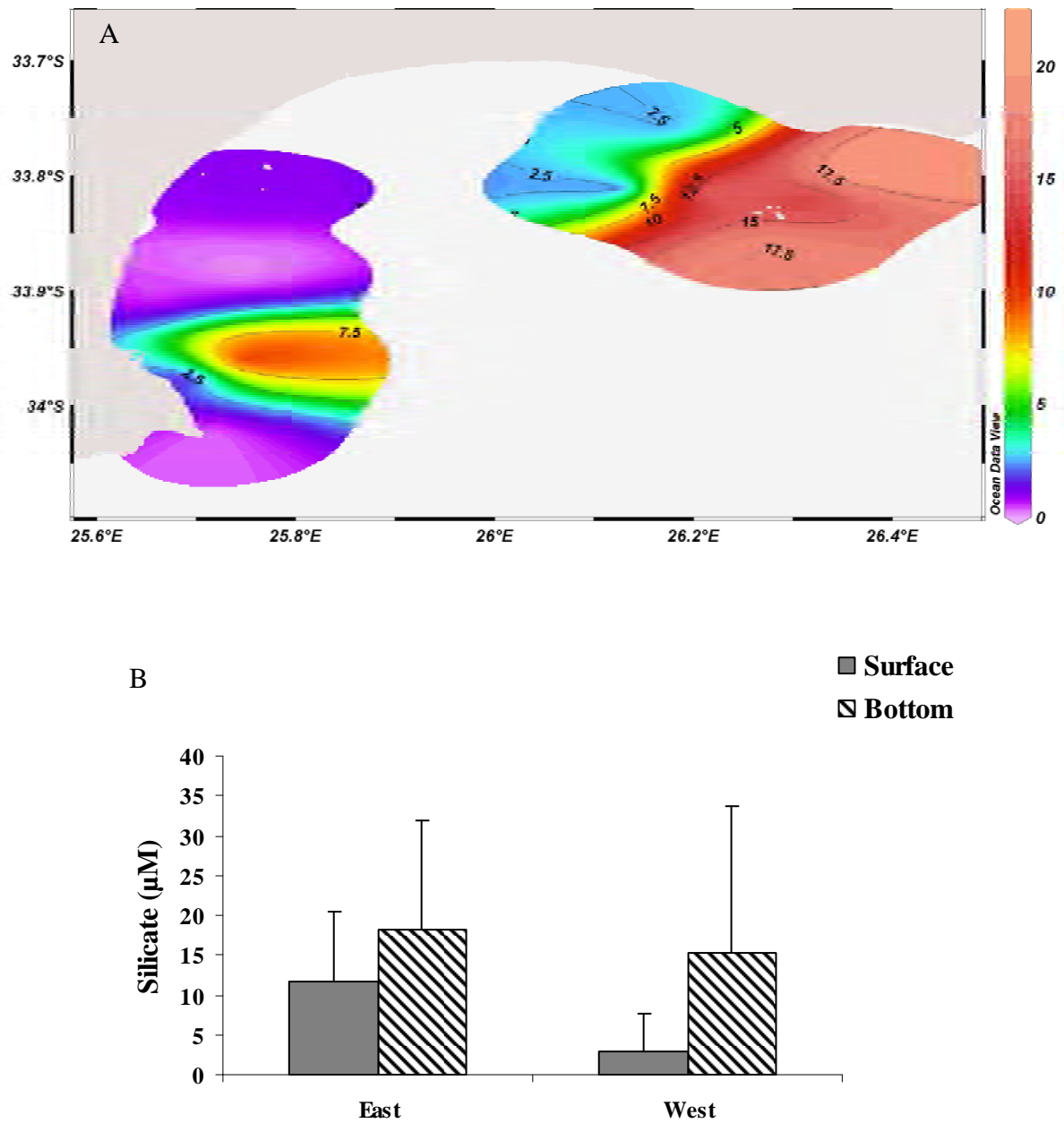


Figure 3.11: A) Surface plots of silicate concentrations (μM); B) Average surface and bottom silicate concentrations for each sector, during summer 2008. Error bars are standard deviations.

3.2 PHYTOPLANKTON BIOMASS

3.2.1 Surface total and size-fractionated chlorophyll-*a* (SFC)

Total surface chlorophyll-*a* (chl-*a*) concentrations reflected no significant spatial variability across Algoa Bay during the summer survey ($P = 0.141$, Table 3.12; Figure

3.12A). The highest total chl-*a* concentrations were recorded in the eastern sector with an average of 3.11 $\mu\text{g.L}^{-1}$ (SD = 2.41) while those in the western sector averaged 1.87 $\mu\text{g.L}^{-1}$ (SD = 0.79) (Figure 3.12B). The microphytoplankton size class (>20 μm) dominated the total phytoplankton biomass in both the eastern and the western sectors. In the western sector, the microphytoplankton made a net contribution of 91 % to the total chl-*a*, which corresponded to an average concentration of 1.69 $\mu\text{g.L}^{-1}$ (SD = 0.74), while nanophytoplankton (2-20 μm) and picophytoplankton (<2.0 μm) contributed 6 % (Mean = 0.12 $\mu\text{g.L}^{-1}$; SD = 0.11) and 3 % (Mean = 0.06 $\mu\text{g.L}^{-1}$; SD = 0.05) to the total concentration, respectively (Figure 3.13B). Microphytoplankton in the eastern sector had an average concentration of 2.56 $\mu\text{g.L}^{-1}$ (SD = 1.90), which corresponded to 84 % of the total pigment. The nano- and picophytoplankton had average concentrations of 0.38 $\mu\text{g.L}^{-1}$ (SD = 0.53) and 0.13 $\mu\text{g.L}^{-1}$ (SD = 0.11), corresponding to 12 % and 4 % of the total pigment, respectively (Figure 3.13A). Microphytoplankton and nanophytoplankton showed no statistical variability between the two sectors ($P > 0.050$ in both sectors; Table 3.13 A and B). The picophytoplankton concentration, on the other hand, exhibited statistical variability between the two sectors ($P = 0.020$; Table 3.13C); the eastern sector exhibited highest concentrations of all size fractions to the total concentration.

Table 3.12: Results of a t-test on log transformed summer total chlorophyll-*a* data.

Source of Variance	t	df	P	Significance
S: East vs. West	1.991	31	0.055	NS

Note: S = surface; NS = No Significant difference; df = degrees of freedom.

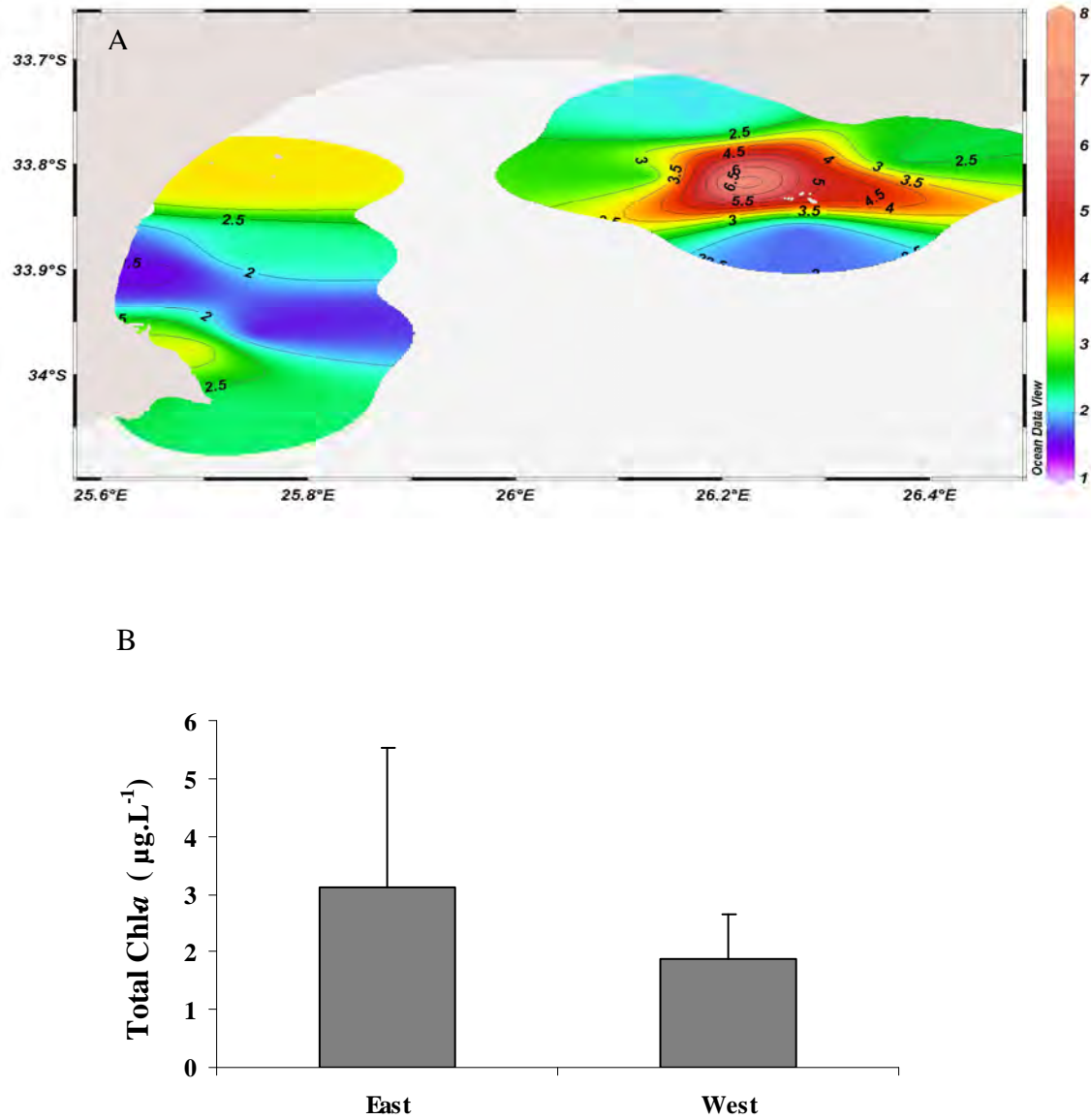


Figure 3.12: A) Surface plot of total chlorophyll-*a* concentration ($\mu\text{g.L}^{-1}$); B) Average surface total chlorophyll-*a* for each sector, during summer 2008. Error bars are standard deviations.

Table 3.13: Results of a series of t-tests on summer size fractionated chlorophyll-*a* data. Note: Only nanophytoplankton data required log transformation.

A. Microphytoplankton				
Source of Variance	t	df	P	Significance
East vs. West	1.79	31	0.082	NS

B. Nanophytoplankton

Source of Variance	t	df	P	Significance
East vs. West	1.72	34	0.094	NS

C. Picophytoplankton

Source of Variance	t	df	P	Significance
East vs. West	2.45	34	0.020	*

Note: * indicate significant P value; NS = No Significant difference; df = degrees of freedom.

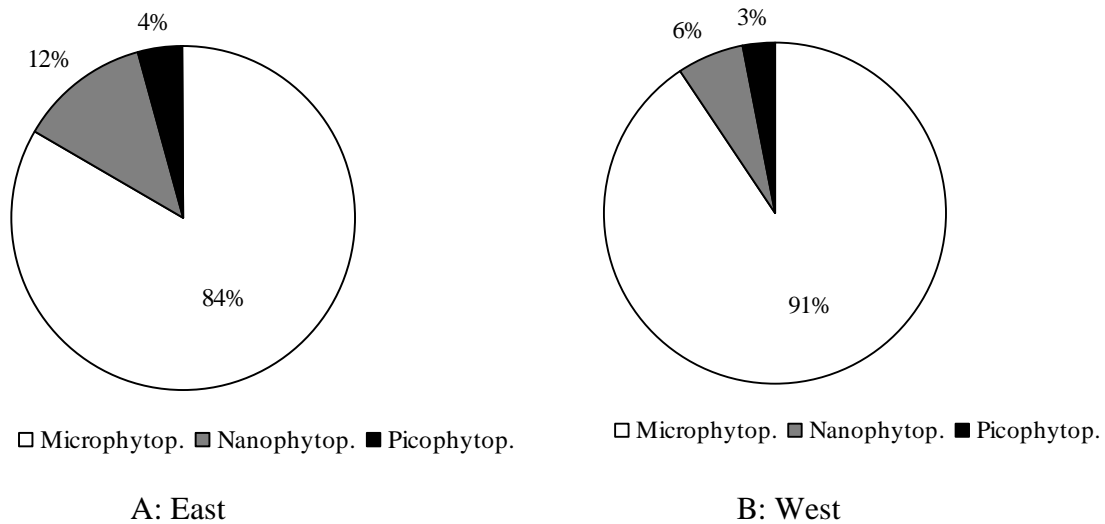


Figure 3.13: Percent contribution of size fractionated chlorophyll-*a* ($\mu\text{g.L}^{-1}$) for each sector of Algoa Bay during summer 2008.

3.2.2 Total and size-fractionated integrated chlorophyll-*a*

Integrated chl-*a* concentrations varied significantly across Algoa Bay during summer 2008 ($P = 0.007$, Table 3.14; Figure 3.14A). The highest concentrations were recorded in the eastern sector (Mean = 89.06 mg.m^{-2} ; SD = 62.92), while in the western sector the average concentration was 44.69 mg.m^{-2} (SD = 15.30) (Figure 3.14B). The microphytoplankton dominated total integrated phytoplankton biomass with contributions of 89% in both sectors, which corresponded to average integrated concentrations of 76.86 mg.m^{-2} (SD = 52.29) and 39.86 mg.m^{-2} (SD = 13.75) in the eastern and western sectors of

the Bay, respectively (Figure 3.15A and B) ($P = 0.007$; Table 3.15A). The nanophytoplankton and picophytoplankton contributed 8 % and 3 % of the total in the eastern and western sectors, respectively (Figure 13.5A and B). Picophytoplankton showed significant differences between the sectors ($P = 0.015$; Table 3.15C), while nanophytoplankton reflected none ($P = 0.092$; Table 3.15B).

Table 3.14: Results of a t-test on summer total integrated chlorophyll-*a* data.

Source of Variance	t	df	P	Significance
S: East vs. West	2.89	29	0.007	*

Note: * indicate significant P value; df = degrees of freedom.

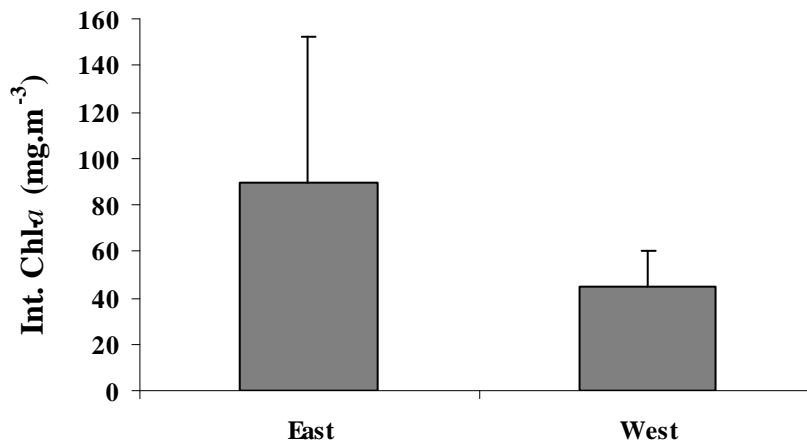


Figure 3.14: Average total integrated chlorophyll-*a* for each sector of Algoa Bay, during summer 2008. Error bars are standard deviations.

Table 3.15: Results of a series of t-tests on summer integrated size fractionated chlorophyll-*a* data. Note: Only nanophytoplankton required log transformation.

A. Integrated Microphytoplankton				
Source of Variance	t	df	P	Significance
East vs. West	2.90	30	0.007	*

B. Integrated Nanophytoplankton

Source of Variance	t	df	P	Significance
East vs. West	1.74	30	0.092	NS

C. Integrated Picophytoplankton

Source of Variance	t	df	P	Significance
East vs. West	2.57	30	0.015	*

Note: * indicates significant P values; NS = No Significant difference; df = degrees of freedom.

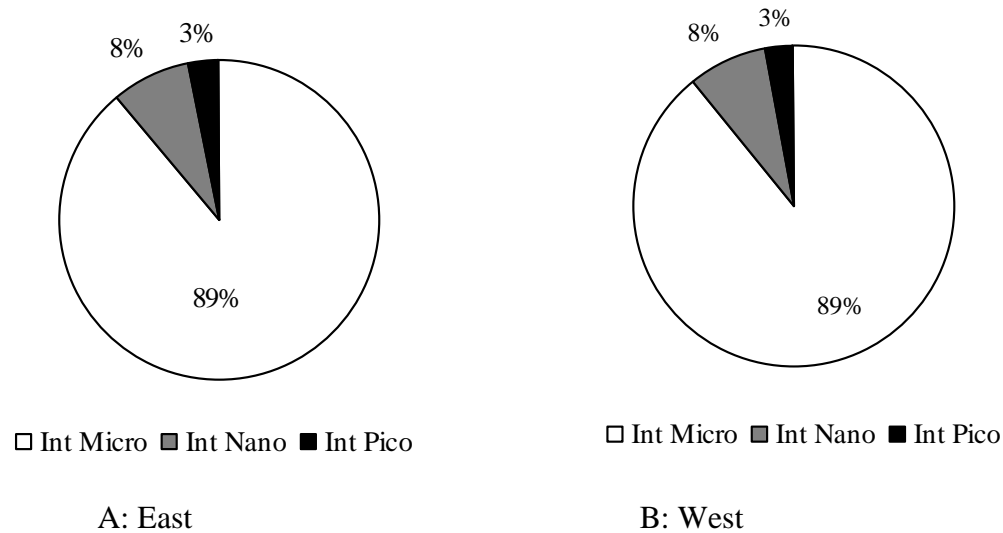


Figure 3.15: Percent contribution of integrated size fractionated chlorophyll-*a* (mg.m⁻²) for each sector during summer 2008.

3.3 ZOOPLANKTON COMMUNITY STRUCTURE

3.3.1 Cluster Analysis

Cluster analysis identified three zooplankton groupings, designated groups A to C, at the 72 % similarity level during the summer 2008 survey (Figure 3.16). Group A consisted of only two sites (one from each sector) located inside the Bay and was designated as the Inner Algoa Bay Group (Figures 3.16. and Figure 3.17). Group B was denoted the Mid Algoa Bay Group and comprised five sites spread across the Bay, four of which were from the eastern sector and one from the western sector of the Bay (Figures 3.16. and Figure 3.17). Group C was identified as the Outer Algoa Bay Group, with five sites spanning the Bay. Four sites from this group were from the western sector and one was from the eastern sector (Figures 3.16. and Figure 3.17). ANOSIM (Primer) showed that all three groupings were significantly different from each other ($P < 0.050$ for all three groups; Table 3.16).

Table 3.16: Results of the ANOSIM pairwise tests of the summer zooplankton abundances between clusters.

Clusters	R	P	Significance
C vs. A	0.45	0.016	*
C vs. B	0.91	0.048	*
A vs. B	0.91	0.048	*

Note: * indicates significant P values

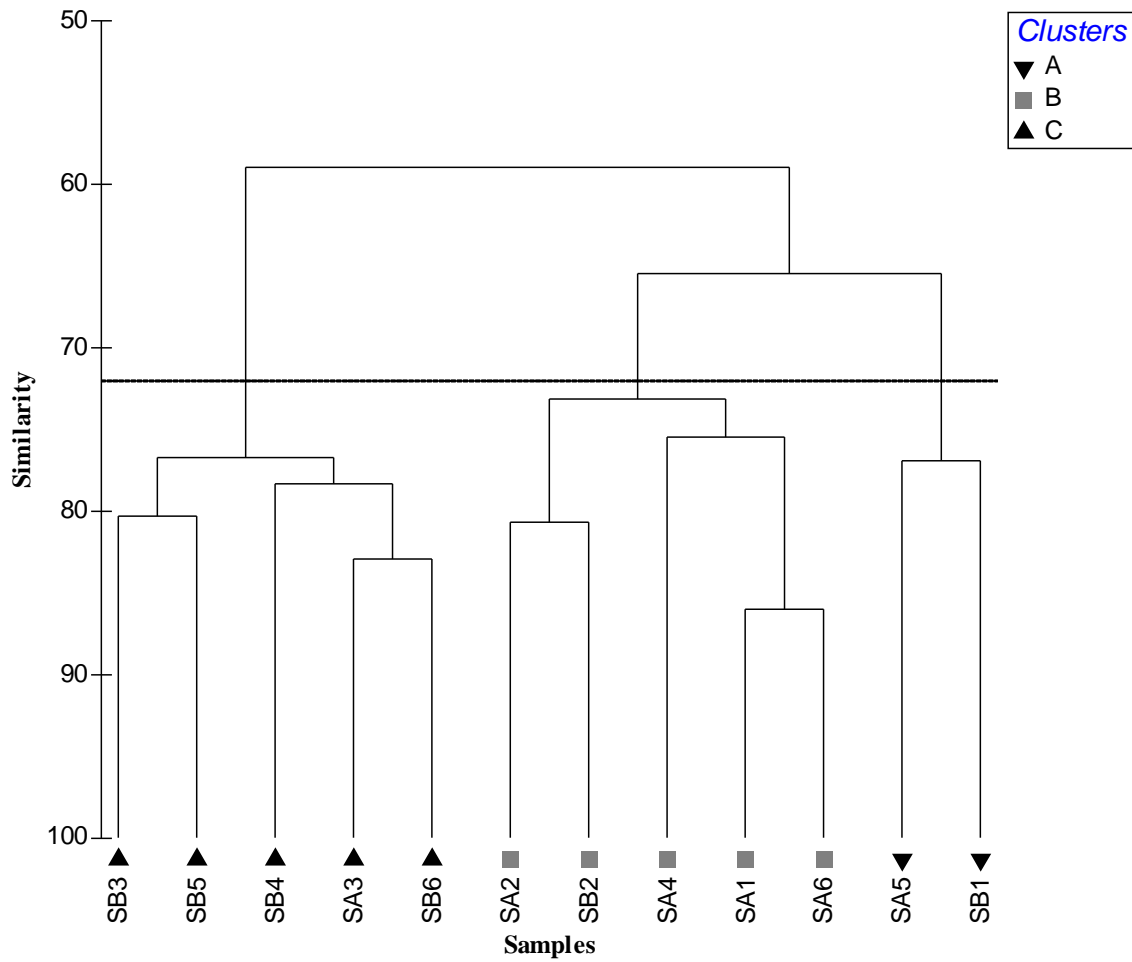


Figure 3.16: Cluster analysis dendrogram of zooplankton abundance data for Algoa Bay during summer 2008. Note: After standardisation and $\text{Log}_{10}(x + 1)$ transformation, Bray-Curtis similarity index was used on abundance data. Identified groupings are indicated by symbols shown in the legend. SA1 – SA6 = Summer eastern sector stations; SB1 – SB6 = Summer western sector stations.

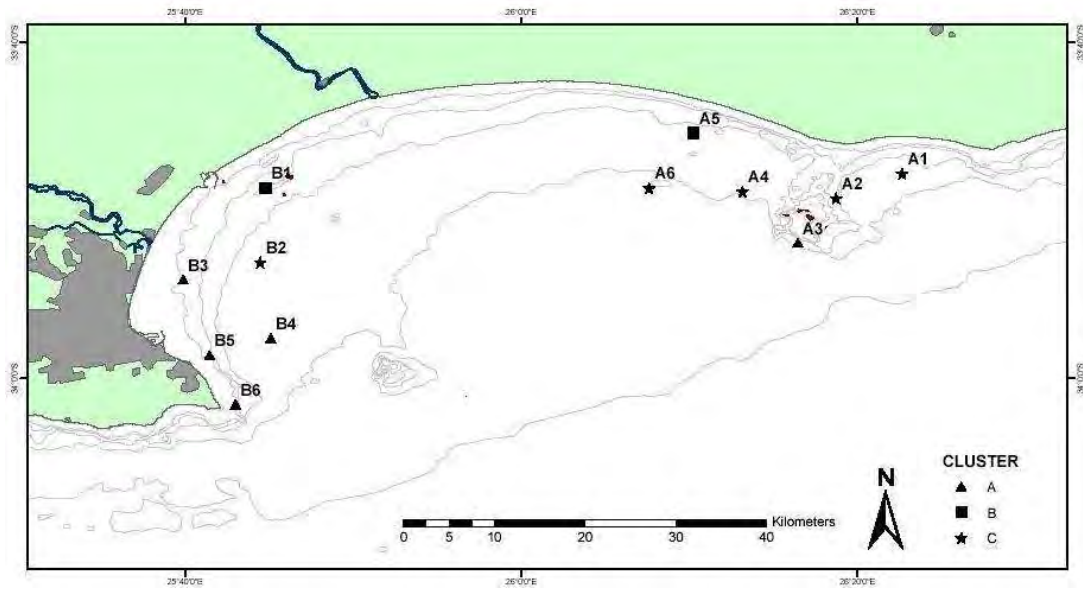


Figure 3.17: Distribution of zooplankton cluster groups in Algoa Bay during summer 2008. Note: A1 – A6 = Eastern sector stations; B1 – B6 = Western sector stations.

3.3.2 Zooplankton abundance

During summer 2008, total zooplankton abundances in Algoa Bay were highly variable. Total zooplankton abundances were significantly different in all three of the groupings identified by the cluster analysis ($P < 0.050$ in all cases; Table 3.17). Average abundances in Cluster B were greatest, at $28283.21 \text{ ind.m}^{-3}$ ($SD = 9623.36$), while those in Cluster C were the lowest recorded, with an average of $10088.92 \text{ ind.m}^{-3}$ ($SD = 8934.49$). The average zooplankton abundance recorded in Cluster A was $18801.97 \text{ ind.m}^{-3}$ ($SD = 7788.09$) (Figure 3.18). The 1000–2000 μm size class contributed the least to total abundances in all three clusters ($P < 0.050$; Table 3.17; Figure 3.18). The greatest contributions to the total abundance were made by the 90–200 μm size class in Cluster B, and by both the 90–200 and 200–500 μm size classes in clusters A and C ($P < 0.050$; Table 3.18; Figure 3.18). All size classes followed a similar trend to total zooplankton, with high abundances in Cluster B and significantly lower values in Cluster C ($P < 0.050$ in all cases; Table 3.18; Figure 3.18).

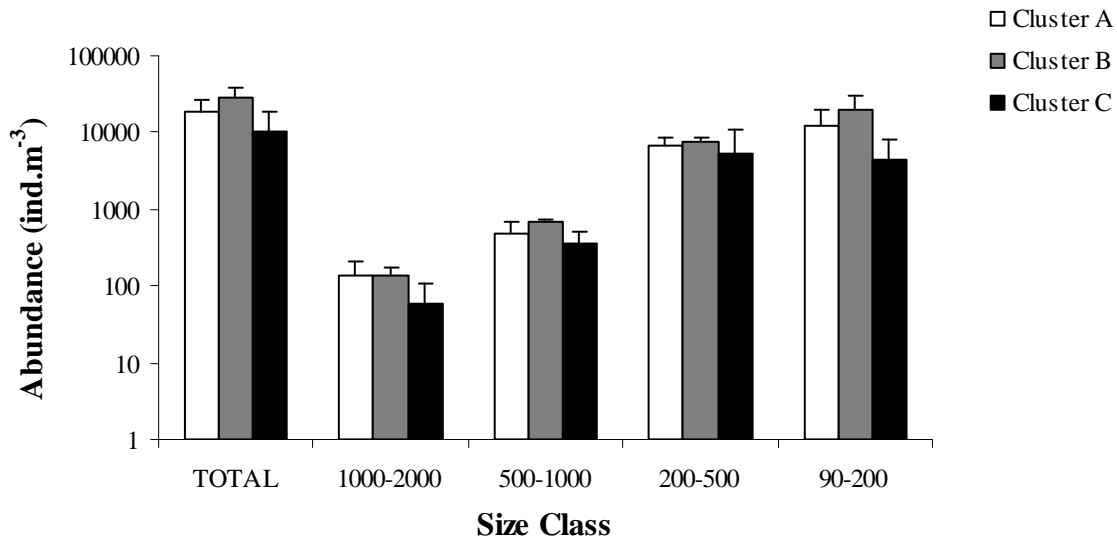


Figure 3.18: Summer total and size fractionated zooplankton abundance (ind.m⁻³) for each cluster. Error bars are standard deviations. (Note: y-axis is on log scale)

Table 3.17: Results of a series of One Way Analysis of Variance (F) statistical tests on zooplankton abundance data by size class. For tests where the main effects showed significant variability, the post-hoc Tukey Test (q) was used to conduct the pairwise multiple comparison procedures. Note: Total and size fractionated abundance data were log transformed prior to testing, with the exception of 1000–2000 μm size class, which was square root transformed.

Size Class (μm)	Source of Variance	F	df	q	P	Significance
Total	All Clusters	29.14	2		<0.001	**
	B vs. C			9.71	<0.001	**
	B vs. A			3.57	0.034	*
	A vs. C			7.99	<0.001	**
1000–2000	All Clusters	16.91	2		<0.001	**
	B vs. C			6.58	<0.001	**
	B vs. A			1.20	0.671	NS
	A vs. C			7.02	<0.001	**
500–1000	All Clusters	9.79	2		<0.001	**
	B vs. C			6.24	<0.001	**
	B vs. A			4.10	0.012	*
	A vs. C			2.75	0.131	NS
200–500	All Clusters	7.14	2		0.001	*
	B vs. C			4.23	0.010	*
	B vs. A			0.70	0.872	NS

Size Class (μm)	Source of Variance	F	df	q	P	Significance
	A vs. C			4.61	0.004	*
90–200	All Clusters	26.81	2		<0.001	**
	B vs. C			9.40	<0.001	**
	B vs. A			3.61	0.032	*
	A vs. C			7.54	<0.001	**

Note: A = Cluster A; B = Cluster B; C = Cluster C; df = Degree of Freedom; * and ** indicate significant and highly significant P values, respectively; NS = No significant difference.

Table 3.18: Results of a series of One Way Analysis of Variance (F) statistical tests on zooplankton abundance data by size cluster. For tests where the main effects showed significant variability, the post-hoc Tukey Test (q) was used to conduct the pairwise multiple comparison procedures. Note: All abundance data were log transformed prior to testing.

Clusters	Source of Variance	F	df	q	P	Significance
Cluster A	All size classes	279.49	3		<0.001	**
	90-200 vs. 1000-2000			34.88	<0.001	**
	90-200 vs. 500-1000			23.89	<0.001	**
	90-200 vs. 200-500			3.17	0.111	NS
	200-500 vs. 1000-2000			31.71	<0.001	**
	200-500 vs. 500-1000			20.72	<0.001	**
	500-1000 vs. 1000-2000			10.98	<0.001	**
Cluster B	All Size classes	315.80	3		<0.001	**
	90-200 vs. 1000-2000			39.30	<0.001	**
	90-200 vs. 500-1000			26.48	<0.001	**
	90-200 vs. 200-500			8.08	<0.001	**
	200-500 vs. 1000-2000			31.22	<0.001	**
	200-500 vs. 500-1000			18.39	<0.001	**
	500-1000 vs. 1000-2000			12.82	<0.001	**
Cluster C	All size classes	218.40	3		<0.001	**
	200-500 vs. 1000-2000			31.25	<0.001	**
	200-500 vs. 500-1000			16.62	<0.001	**
	200-500 vs. 90-200			1.07	0.873	NS
	90-200 vs. 1000-2000			30.17	<0.001	**
	90-200 vs. 500-1000			15.55	<0.001	**
	500-1000 vs. 1000-2000			14.62	<0.001	**

Note: Sources of variance are zooplankton size classes (μm); df = Degree of Freedom; ** indicate highly significant P values; NS = No Significant difference.

3.3.3 Dominant zooplankton taxa and species

Copepods numerically dominated zooplankton densities in all size classes, except in the 1000–2000 size class, which was dominated by Chaetognatha (Figure 3.19 a–d). Other groups that contributed substantially towards zooplankton abundance included Siphonophora, Appendicularia, Cladocera, Euphausia, Hydroidmedusae and Bivalvia (veligers). Groups that contributed less than 10% to total abundances in each size class were combined to form “Other groups”. Most zooplankton groups reflected high variability between the clusters ($P < 0.050$; Tables 3.19–3.22). There were, however, some groups that displayed no significant variability between the clusters ($P > 0.050$; Tables 3.19–3.22). Species that influenced abundance of the top groups are listed in the Appendix (Table 6) including the taxa that comprised “Other Groups”.

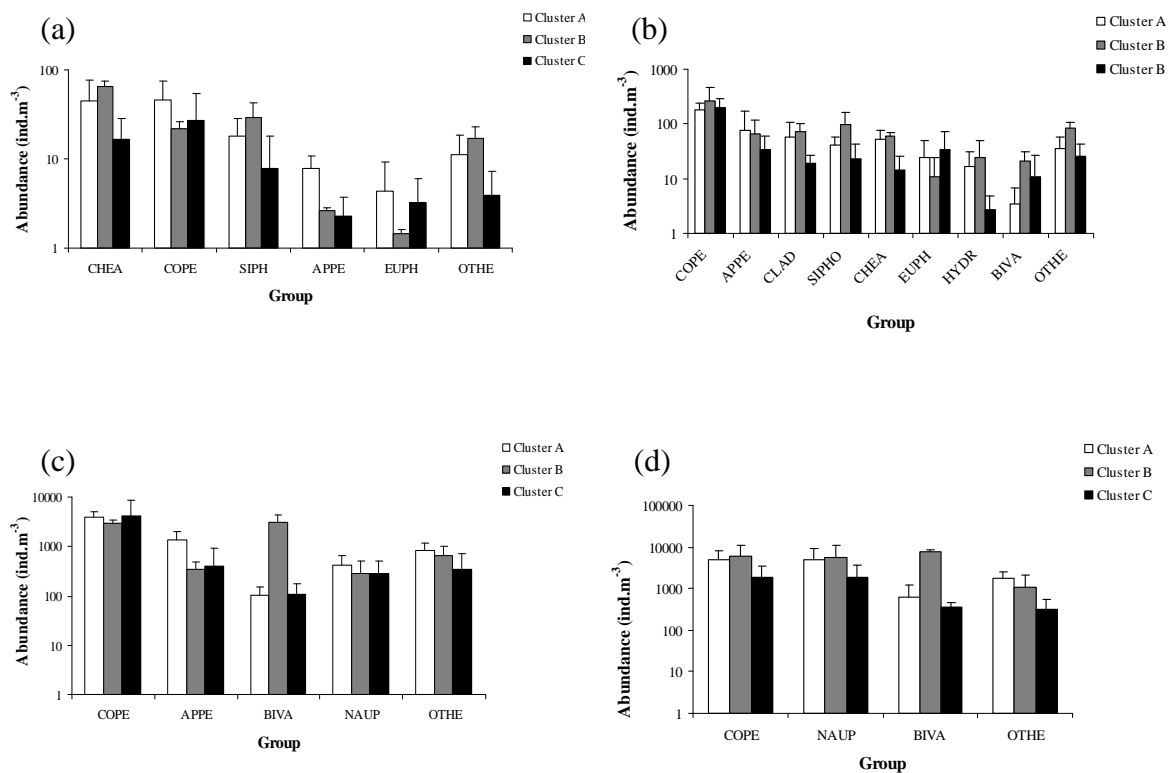


Figure 3.19: Dominant summer zooplankton groups from (a) 1000–2000 µm; (b) 500–1000 µm; (c) 200–500 µm; (d) 90–200 µm size classes. COPE = Copepoda; CHEA = Chaetognatha; SIPH = Siphonophora; APPE = Appendicularia; EUPH = Euphausia; BIVA = Bivalvia; CLAD = Cladocera; HYDR = Hydroidmedusae; OTHE = Other Groups. (Note: y-axis is on log scale; Biva = veligers)

Table 3.19: Results of a series of non-parametric Kruskal-Wallis One Way Analysis of Variance on Ranks (H) statistical tests on the dominant zooplankton groups in the 1000–2000 μm size class. For tests where the main effects showed significant variability, the post-hoc Dunn’s Method (Q) was used to conduct the pairwise multiple comparison procedures. Non-parametric tests were run on data that exhibited no normality/equal variance.

Group	Source of Variance	df	H	Q	P	Significance
Chaetognatha	B vs. C	2		5.29	<0.050	*
	B vs. A			2.22	>0.050	NS
	A vs. C			4.06	<0.050	*
Copepoda	A vs. C	2		3.33	<0.050	*
	A vs. B			2.41	<0.050	*
	B vs. C			0.10	>0.050	NS
Siphonophora	B vs. C	2		4.84	<0.050	*
	B vs. A			1.85	>0.050	NS
	A vs. C			3.92	<0.050	*
Appendicularia	A vs. C	2		4.17	<0.050	*
	A vs. B			2.81	<0.050	*
	B vs. C			0.34	>0.050	NS
Euphausia	A, B, C	2	2.35		0.308	NS
Other Groups	B vs. C			5.57	<0.050	*
	B vs. A			2.56	<0.050	*
	A vs. C			3.95	<0.050	*

Note: A = Cluster A, B = Cluster B, C = Cluster C, * indicate significant P values, NS = No significant difference; df = degrees of freedom.

Table 3.20: Results of a series of One Way Analysis of Variance (F) and the non-parametric equivalent, Kruskal-Wallis One Way Analysis of Variance on Ranks (H), statistical tests on dominant zooplankton groups in the 500–1000 μm size class. For tests where the main effects showed significant variability, the post-hoc Tukey Test (q; parametric) or Dunn’s Method (Q; non-parametric) was used to conduct the pairwise multiple comparison procedures. Non-parametric tests were run on data that exhibited no normality/equal variance even after transformation.

Group	Source of Variance	df	F	q	H	Q	P	Significance
Copepoda	A, B, C	2	1.10				0.337	NS
Appendicularia	A, B, C	2			4.05		0.132	NS
Cladocera	B vs. C	2				4.44	<0.050	*
	B vs. A					3.02	<0.050	*
	A vs. C					1.85	>0.050	NS
Siphonophora	B vs. C	2				5.00	<0.050	*
	B vs. A					3.07	<0.050	*
	A vs. C					2.52	<0.050	*
Chaetognatha	B vs. C	2				5.04	<0.050	*
	B vs. A					2.31	>0.050	NS
	A vs. C					3.85	<0.050	*
Euphausia	C vs. B	2				2.34	>0.050	NS
	C vs. A					2.10	>0.050	NS
	A vs. B					0.74	>0.050	NS
Hydroidmedusae	B vs. C	2				3.91	<0.050	*
	B vs. A					1.05	>0.050	NS
	A vs. C					3.75	<0.050	*
Bivalvia	B vs. A	2				3.15	<0.050	*
	B vs. C					1.99	>0.050	NS
	C vs. A					1.54	>0.050	NS
Other Groups	B vs. C	2		8.37			<0.001	**
	B vs. A			6.67			<0.001	**
	A vs. C			2.25			0.254	NS

Note: A = Cluster A; B = Cluster B; C = Cluster C; * and ** indicate significant and highly significant P values, respectively; NS = No significant difference; df = degrees of freedom.

Table 3.21: Results of a series of One Way Analysis of Variance (F) and the non-parametric equivalent, Kruskal-Wallis One Way Analysis of Variance on Ranks (H), statistical tests on dominant zooplankton groups in the 200–500 μm size class. For tests where the main effects showed significant variability, the post-hoc Dunn's Method (Q) was used to conduct the pairwise multiple comparison procedures. Non-parametric tests were run on data that exhibited no normality/equal variance.

Group	Source of Variance	df	F	H	Q	P	Significance
Copepoda	A, B, C	2		5.28		0.071	NS
Appendicularia	A vs. C	2			4.98	<0.050	*
	A vs. B				3.22	<0.050	*
	B vs. C				0.55	>0.050	NS
Bivalvia	B vs. A	2			5.75	<0.050	*
	B vs. C				5.06	<0.050	*
	C vs. A				0.94	>0.050	NS
Nauplii	A, B, C	2	2.88			0.061	NS
Other Groups	A vs. C	2			4.69	<0.050	*
	A vs. B				0.18	>0.050	NS
	B vs. C				3.36	<0.050	*

Note: A = Cluster A, B = Cluster B, C = Cluster C, * indicate significant P values, NS = No significant difference; df = degrees of freedom.

Table 3.22: Results of a series of One Way Analysis of Variance (F) and the non-parametric equivalent, Kruskal-Wallis One Way Analysis of Variance on Ranks (H), statistical tests on dominant zooplankton groups in the 90–200 μm size class. For tests where the main effects showed significant variability, the post-hoc Tukey Test (q; parametric) or Dunn’s Method (Q; non-parametric) was used to conduct the pairwise multiple comparisons. Non-parametric tests were run on data that exhibited no normality/equal variance.

Group	Source of Variance	q	df	Q	P	Significance
Copepoda	B vs. C	6.45	2		<0.001	**
	B vs. A	1.64			0.479	NS
	A vs. C	6.31			<0.001	**
Nauplii	B vs. C		2	3.26	<0.050	*
	B vs. A			0.38	>0.050	NS
	A vs. C			3.78	<0.050	*
Bivalvia	B vs. C		2	6.59	<0.050	*
	B vs. A			5.74	<0.050	*
	A vs. C			1.08	>0.050	NS
Other Groups	A vs. C		2	5.29	<0.050	*
	A vs. B			1.06	>0.050	NS
	B vs. C			2.93	<0.050	*

Note: A = Cluster A; B = Cluster B; C = Cluster C; * and ** indicate significant and highly significant P values, respectively; NS = No significant difference; df = degrees of freedom.

3.3.4 Species richness and diversity

The 1000–2000 μm size class exhibited higher species richness in Cluster C with an average of 5.92 (SD = 1.18) and significantly lower values in Cluster A, where values averaged 5.07 (SD = 1.29) (P = 0.003; Table 3.23; Figure 3.20a). Species diversity for this size class showed no significant variability between the clusters (P>0.050; Table 3.24, Figure 3.20b) with an average species diversity of 3.52 (SD = 0.52) calculated for Algoa Bay.

In the 500–1000 μm size class, the highest species richness values were recorded in Clusters B and C (Mean = 4.56; SD = 0.68, and Mean = 4.69; SD = 1.05, respectively), while the lowest was recorded in Cluster A, with an average of 4.30 (SD = 1.41) (Figure 3.20a). However, species richness showed no significant variability between the clusters

($P > 0.050$; Table 3.23). Higher species diversity values were recorded in Cluster B, with an average of 4.18 (SD = 0.23) and significantly lower values in Cluster A with an average of 3.68 (SD = 0.72) ($P = 0.006$; Table 3.24; Figure 3.20b).

The 200–500 μm size class exhibited higher species richness values of 1.84 (SD = 0.31) and 1.841 (SD = 0.57) in Clusters B and C, respectively, while lower values were recorded in Cluster A with an average value of 1.716 (SD = 0.43) (Figure 3.20a). These differences were, however, not significant ($P > 0.050$; Table 3.23). Species diversity reflected significantly higher values in Cluster A and lower values in Cluster C ($P = 0.008$; Table 3.24; Figure 3.20b).

Species richness in the 90–200 μm size class was variable with higher average values in Clusters A and C (Mean = 0.89; SD = 0.16 for A; Mean = 0.91; SD = 0.18 for C) and significantly lower values in Cluster B (Mean = 0.68; SD = 0.12) ($P < 0.050$ in both cases; Table 3.23; Figure 3.20a). There were no significant differences in species diversity in the 90–200 μm size class between the clusters ($P > 0.050$ in all cases; Table 3.24), with an average of 1.89 (SD = 0.33) calculated for the whole bay.

The 90–200 μm size class contributed the least in all Clusters for both species richness and species diversity ($P < 0.050$; Table 3.25 and 3.26; Figure 3.20a and 3.20b). In Clusters A and B, the 500–1000 and 1000–2000 μm size classes had the greatest species richness, but in Cluster C, the 1000–2000 μm size class dominated species richness (Table 3.25; Figure 3.20a). In Cluster A, the 500–1000 and 1000–2000 μm size classes made the greatest contribution to species diversity. In Clusters B and C, the 500–1000 μm size class had highest species diversity values (Table 3.26; Figure 3.20b).

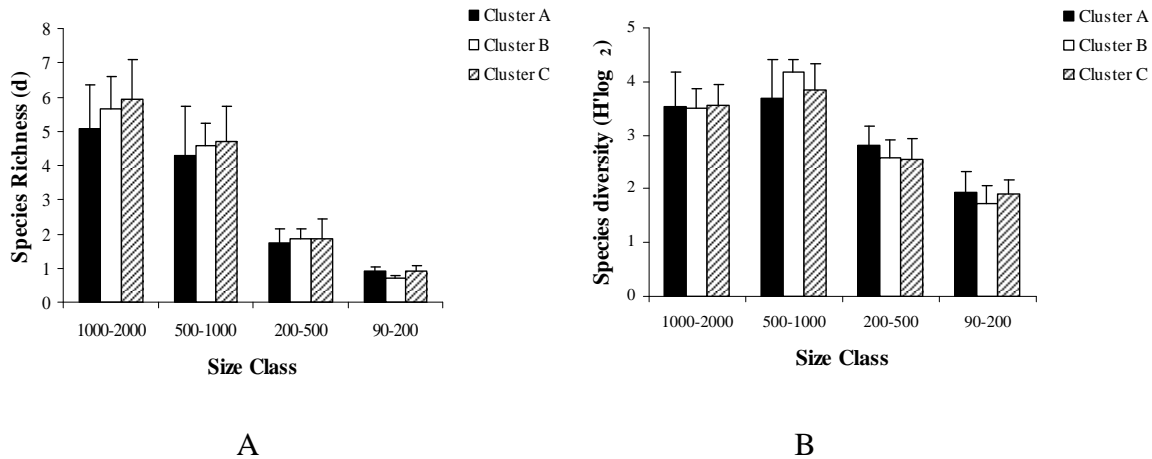


Figure 3.20: (A) Margalef's species richness (d); (B) Shannon species diversity ($H' \log_2$) indices for zooplankton abundance data in Algoa Bay, during summer 2008.

Table 3.23: Results of a series of One Way Analysis of Variance (F) and the non-parametric equivalent, Kruskal-Wallis One way Analysis of Variance on Ranks (H), statistical tests on zooplankton species richness data by size class. For tests where the main effects showed significant variability, the post-hoc Tukey test (q; parametric) or Dunn's Method (Q; non-parametric) was used to conduct the pairwise multiple comparison procedures. Non-parametric tests were run on data that exhibited no normality/equal variance even after transformation.

Size Class (μm)	Source of Variance	q	F	H	df	Q	P	Significance
90–200	All Clusters			23.66	2		<0.001	**
	C vs. B					4.70	<0.050	*
	C vs. A					0.64	>0.050	NS
	A vs. B					4.20	<0.050	*
200–500	A, B, C			2.26	2		0.323	NS
500–1000	A, B, C		1.21		2		0.300	NS
1000–2000	All Clusters		5.77		2		0.004	*
	C vs. A	4.76					0.003	*
	C vs. B	1.16					0.690	NS
	B vs. A	2.44					0.199	NS

Note: A = Cluster A; B = Cluster B; C = Cluster C; df = Degree of Freedom; * and ** indicate significant and highly significant P values, respectively; NS = No significant differences; df = degrees of freedom.

Table 3.24: Results of a series of One Way Analysis of Variance (F) and the non-parametric equivalent, Kruskal-Wallis One Way Analysis of Variance on Ranks (H), statistical tests on zooplankton species diversity data by size class. For tests where the main effects showed significant variability, the post-hoc Tukey test (q; parametric) was used to conduct the pairwise multiple comparison procedures. Non-parametric tests were run on data that exhibited no normality/equal variance even after transformation.

Size Class (μm)	Source of Variance	Q	F	H	df	P	Significance
90–200	A, B, C			5.35	2	0.069	NS
200–500	All Clusters		5.42		2	0.006	*
	A vs. C	4.32				0.008	*
	A vs. B	3.22				0.063	NS
	B vs. C	0.043				1.000	NS
500–1000	All Clusters		4.99		2	0.008	*
	B vs. A	4.46				0.006	*
	B vs. C	3.09				0.078	NS
	C vs. A	1.18				0.407	NS
1000–2000	A, B, C			1.06	2	0.588	NS

Note: A = Cluster A; B = Cluster B; C = Cluster C; df = Degree of Freedom; * and ** indicate significant and highly significant P values, respectively; NS = No significant difference.

Table 3.25: Results of a series of One Way Analysis of Variance (F) and the non-parametric equivalent, Kruskal-Wallis One way Analysis of Variance on Ranks (H), statistical tests on zooplankton species richness data by cluster. For tests where the main effects showed significant variability, the post-hoc Tukey test (q; parametric) or Dunn's Method (Q; non-parametric) was used to conduct the pairwise multiple comparison procedures. Non-parametric tests were run on data that exhibited no normality/equal variance even after transformation.

Clusters	Source of Variance	q	H	Q	F	df	P	Significance	
Cluster A	All size classes		146.65			3	<0.001	**	
	1000–2000 vs. 90–200			10.78			<0.050	*	
	1000–2000 vs. 200–500			6.88			<0.050	*	
	1000–2000 vs. 500–1000			1.60			>0.050	NS	
	500–1000 vs. 90–200			9.17			<0.050	*	
	500–1000 vs. 200–500			5.27			<0.050	*	
	200–500 vs. 90–200			3.95			<0.050	*	
Cluster B	All size classes		62.76			3	<0.001	**	
	1000–2000 vs. 90–200			7.29			<0.050	*	
	1000–2000 vs. 200–500			4.71			<0.050	*	
	1000–2000 vs. 500–1000			1.68			>0.050	NS	
	500–1000 vs. 90–200			5.60			<0.050	*	
	500–1000 vs. 200–500			3.02			<0.050	*	
	200–500 vs. 90–200			2.58			>0.050	NS	
Cluster C	All size classes				617.4	7	3	<0.001	**
	1000–2000 vs. 90–200	53.64					<0.001	**	
	1000–2000 vs. 200–500	34.20					<0.001	**	
	1000–2000 vs. 500–1000	6.84					<0.001	**	
	500–1000 vs. 90–200	46.79					<0.001	**	
	500–1000 vs. 200–500	27.35					<0.001	**	
	200–500 vs. 90–200	19.44					<0.001	**	

Note: Sources of variance are zooplankton size classes (μm); df = Degree of Freedom; * and ** indicate significant and highly significant P values, respectively; NS = No significant difference.

Table 3.26: Results of a series of One Way Analysis of Variance (F) and the non-parametric equivalent, Kruskal-Wallis One way Analysis of Variance on Ranks (H), statistical tests on zooplankton species diversity data by cluster. For tests where the main effects showed significant variability, the post-hoc Tukey test (q; parametric) or Dunn's Method (Q; non-parametric) was used to conduct the pairwise multiple comparison procedures. Non-parametric tests were run on data that exhibited no normality/equal variance even after transformation.

Clusters	Source of Variance	q	H	Q	F	df	P	Significance
Cluster A	All size classes		127.65			3	<0.001	**
	1000–2000 vs. 90–200			9.97			<0.050	*
	1000–2000 vs. 200–500			5.68			<0.050	*
	1000–2000 vs. 500–1000			0.93			>0.050	NS
	500–1000 vs. 90–200			9.03			<0.050	*
	500–1000 vs. 200–500			4.74			<0.050	*
	200–500 vs. 90–200			4.29			<0.050	*
Cluster B	All size classes				195.69	3	<0.001	**
	1000–2000 vs. 90–200	31.99					<0.001	**
	1000–2000 vs. 200–500	21.12					<0.001	**
	1000–2000 vs. 500–1000	8.92					<0.001	**
	500–1000 vs. 90–200	23.06					<0.001	**
	500–1000 vs. 200–500	12.20					<0.001	**
	200–500 vs. 90–200	10.86					<0.001	**
Cluster C	All size classes				255.51	3	<0.001	**
	1000–2000 vs. 90–200	34.64					<0.001	**
	1000–2000 vs. 200–500	21.69					<0.001	**
	1000–2000 vs. 500–1000	4.46					0.009	*
	500–1000 vs. 90–200	30.18					<0.001	**
	500–1000 vs. 200–500	17.22					<0.001	**
	200–500 vs. 90–200	12.95					<0.001	**

Note: Sources of variance are zooplankton size classes (μm); df = Degree of Freedom; * and ** indicate significant and highly significant P values, respectively; NS = No significant difference.

3.3.5 Zooplankton biomass

During summer 2008, zooplankton biomass was highly variable in Algoa Bay. The average total zooplankton biomass values in Clusters A and B were 133.71 mg.m^{-3} (SD = 44.21) and 161.94 mg.m^{-3} (SD = 20.34), respectively. In Cluster C, the total zooplankton biomass was significantly lower with an average 76.59 mg.m^{-3} (SD = 22.97) ($P < 0.050$ in both cases; Table 3.27; Figure 3.21). All size classes followed the same trend as total biomass, except for the 500–1000 μm size class which showed no statistical differences between the cluster groups (Table 3.28).

The 500–1000 μm size class contributed the most to total biomass with an average value of 58.67 mg.m^{-3} (SD = 17.44), while the 1000–2000 μm size class contributed the least with an average of 6.64 mg.m^{-3} (SD = 3.30) ($P > 0.050$; Table 3.27; Figure 3.21).

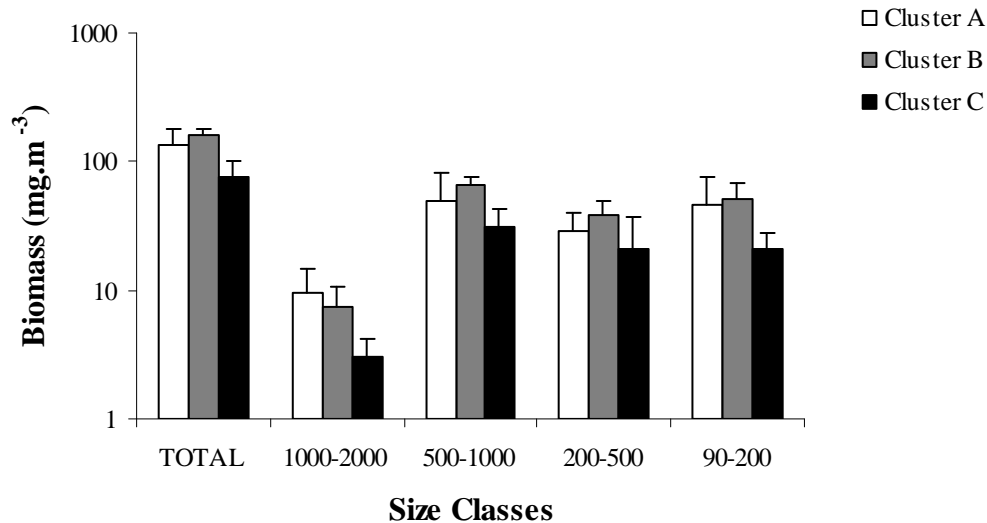


Figure 3.21: Summer total and size fractionated zooplankton biomass (mg.m^{-3}) contribution in each cluster from each of the size classes. Error bars are standard deviations. (Note: y-axis is on log scale)

Table 3.27: Results of a series of One Way Analysis of Variance (F) and the non-parametric equivalent, Kruskal-Wallis One Way Analysis of Variance on Ranks (H), statistical tests on zooplankton biomass by size class data. For tests where the main effects showed significant variability, the post-hoc Tukey test (q; parametric) or Dunn's Method (Q; non-parametric) was used to conduct the pairwise multiple comparison procedures. Cluster biomass data were log transformed prior to testing with the exception of 90–200 μm size class which was square root transformed.

Size Class (μm)	Source of Variance	H	Q	F	df	q	P	Significance
Total	All Clusters			20.17	2		<0.001	**
	B vs. C					7.77	<0.001	**
	B vs. A					2.36	0.221	NS
	A vs. C					7.05	<0.001	**
1000–2000	All Clusters	50.89			2		<0.001	**
	A vs. C		6.69				<0.050	*
	A vs. B		0.31				>0.050	NS
	B vs. C		4.79				<0.050	*
500–1000	A, B, C			2.78	2		0.066	NS
200–500	All Clusters			8.47	2		<0.001	**
	B vs. C					5.08	0.002	*
	B vs. A					1.60	0.496	NS
	A vs. C					4.53	0.005	*
90–200	All clusters							
	B vs. C					4.96	0.002	*
	B vs. A					1.37	0.594	NS
	A vs. C					4.68	0.004	*

Note: A = Cluster A; B = Cluster B; C = Cluster C; DF = Degree of Freedom; * and ** indicate significant and highly significant P values, respectively; NS = No significant difference.

Table 3.28: Results of a series of One Way Analysis of Variance (F) and the non-parametric equivalent, Kruskal-Wallis One way Analysis of Variance on Ranks (H), statistical tests on zooplankton biomass by cluster data. For tests where the main effects showed significant variability, the post-hoc Tukey test (q; parametric) or Dunn’s Method (Q; non-parametric) was used to conduct the pairwise multiple comparison procedures. Non-parametric tests were run on data that failed normality/equal variance even when transformed prior to testing, with the exception of Cluster B data which was log transformed.

Clusters	Source of Variance	H	F	df	q	Q	P	Significance
Cluster A	All size classes	59.15		3			<0.001	**
	500–1000 vs. 1000–2000					6.92	<0.050	*
	500–1000 vs. 200–500					1.41	>0.050	NS
	500–1000 vs. 90–200					0.79	>0.050	NS
	90–200 vs. 1000–2000					6.13	<0.050	*
	90–200 vs. 200–500					0.61	>0.050	NS
	200–500 vs. 1000–2000					5.51	<0.050	*
Cluster B	All size classes		26.86	3			<0.001	**
	500–1000 vs. 1000–2000				11.19		<0.001	**
	500–1000 vs. 200–500				2.10		0.451	NS
	500–1000 vs. 90–200				0.80		0.941	NS
	90–200 vs. 1000–2000				10.38		<0.001	**
	90–200 vs. 200–500				1.29		0.796	NS
	200–500 vs. 1000–2000				9.08		<0.001	**
Cluster C	All size classes	93.84		3			<0.001	**
	500–1000 vs. 1000–2000					9.38	<0.050	*
	500–1000 vs. 200–500					3.21	<0.050	*
	500–1000 vs. 90–200					2.81	<0.050	*
	90–200 vs. 1000–2000					6.57	<0.050	*
	90–200 vs. 200–500					0.40	>0.050	NS
	200–500 vs. 1000–2000					6.16	<0.050	*

Note: Sources of variance are zooplankton size classes (μm); df = Degree of Freedom; * and ** indicate significant and highly significant P values, respectively; NS = No significant difference.

3.3.6 Indicator Species Assessment (ISA)

Taxa that were unique to each cluster, identified by cluster analysis, were determined by taking an IndVal of $\geq 50\%$ and are listed in Table 3.29. The top five taxa that contributed to cluster separation were mussel larvae (Bivalvia), *Chaetopterus* larvae, *Acrocalanus*

longicornis, *Tubellaria* sp. and *Centropages typicus* in Cluster A; *Oncaea conifera*, *Oithona setigera*, *Oithona plumifera*, Euphauea larvae and *Tomopteris* spp. in Cluster B; and *Calanoides macrocarinatus*, Ophiuroidea spp, *Miracia minor*, *Corycaeus longistylis* and *Doliolum valvidae* in Cluster C. In all three clusters, copepods contributed to ~ 40 % of indicator taxa (i.e., IndVals ≥ 50 %; Table 3.29).

Table 3.29: Indicator species/taxa with indicator values (IndVal) ≥ 50 % from all three clusters during summer 2008.

Cluster A		Cluster B		Cluster C	
Species/Taxa	IndVal.	Species/Taxa	Ind.Val.	Species/Taxa	IndVal.
Mussel larvae	89.85	<i>Oncaea conifera</i>	80.97	<i>Calanoides macrocarinatus</i>	87.96
<i>Chaetopterus</i> larvae	86.67	<i>Oithona setigera</i>	77.13	Ophiuroidea spp.	87.21
<i>Acrocalanus longicornis</i>	75.29	<i>Oithona plumifera</i>	62.62	<i>Miracia minor</i>	79.85
<i>Tubellaria</i> spp.	72.28	Euphausiid larvae	56.03	<i>Corycaeus longistylis</i>	78.01
<i>Centropages typicus</i>	70.46	<i>Tomopteris</i> spp.	55.64	<i>Doliolum valvidae</i>	77.62
<i>Eutonina</i> spp.	67.78	Nematoda spp.	51.97	Other egg	73.47
Brachyura larvae	66.44			<i>Mesocalanus tenuicornis</i>	73.40
<i>Rhynchorella</i> spp.	65.50			<i>Microstella norvegica</i>	72.87
<i>Limacina</i> spp.	64.56			<i>Pseudodiaptomus nudus</i>	68.74
<i>Centropages orsinii</i>	63.30			<i>Oikopleura</i> spp.	68.55
<i>Sagitta setosa</i>	61.40			<i>Tiarospidium</i> spp.	63.53
Cladocera spp.	60.57			<i>Cosmocalanus darwinii</i>	63.04
<i>Microstella rosea</i>	58.28			<i>Luciferidae typus</i>	60.00
<i>Euterpina acutifrons</i>	58.22			Salp spp.	60.00
<i>Centropages brachiatus</i>	57.25			Euphausiid juvenile	59.82
<i>Dolilum nationalis</i>	54.64			<i>Sagitta macrocephala</i>	58.69
Fish larvae	53.06			Appendicularia spp.	58.34
<i>Chelophyes appendiculata</i>	51.07			<i>Temora turbinata</i>	57.37
<i>Eucalanus elongatus</i>	50.00			<i>Subeucalanus pileatus</i>	55.56
<i>Oithona fallax</i>	50.00			<i>Obelia</i> spp.	55.11
				Decapoda larvae	54.08
				Actinula larvae	51.58
				Ostracoda spp.	51.34
				<i>Rhincalanus nasutus</i>	51.27
				Fish egg	51.01
				<i>Podocoryn</i> spp.	50.05

3.4 ENVIRONMENTAL DRIVERS OF ZOOPLANKTON COMMUNITY STRUCTURE

The Canonical Correspondence Analysis (CCA) grouped the summer samples in a similar pattern to that of the Cluster Analysis. However, the groups were not identical and there was some degree of overlapping (Figure 3.22). The environmental variables that exhibited the highest correlation coefficients (>0.65) were considered to be important in determining observed patterns in the zooplankton community structure. These included integrated microphytoplankton concentrations and bottom water turbidity along the first ordination axis; and bottom water temperature, salinity and nitrate concentrations on the second ordination axis (Table 3.30; Figure 3.22). Integrated microphytoplankton concentrations showed significant variability between the three clusters with elevated values recorded in Clusters A and B ($P < 0.001$; Table 3.31). Bottom water temperature, turbidity and nitrate concentrations exhibited no statistical variability between the three clusters ($P > 0.050$ in all cases; Table 3.31). Bottom water salinity, on the other hand, was statistically variable with the highest values in Clusters A and C, while lower values were recorded in Cluster B ($P < 0.016$; Table 3.31). Taxa with indicator values (IndVals) $\geq 50\%$ were plotted as a species ordination (Figure 3.23). The pattern observed in the species ordination is more distinct than in the sample ordination, with a clear separation between taxa from the three clusters. There was, however, a small degree of overlap between Clusters A and C (Figure 3.23).

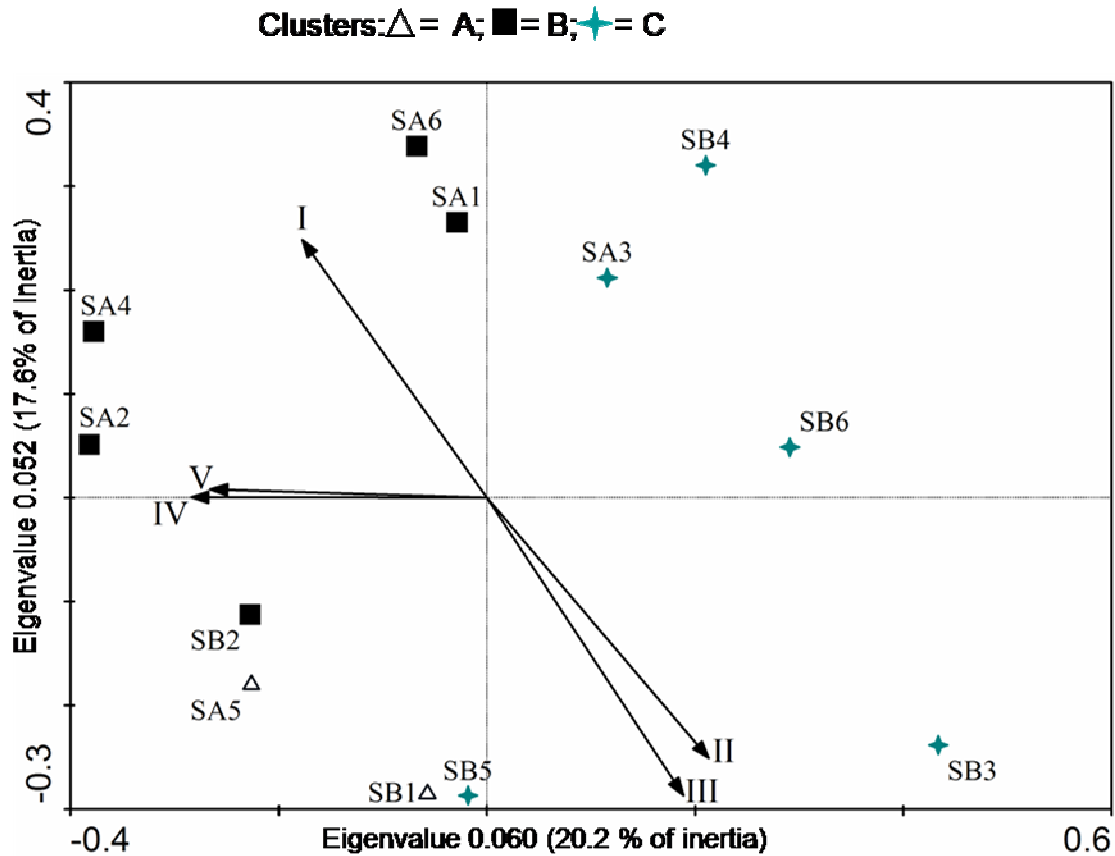


Figure 3.22: Ordination plot of samples and important environmental variables from results of the summer CCA. Samples are presented as symbols related to the cluster analysis sample groupings. The direction and length of the arrows indicate the increase in values of the particular environmental variables. Note: I = Bottom Nitrate; II = Bottom Temperature, III = Bottom Salinity, IV = Integrated Microphytoplankton; V = Bottom Turbidity.

Table 3.30: Correlation coefficients between the environmental variables and the species-derived sample scores on Axes 1 and 2 of the Canonical Correspondence Analysis, during summer 2008. Values marked in bold had strong correlations (>0.65) and therefore indicate the environmental variables responsible for co-variance with observed zooplankton patterns.

Environmental Variable	Axis 1	Axis2
Surface Temperature	0.53	-0.44
Surface Salinity	0.46	-0.07
Water Column Stability	-0.03	0.11
Surface Dissolved Oxygen	-0.34	0.58
Surface Turbidity	-0.56	0.42
Surface Chlorophyll-a	-0.64	0.04
Surface Microphytoplankton	-0.62	-0.01
Surface Nanophytoplankton	-0.58	0.24
Surface Picophytoplankton	-0.45	0.27
Integrated Chlorophyll-a	-0.64	0.09
Integrated Microphytoplankton	-0.69	0.00
Integrated Nanophytoplankton	-0.49	-0.04
Integrated Picophytoplankton	-0.55	0.10
Surface Nitrate	-0.41	0.04
Surface Nitrite	-0.63	0.16
Surface Ammonia	-0.07	0.21
Surface Phosphate	-0.22	0.49
Surface Silicate	-0.22	0.61
Surface Seston	-0.45	0.32
Bottom Temperature	0.52	-0.66
Bottom Salinity	0.46	-0.75
Bottom Dissolved Oxygen	0.24	0.02
Bottom Turbidity	-0.65	0.02
Bottom Nitrate	-0.43	0.65
Bottom Nitrite	0.19	0.38
Bottom Ammonia	-0.35	-0.14
Bottom Phosphate	-0.44	-0.03
Bottom Silicate	-0.42	-0.12
Bottom Seston	0.08	0.21

Table 3.31: Average cluster values (with standard deviation, SD) of important environmental variables identified with the Canonical Correspondence Analysis. One Way Analysis of Variance (F) or the non-parametric equivalent, Kruskal–Wallis One Way Analysis of Variance on Ranks (H), tests were conducted to identify any significant variability in important environmental variables between the clusters. Values marked in bold represent those that are significantly higher. Note: Integrated microphytoplankton data were log transformed while other variables required no transformation prior to testing.

Variable	Cluster A		Cluster B		Cluster C		F	H	df	P	Significance
	Average	SD	Average	SD	Average	SD					
Integrated Microphytoplankton	76.36	40.57	69.08	48.28	33.63	12.26	9.69		2	<0.001	**
Bottom Temperature	13.14	2.33	11.92	0.76	14.00	2.18		5.32	2	0.070	NS
Bottom Turbidity	2.86	0.13	2.90	0.19	2.72	0.33		2.38	2	0.303	NS
Bottom Salinity	34.54	0.22	34.38	0.10	34.53	0.15	4.70		2	0.016	*
Bottom Nitrate	9.20	10.87	14.64	2.69	8.33	7.86		2.01	2	0.407	NS

Note: * and ** indicate significant and highly significant P values, respectively; NS = No significant difference; df = degrees of freedom

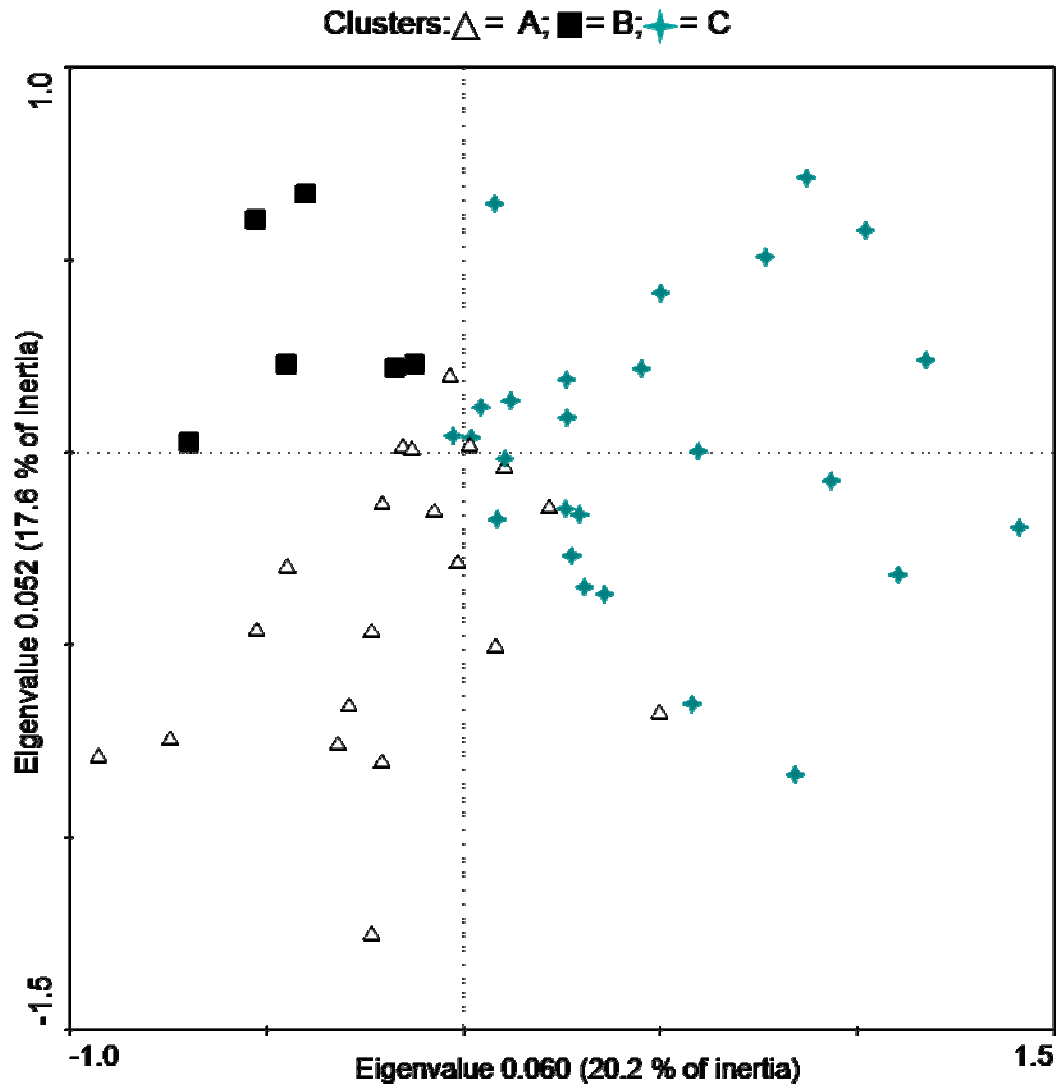


Figure 3.23: Ordination plot of species from results of the summer CCA. Only those species with indicator values $\geq 50\%$ are presented. The symbols represent the indicator species from each cluster.

CHAPTER 4: RESULTS – WINTER SURVEY

4.1 PHYSICAL-CHEMICAL ENVIRONMENT

4.1.1 Temperature, salinity and water column stability

Temperature

Surface seawater temperatures exhibited significant spatial variability across Algoa Bay during the winter survey (Figure 4.1A). Surface seawater temperatures were significantly lower ($P = 0.002$; Table 4.1) in the eastern sector of Algoa Bay, with an average of $15.81\text{ }^{\circ}\text{C}$ ($SD = 0.26$), than they were in the western sector, where the average was $16.21\text{ }^{\circ}\text{C}$ ($SD = 0.44$) (Figures 4.1A and 4.1B). Bottom water temperatures also varied significantly across the Bay with average values in the east (Mean = $14.61\text{ }^{\circ}\text{C}$; $SD = 0.33$) being significantly lower than those in the west (Mean $15.26\text{ }^{\circ}\text{C}$; $SD = 0.76$) ($P < 0.001$; Table 4.1; Figure 4.1B). Throughout the study area, seawater temperatures in the surface waters were significantly higher than those recorded in the bottom waters ($P = 0.007$ and $P < 0.001$; east and west sectors; Table 4.1; Figure 4.1B).

Table 4.1: Results of a series of non-parametric Mann-Whitney U Rank Sum tests for winter temperature data. Note that even after transformation, all temperature data remained non-normal and/or exhibited unequal variances.

Source of Variance	U	P	Significance
East: S vs. B	110.00	0.007	*
West: S vs. B	47.50	<0.001	**
Surface: E vs. W	95.50	0.002	*
Bottom :E vs. W	0.00	<0.001	**

Note: S = Surface; B = Bottom; E = East; W = West; * and ** indicate significant and highly significant P values respectively

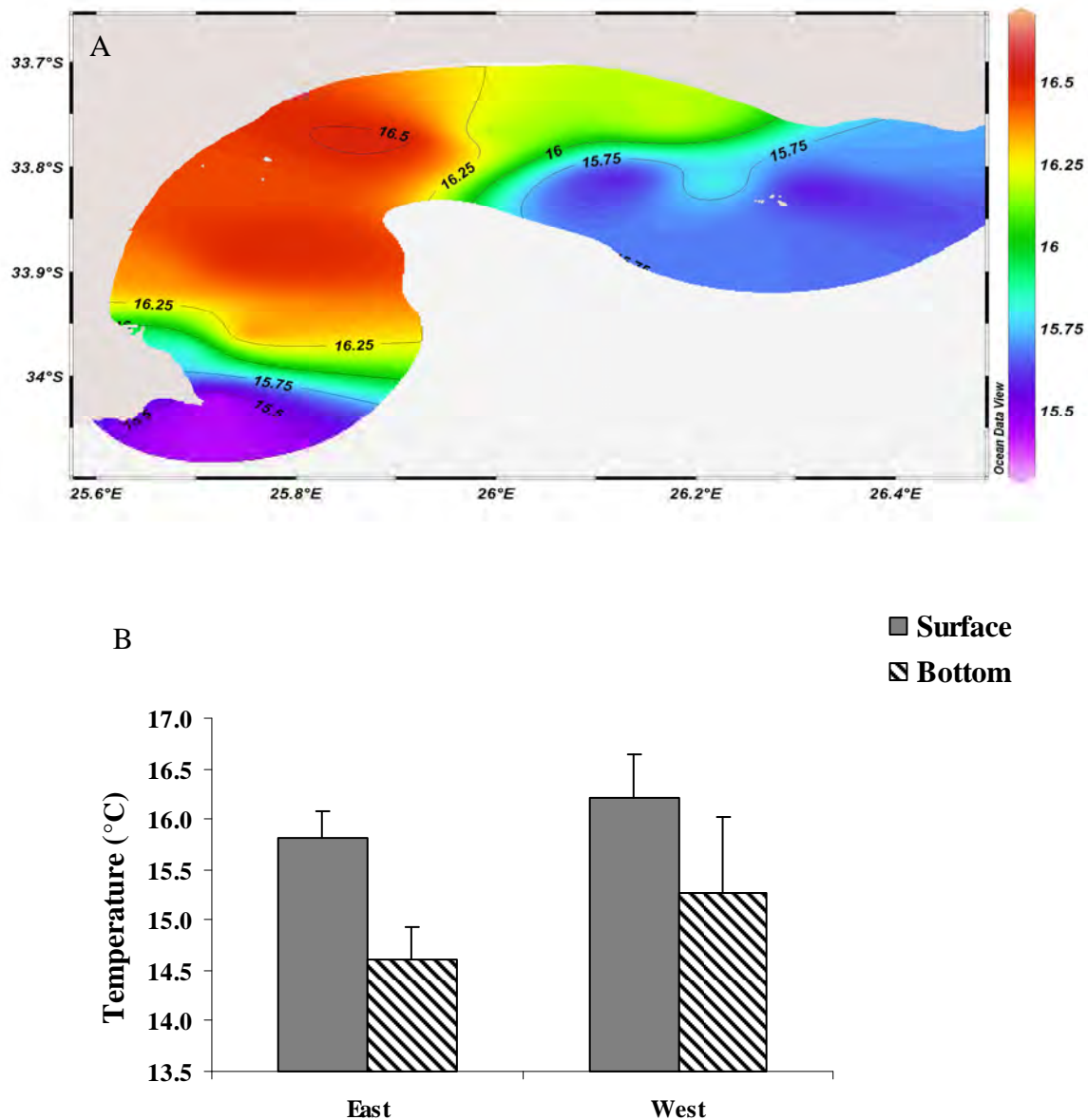


Figure 4.1: A) Surface plot of seawater temperature (°C); B) Average surface and bottom seawater temperatures for each sector, during winter 2008. Error bars are standard deviations.

Salinity

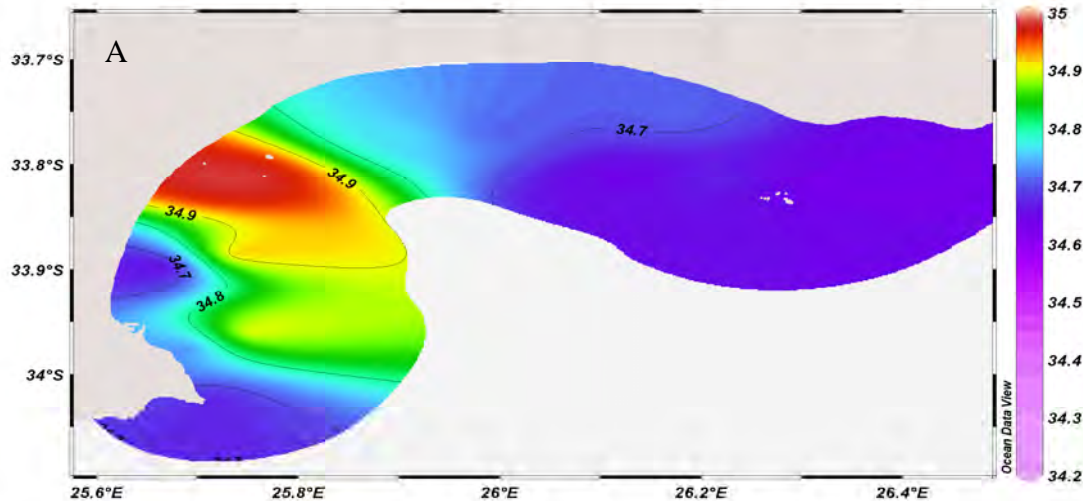
Surface salinity demonstrated a similar pattern in variability to that of surface temperature during the winter survey (Figure 4.2A). Surface salinities reflected significant variability between the eastern and western sectors ($P < 0.001$; Table 4.2), where average salinities were 34.66 (SD = 0.03) and 34.80 (SD = 0.17), respectively

(Figure 4.2B). Similarly, bottom water salinities were significantly higher ($P < 0.001$; Table 4.2) in the western sector (Mean = 34.78; SD = 0.14) than in the eastern sector (Mean = 34.54; SD = 0.05) (Figure 4.2B). In the eastern sector salinity was significantly higher in the surface waters ($P < 0.001$), while in the western sector no significant variability with depth was observed ($P = 0.137$; Table 4.2).

Table 4.2: Results of a series of Two Way Analysis of Variance (F) for rank transformed winter salinity data. For tests where the main effects showed significant variability, a post-hoc Tukey Test (q) was used to conduct a pairwise multiple comparison procedure.

Source of Variance	F	df	q	P	Significance
Sector	66.38	1	--	<0.001	**
Depth	20.07	1	--	<0.001	**
Sector x Depth	5.53	1	--	0.021	*
East: S vs. B	--	--	6.83	<0.001	**
West: S vs. B	--	--	2.12	0.137	NS
Surface: E vs. W	--	--	5.79	<0.001	**
Bottom: E vs. W	--	--	10.50	<0.001	**

Note: S = Surface; B = Bottom; E = East; W = West; * and ** indicate significant and highly significant P values respectively; NS = No Significant difference; -- = not tested; df = degrees of freedom.



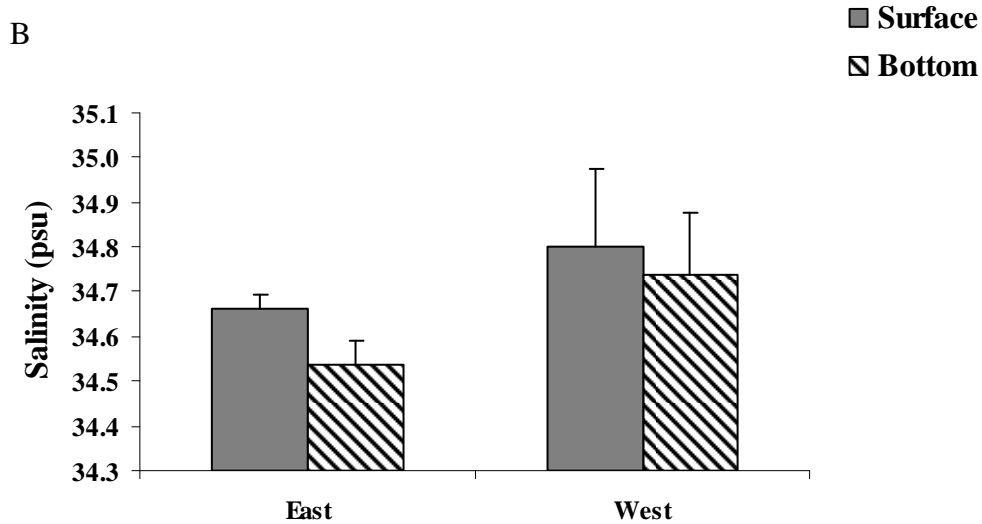


Figure 4.2: A) Surface plot of salinity (Psu); B) Average surface and bottom salinity for each sector, during winter 2008. Error bars are standard deviations.

Water column stability

Water column stability showed no significant spatial variability across Algoa Bay during the winter survey ($P = 0.795$; Table 4.3) Average water column stability in winter was 1.99×10^{-4} ($SD = 0.55 \times 10^{-4}$) and 1.90×10^{-4} ($SD = 1.64 \times 10^{-4}$), for the eastern and western sectors of the Bay, respectively (Figure 4.3).

Table 4.3: Results of non-parametric Mann-Whitney U Rank Sum test for winter stability data.

Source of Variance	U	P	Significance
East vs. West	210	0.795	NS

Note: NS = No Significant difference

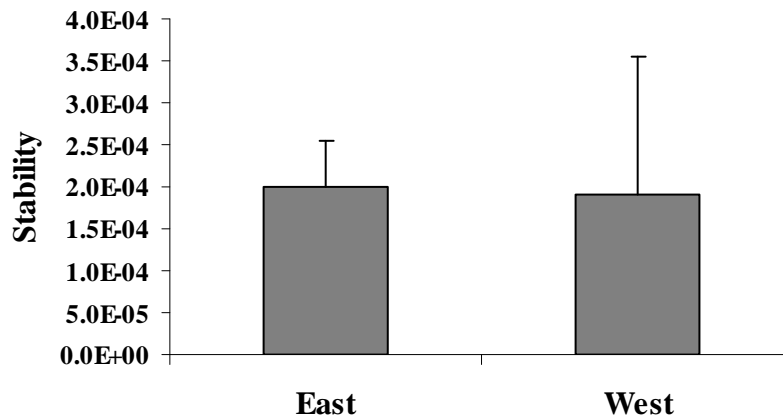


Figure 4.3: Average water column stability for each sector, during winter 2008. Error bars are standard deviations. Note: Scientific notation used for clear differentiation in values.

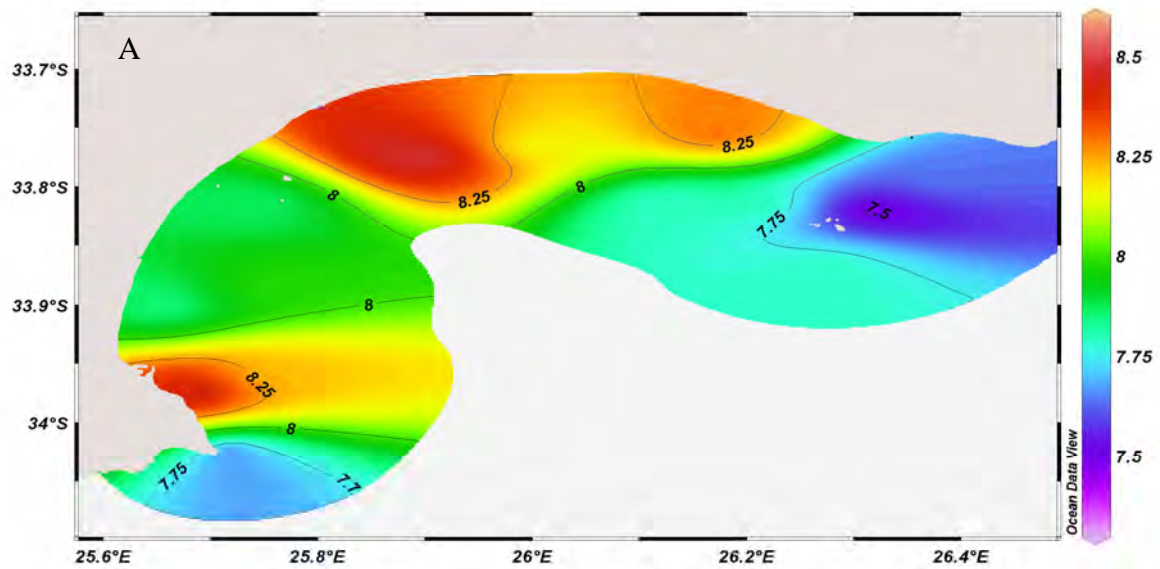
4.1.2 Dissolved oxygen

During winter 2008, surface water dissolved oxygen concentrations, showed no significant spatial variability across Algoa Bay ($P = 0.055$; Table 4.4; Figure 4.4A). Surface water dissolved oxygen values however, were observed to be higher in the western sector, with averages of 8.07 mg.L^{-1} ($SD = 0.034$), than they were in the eastern sector, where the average was 7.84 mg.L^{-1} ($SD = 0.28$) (Figure 4.4B). Bottom water dissolved oxygen concentrations demonstrated spatial variability with the western sector exhibiting a significantly higher ($P < 0.001$; Table 4.4) average value of 7.74 mg.L^{-1} ($SD = 0.51$) than the eastern sector, where the average was 7.18 mg.L^{-1} ($SD = 0.34$) (Figure 4.4B). In both the eastern and western sectors, dissolved oxygen concentrations in surface waters were significantly higher than in bottom waters ($P < 0.001$ and $P = 0.006$, respectively; Table 4.4; Figure 4.4B).

Table 4.4: Results of a series of Two Way Analysis of Variance (F) for rank transformed winter dissolved oxygen data. For tests where main effects showed significant variability, a post-hoc Tukey Test (q) was used to conduct pairwise multiple comparison procedures

Source of Variance	F	df	q	P	Significance
Sector	22.78	1	--	<0.001	**
Depth	36.41	1	--	<0.001	**
Sector x Depth	4.06	1	--	0.047	*
East: S vs. B	--	--	8.04	<0.001	**
West: S vs. B	--	--	4.01	0.006	*
Surface: E vs. W	--	--	2.75	0.055	NS
Bottom: E vs. W	--	--	6.78	<0.001	**

Note: S = Surface; B = Bottom; E = East; W = West; * and ** indicate significant and highly significant P values respectively; NS = No Significant difference, -- = not tested; df = degrees of freedom



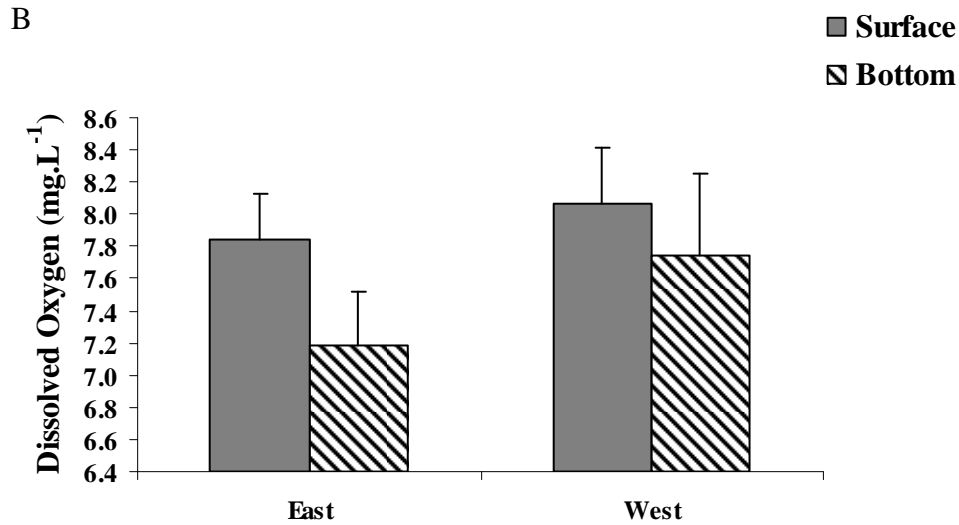


Figure 4.4: A) Surface plot of dissolved oxygen (mg.L⁻¹); B) Average surface and bottom dissolved oxygen for each sector, during winter 2008. Error bars are standard deviations.

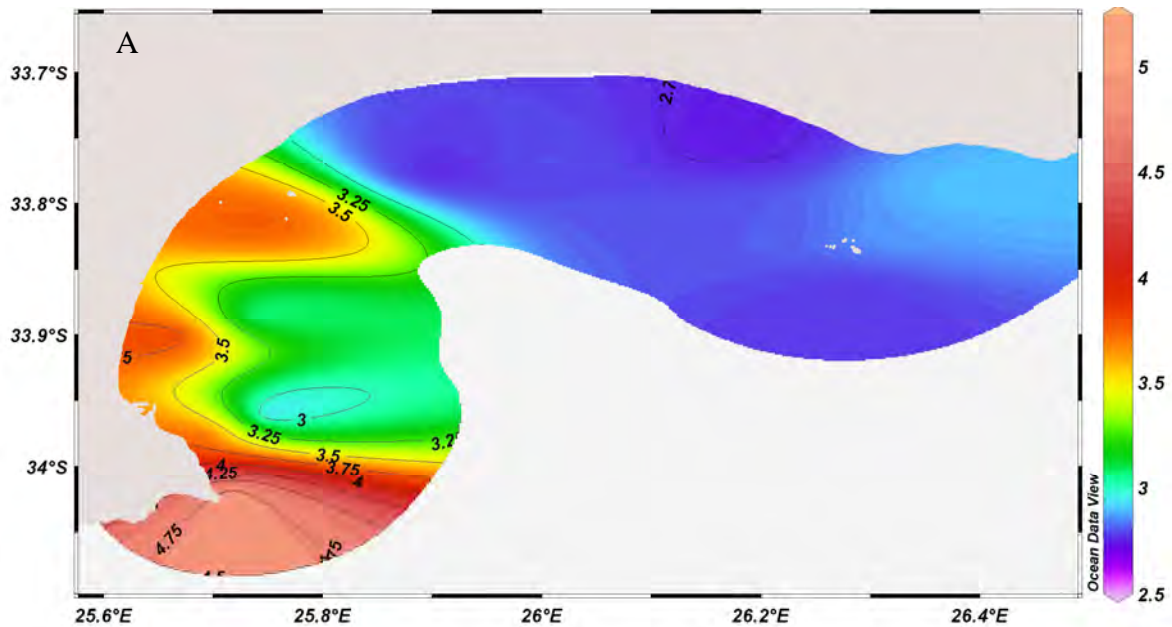
4.1.3 Turbidity

Winter surface turbidity values were statistically higher in the western sector, with an average value of 3.57 NTU (SD = 0.81), whereas the recorded average in the eastern sector was 2.81 NTU (SD = 0.06) ($P = 0.003$; Table 4.5; Figures 4.5A and B). Similarly, bottom water turbidity values recorded in the western sector, with an average of 3.94 NTU (SD = 0.82), were significantly higher than the average of 3.22 NTU (SD = 0.38) recorded in the east ($P = 0.001$; Table 4.5; Figure 4.5B). In the eastern sector, turbidity varied significantly with depth ($P < 0.001$; Table 4.5; Figure 4.5B). However, surface turbidity values in the western sector showed no variability from that of the bottom waters ($P = 0.077$; Table 4.5).

Table 4.5: Results of a series of non-parametric Mann-Whitney U Rank Sum tests for winter turbidity data. Note that even after transformation, all turbidity data remained non-normal and/or exhibited unequal variances.

Source of Variance	U	P	Significance
East: S vs. B	35.50	<0.001	**
West: S vs. B	150.00	0.077	NS
Surface: E vs. W	103.50	0.003	*
Bottom: E vs. W	93.00	0.001	*

Note: S = Surface; B = Bottom; E = East; W = West; * and ** indicate significant and highly significant P values respectively; NS = No Significant difference.



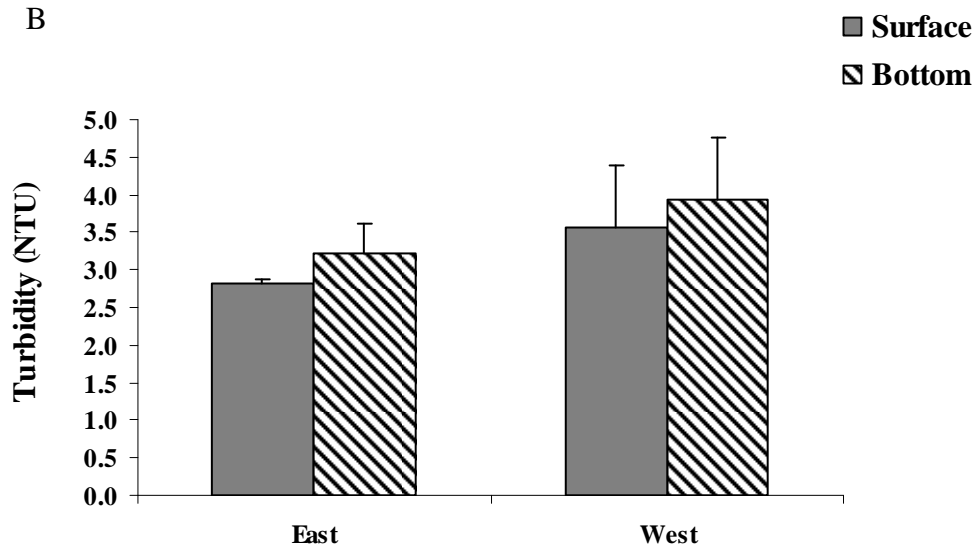


Figure 4.5: A) Surface plot of turbidity (NTU); B) Average surface and bottom turbidity for each sector, during winter 2008. Error bars are standard deviations.

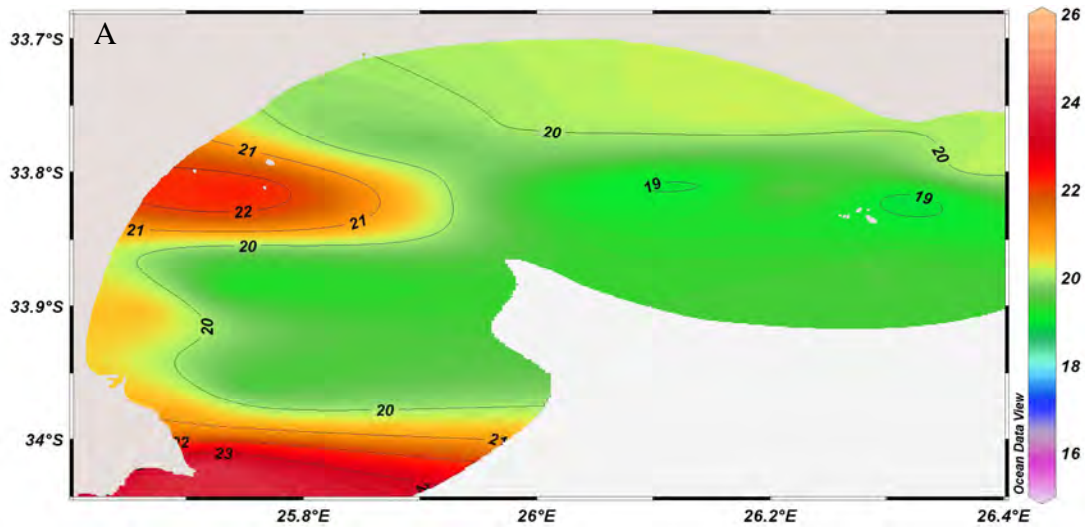
4.1.4 Seston

During winter 2008, surface seston concentrations varied significantly across Algoa Bay ($P = 0.033$; Table 4.6; Figure 4.6A). The mean surface seston concentration in western and eastern sectors of the Bay were 21.24 mg.L^{-1} ($SD = 3.52$) and 19.61 mg.L^{-1} ($SD = 1.24$), respectively (Figure 4.6B). Similarly, bottom waters exhibited significantly higher seston concentrations in the western sector, with an average of 24.22 mg.L^{-1} ($SD = 5.38$), than the lower average of 20.69 mg.L^{-1} ($SD = 1.38$) in the eastern sector ($P = 0.001$; Table 4.6; Figure 4.6B). Both the eastern and western sectors showed significant differences in seston between the surface and bottom waters ($P = 0.014$ and $P < 0.001$, respectively; Table 4.6).

Table 4.6: Results of a series of Two Way Analysis of Variance (F) for rank transformed winter seston data. For tests where main effects showed significant variability, a post-hoc Tukey Test (q) was used to conduct pairwise multiple comparison procedures.

Source of Variance	F	df	q	P	Significance
Sector	15.22	1	--	<0.001	**
Depth	19.09	1	--	<0.001	**
Sector x Depth	0.68	1	--	0.411	NS
East: S vs. B	--	--	3.54	0.014	*
West: S vs. B	--	--	5.19	<0.001	**
Surface: E vs. W	--	--	3.07	0.033	*
Bottom: E vs. W	--	--	4.72	0.001	*

Note: S = Surface; B = Bottom; E = East; W = West; * and ** indicate significant and highly significant P values respectively; NS = No Significant difference; -- = not tested; df = degrees of freedom.



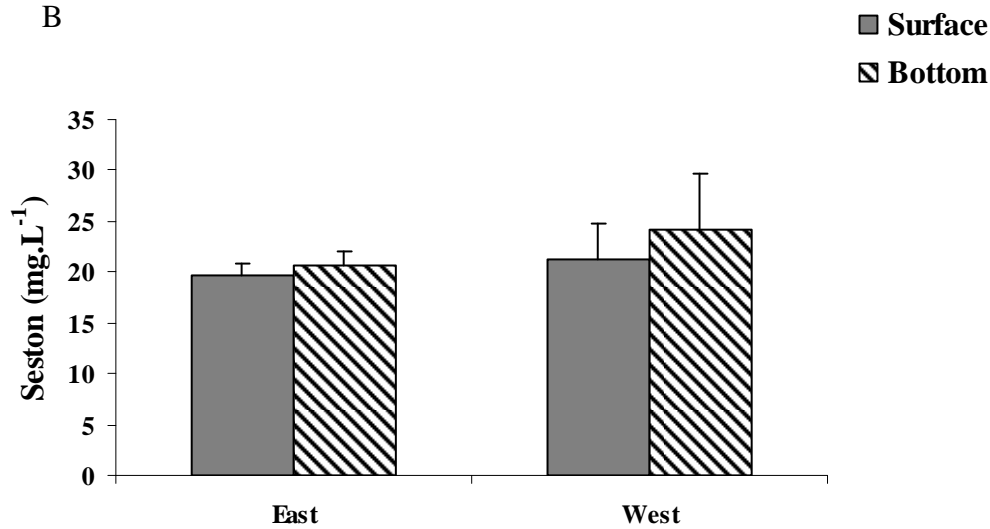


Figure 4.6: A) Surface plot of seston (mg.L⁻¹); B) Average surface and bottom seston for each sector, during winter 2008. Error bars are standard deviations.

4.1.5 Nutrients

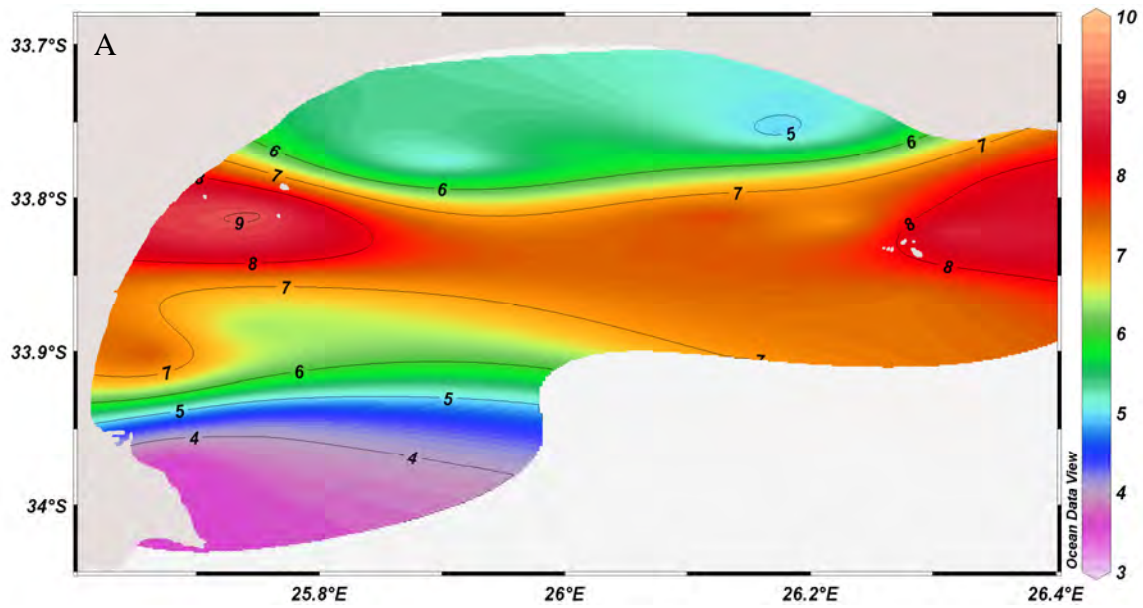
Nitrate

Surface seawater nitrate concentrations did not vary significantly across Algoa Bay during the winter survey ($P = 0.339$; Table 4.7; Figure 4.7A). Surface nitrate concentrations were, however, lower in the western sector with an average concentration of $5.96 \mu\text{M}$ ($\text{SD} = 2.23$). In the eastern sector of the Bay the mean average nitrate concentration was $7.15 \mu\text{M}$ ($\text{SD} = 1.74$) (Figure 4.7B). Similarly, although not statistically significant ($P = 0.339$), bottom water nitrate concentrations were higher in the eastern sector, with an average of $10.16 \mu\text{M}$ ($\text{SD} = 1.47$) than the lower average of $8.91 \mu\text{M}$ ($\text{SD} = 3.26$) recorded in the western sector, (Table 4.7; Figure 4.7B). Surface nitrate concentrations, within both the east and western sectors, were significant lower than those of the bottom waters ($P = 0.021$ and $P = 0.023$ respectively; Table 4.7; Figure 4.7B).

Table 4.7: Results of a series of Two Way Analysis of Variance (F) for winter nitrate data. For main effects that showed significant variability, a post-hoc Tukey Test (q) was used to conduct pairwise multiple comparison procedures.

Source of Variance	F	df	q	P	Significance
Sector	1.99	1	--	0.171	NS
Depth	11.96	1	--	0.002	NS
Sector x Depth	0.00	1	--	0.975	NS
East: S vs. B	--	--	3.49	0.021	*
West: S vs. B	--	--	3.42	0.023	*
Surface: E vs. W	--	--	1.38	0.339	NS
Bottom: E vs. W	--	--	1.44	0.318	NS

Note: S = Surface; B = Bottom; E = East; W = West; * indicate significant P values, and NS = No Significant difference; -- = not tested; df = degrees of freedom.



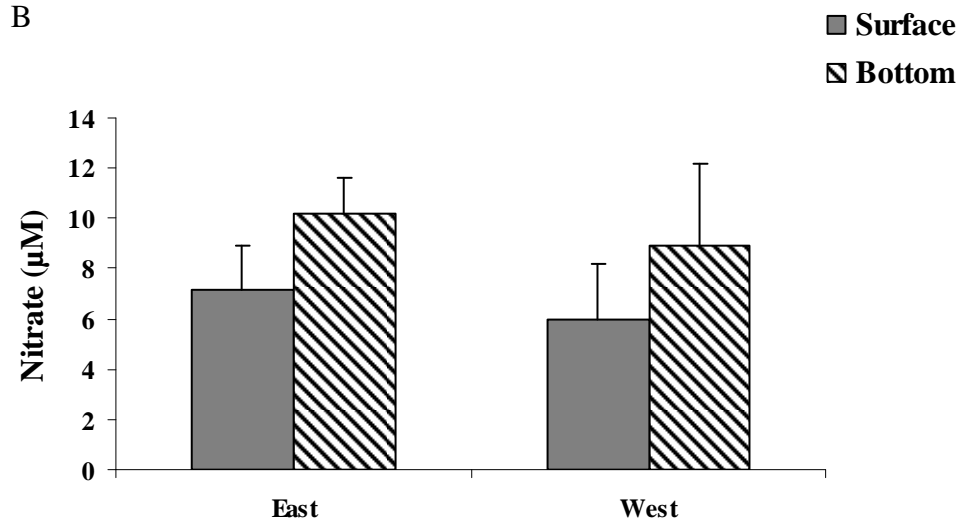


Figure 4.7: A) Surface plot of nitrate concentrations (μM); B) Average surface and bottom nitrate concentrations for each sector, during winter 2008. Error bars are standard deviations

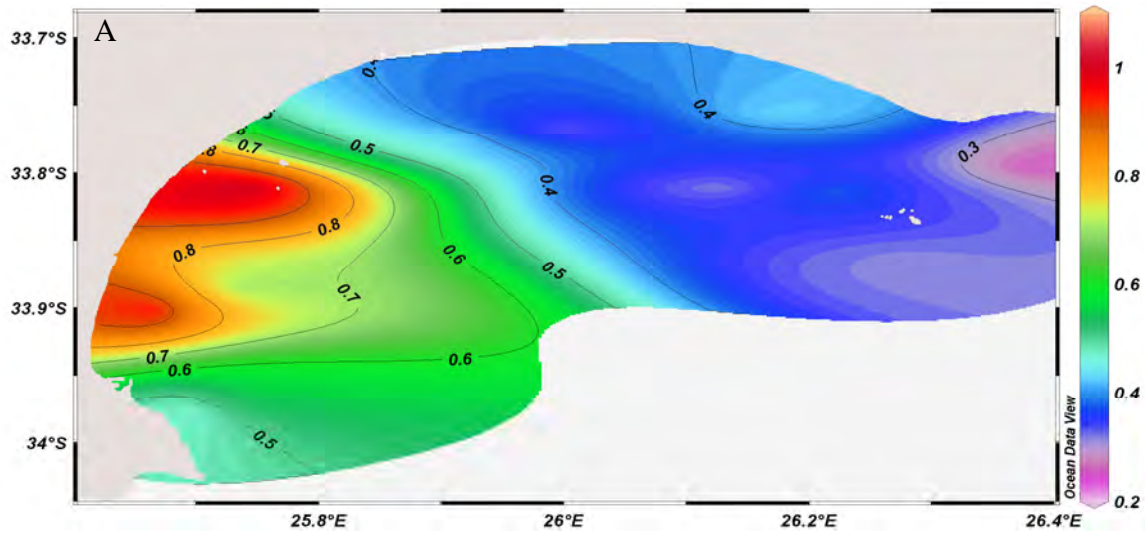
Nitrite

During the winter survey, surface nitrite concentrations in the western sector (Mean = $0.70 \mu\text{M}$; SD = 0.25) of Algoa Bay were significantly higher than those recorded in the eastern sector (Mean = $0.32 \mu\text{M}$; SD = 0.09) ($P < 0.001$; Table 4.8; Figure 4.8 A and B). Similarly, bottom water nitrite concentrations were significantly higher in the western sector (Mean = $0.64 \mu\text{M}$; SD = 0.16), than those recorded in the eastern sector (Mean = $0.38 \mu\text{M}$; SD = 0.13) ($P = 0.011$; Table 4.8; Figure 4.8B). Nitrite concentrations showed no significant variability with depth in either sector ($P = 0.505$ and $P = 0.468$, respectively; Table 4.8).

Table 4.8: Results of a series of Two Way Analysis of Variance for winter nitrate data. For tests where main effects showed significant variability, a post-hoc Tukey Test (q) was used to conduct pairwise multiple comparison procedures.

Source of Variance	F	df	q	P	Significance
Sector	24.30	1	--	<0.001	**
Depth	0.00	1	--	0.966	NS
Sector x Depth	1.00	1	--	0.327	NS
East: S vs. B	--	--	0.95	0.505	NS
West: S vs. B	--	--	1.04	0.468	NS
Surface: E vs. W	--	--	5.93	<0.001	**
Bottom: E vs. W	--	--	3.93	0.011	*

Note: S = Surface; B = Bottom; E = East; W = West; * and ** indicate significant and highly significant P values, respectively, and NS = No Significant difference; -- = not tested; df = degrees of freedom.



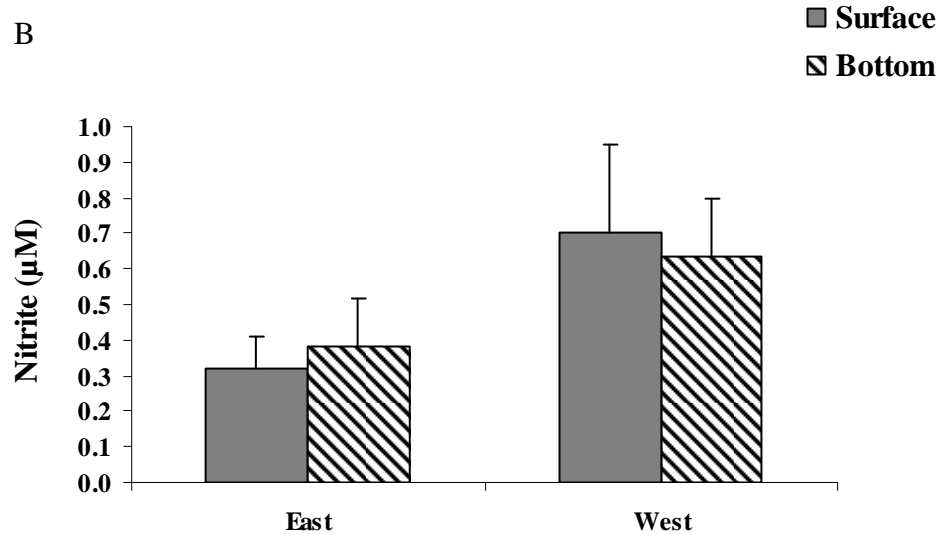


Figure 4.8: A) Surface plot of nitrite concentrations (μM); B) Average surface and bottom nitrite concentrations for each sector, during winter 2008. Error bars are standard deviations

Ammonia

Surface ammonia concentrations reflected little spatial variability across Algoa Bay during winter 2008 (Figure 4.9A). Ammonia concentrations exhibited no significant variability with either sector or depth ($P > 0.050$ for all tests; Table 4.9). Average surface ammonia concentrations were relatively higher in the western sector (Mean = $1.58 \mu\text{M}$; SD = 0.43) than those recorded in the eastern sector (Mean = $1.28 \mu\text{M}$; SD = 0.54) (Figure 4.9B). Similarly, bottom water ammonia concentrations recorded in the western sector were relatively higher, with average of $1.73 \mu\text{M}$ (SD = 0.59), than those recorded in the eastern sector, where the average was $1.38 \mu\text{M}$ (SD = 0.25) (Figure 4.9B).

Table 4.9: Results of a series of Two Way Analysis of Variance (F) for summer surface ammonia concentration data.

Source of Variance	df	F	P	Significance
Sector	1	3.35	0.079	NS
Depth	1	0.48	0.493	NS
Sector x Depth	1	0.01	0.898	NS

Note: NS = No Significant difference; Sector is comparison between East and West; Depth is a comparison between surface and bottom; df = degrees of freedom.

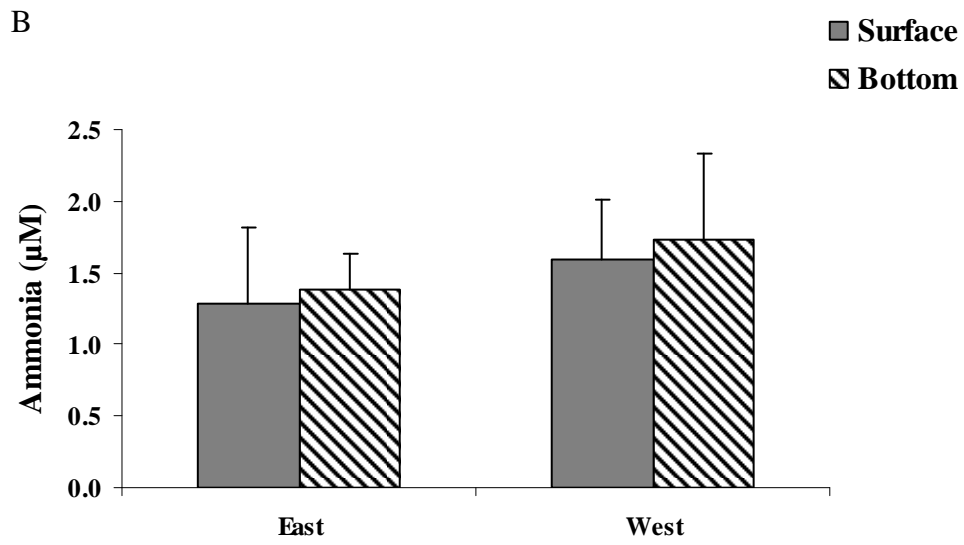
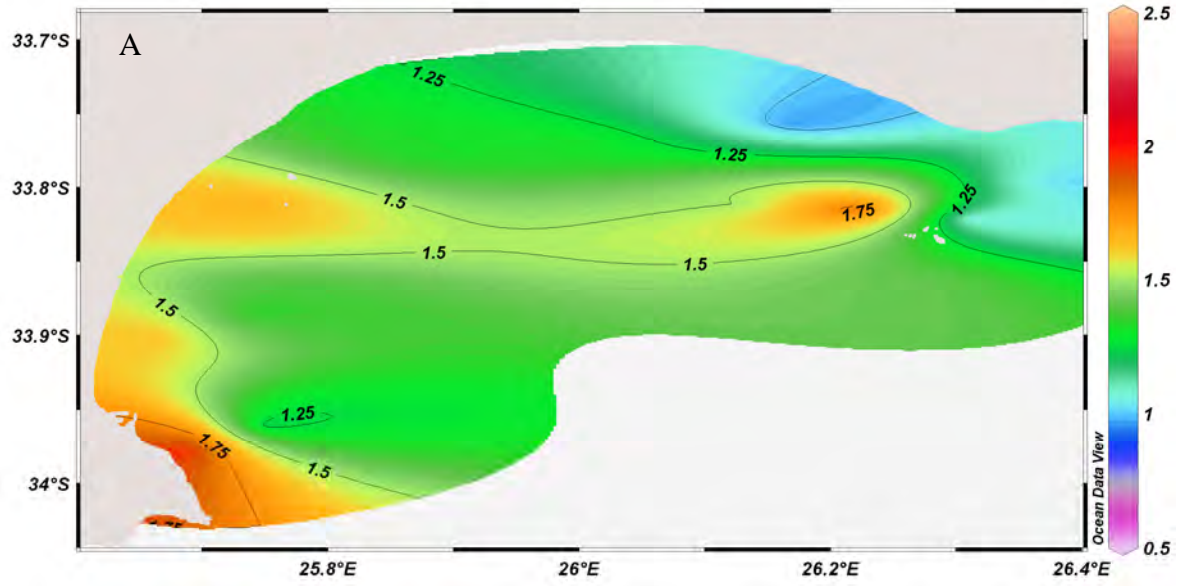


Figure 4.9: A) Surface plot of ammonia concentrations (µM); B) Average surface and bottom ammonia concentrations for each sector, during winter 2008. Error bars are standard deviations

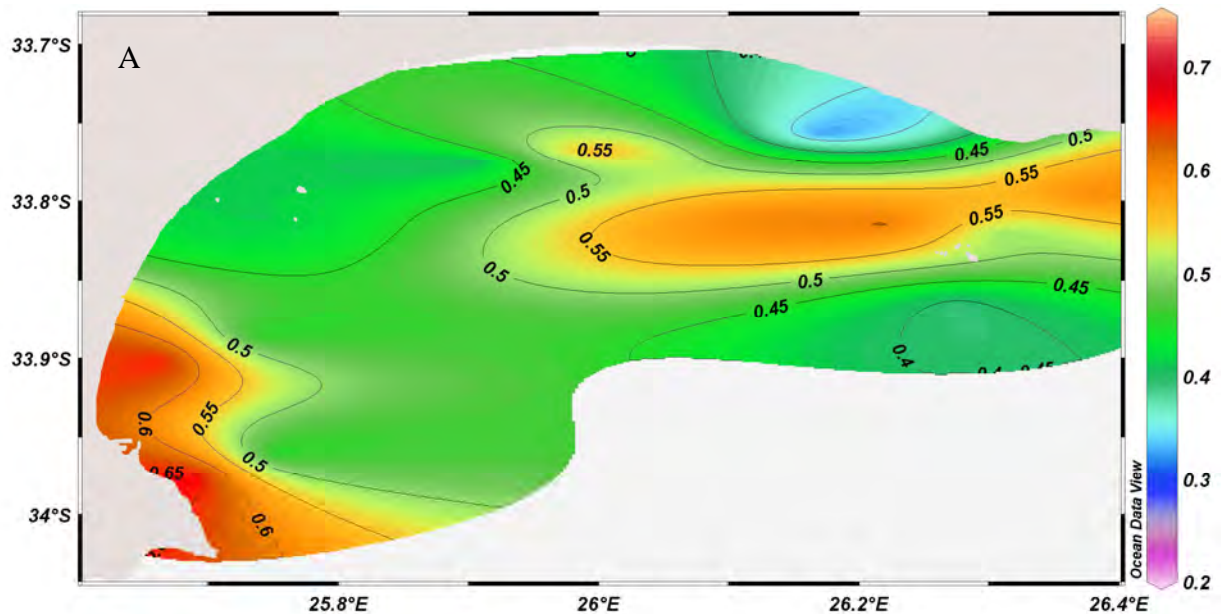
Phosphate

Surface phosphate concentrations demonstrated little spatial variability across Algoa Bay during the winter survey (Figure 4.10A). Phosphate concentrations exhibited no significant variability either with depth or sector ($P > 0.050$ for all tests; Table 4.10). Higher average surface concentrations of $0.55 \mu\text{M}$ (SD = 0.17) were observed in the eastern sector, compared to the average value of $0.52 \mu\text{M}$ (SD = 0.19) in the western sector, (Figure 4.10B). In contrast, relatively higher bottom water phosphate concentrations were recorded in the western sector with an average of $0.61 \mu\text{M}$ (SD = 0.10), compared with the eastern sector average of $0.59 \mu\text{M}$ (SD = 0.19) (Figure 4.10B).

Table 4.10: Results of a series of Two Way Analysis of Variance (F) for winter surface phosphate concentration data. Note: All tested parameters were not significant

Source of Variance	df	F	P	Significance
Sector	1	0.01	0.917	NS
Depth	1	1.96	0.174	NS
Sector x Depth	1	0.04	0.841	NS

Note: NS = No Significant difference; Sector is comparison between East and West; Depth is a comparison between surface and bottom; df = degrees of freedom.



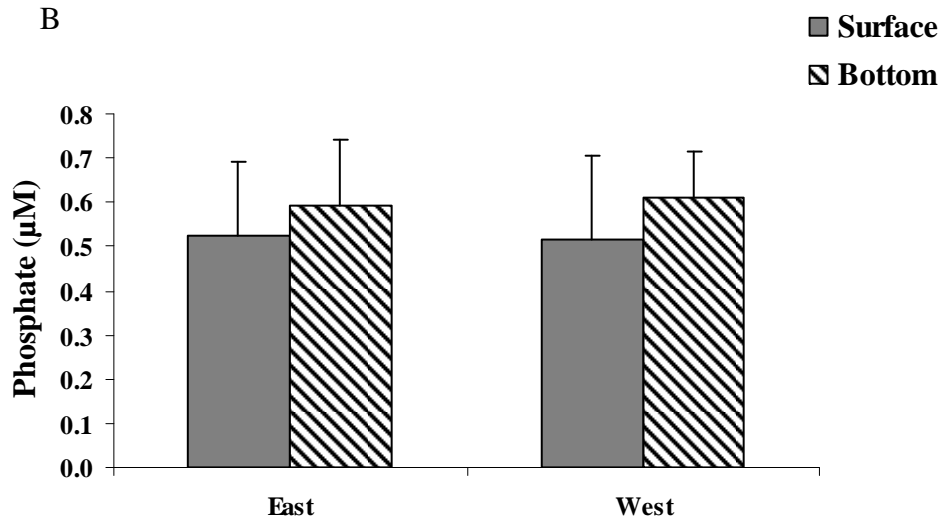


Figure 4.10: A) Surface plots of phosphate concentrations (μM); B) Average surface and bottom phosphate concentrations for each sector, during winter 2008. Error bars are standard deviations.

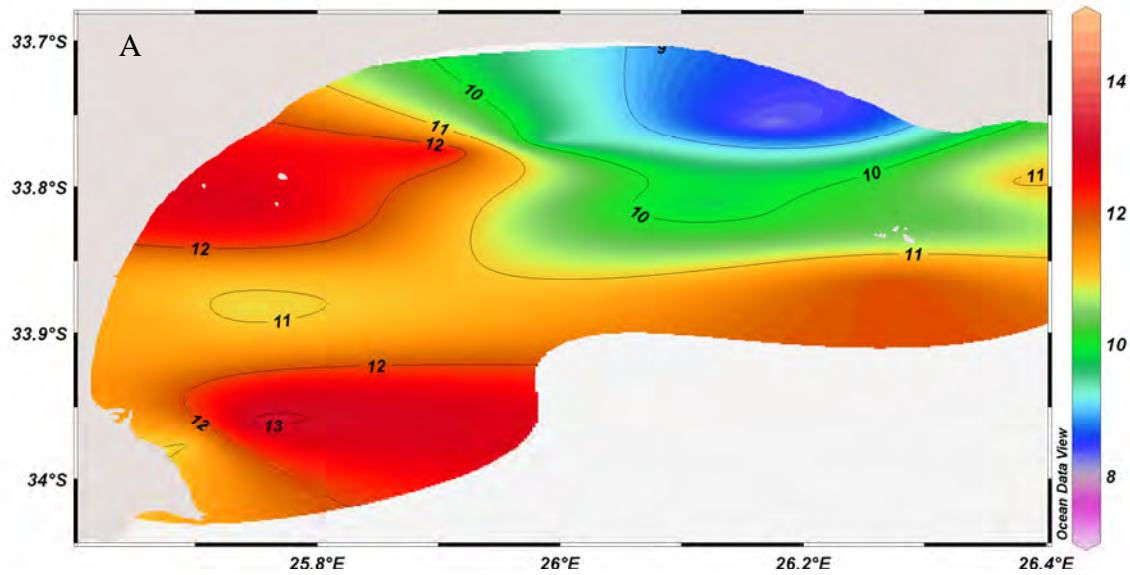
Silicate

Surface silicate concentrations did not vary significantly across Algoa Bay during winter 2008 ($P = 0.077$; Table 4.11; Figure 4.11A). Surface silicate concentrations were highest in the western sector, with an average of $12.89 \mu\text{M}$ ($SD = 2.51$), compared to the eastern sector, where the average silicate concentration was $9.83 \mu\text{M}$ ($SD = 1.72$) (Figure 4.11B). Bottom water silicate concentrations again demonstrated no significant spatial pattern ($P = 0.540$; Table 4.11; Figure 4.11B). The average silicate concentration in the bottom waters in the east was $14.54 \mu\text{M}$ ($SD = 2.59$) while that in the west was $15.52 \mu\text{M}$ ($SD = 4.12$). In both the eastern and western sectors, there were no significant differences in silicate concentrations between the surface and bottom waters ($P > 0.050$ for both sectors; Table 4.11).

Table 4.11: Results of a series of Two Way Analysis of Variance for winter silicate data. For tests where main effects showed significant variability, a post-hoc Tukey Test (q) was used to conduct pairwise multiple comparison procedures.

Source of Variance	F	df	q	P	Significance
Sector	3.11	1	--	0.091	NS
Depth	10.22	1	--	0.004	*
Sector x Depth	0.81	1	--	0.376	NS
East: S vs. B	--	--	4.18	0.007	*
West: S vs. B	--	--	2.25	0.125	NS
Surface: E vs. W	--	--	2.61	0.077	NS
Bottom: E vs. W	--	--	0.88	0.540	NS

Note: * indicates significant P value; NS = No Significant difference; S = Surface; B = Bottom; E = East; W = West; -- = not tested; df = degrees of freedom.



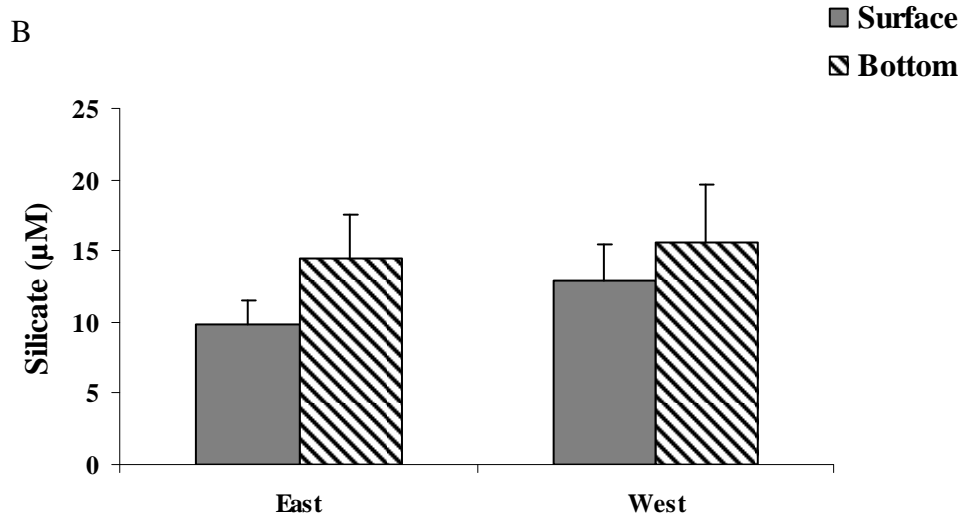


Figure 4.11: A) Surface plots of silicate concentrations (μM); B) Average surface and bottom silicate concentrations for each sector, during winter 2008. Error bars are standard deviations.

4.2 PHYTOPLANKTON BIOMASS

4.2.1 Surface total and size-fractionated chlorophyll-*a* (SFC)

The surface total chlorophyll-*a* (chl-*a*) concentrations in the western sector of Algoa Bay were significantly higher than those recorded in the eastern sector during the winter survey ($P = 0.047$; Table 4.12; Figure 4.12). Average total chl-*a* concentrations were estimated at $0.55 \mu\text{g.L}^{-1}$ ($\text{SD} = 0.45$) in the western sector of Algoa Bay and $0.49 \mu\text{g.L}^{-1}$ ($\text{SD} = 0.68$) in the eastern sector (Figure 4.12). The microphytoplankton size fraction dominated the total phytoplankton biomass in both sectors. Microphytoplankton biomass exhibited an average concentration of $0.47 \mu\text{g.L}^{-1}$ ($\text{SD} = 0.67$) in the eastern sector which corresponded to $\sim 97\%$ of the total chl-*a*. The average nano- and picophytoplankton concentrations in the eastern sector were $0.006 \mu\text{g.L}^{-1}$ ($\text{SD} = 0.005$) and $0.011 \mu\text{g.L}^{-1}$ ($\text{SD} = 0.007$), corresponding to 1% and 2% of the total pigment, respectively (Figure 4.13A). In the western sector, the microphytoplankton contributed 84% (Mean = $0.52 \mu\text{g.L}^{-1}$; $\text{SD} = 0.44$) to the total chl-*a* biomass, while the nano- and picophytoplankton fractions (Mean = $0.017 \mu\text{g.L}^{-1}$; $\text{SD} = 0.012$, and Mean = $0.015 \mu\text{g.L}^{-1}$; $\text{SD} = 0.008$, respectively) both contributed $\sim 3\%$ to total chl-*a* biomass. The nano- and picophytoplankton

concentrations were highest in the western sector of Algoa Bay ($P < 0.050$; Table 4.13). Microphytoplankton demonstrated no significant spatial variability between the sectors ($P > 0.050$). The nano- and picophytoplankton, however, reflected significant spatial variability between the two sectors ($P < 0.001$, and $P = 0.008$, respectively; Table 4.13A and 4.13C).

Table 4.12: Results of a t-test on log transformed winter total chlorophyll-*a* data

Source of Variance	t	df	P	Significance
Surface: E vs. W	-2.04	40	0.047	*

Note: * indicates significant P value; df = degrees of freedom

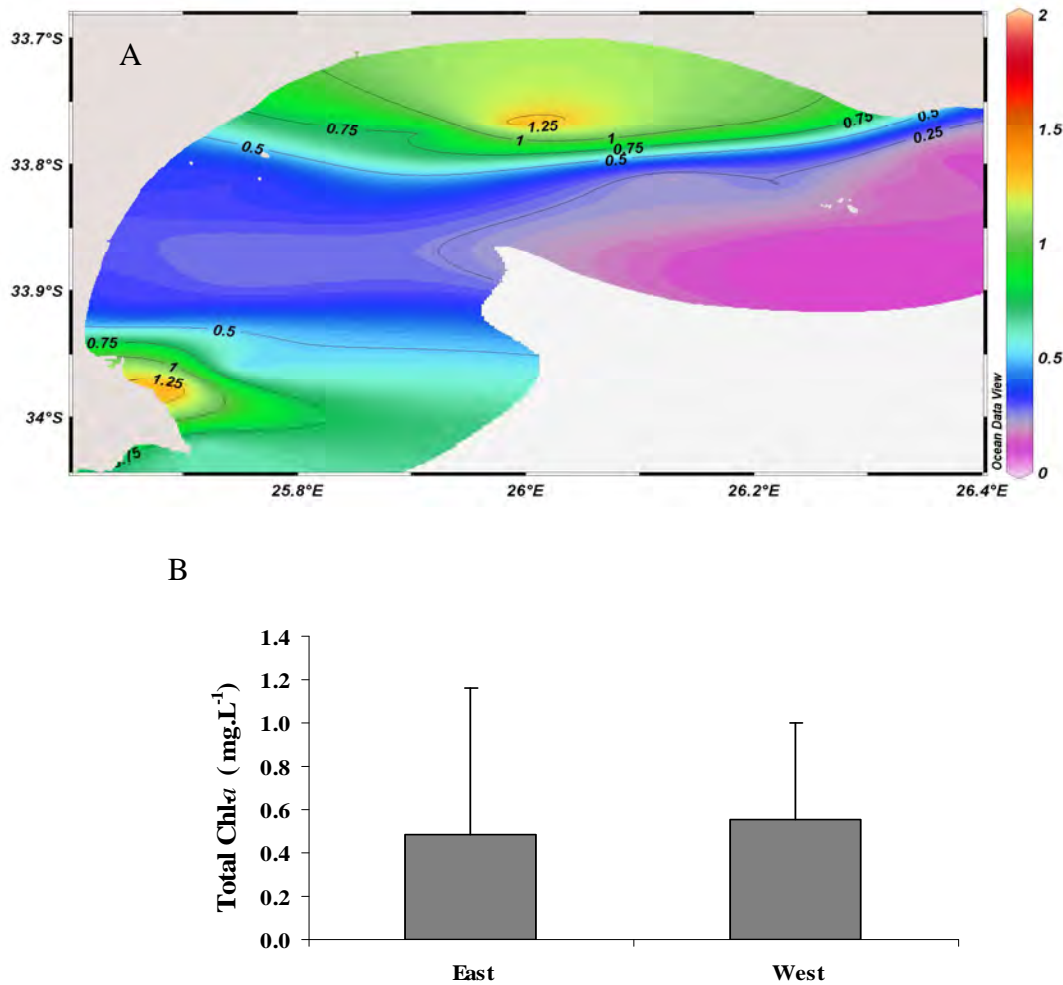


Figure 4.12: A) Surface plot of total chlorophyll-*a* ($\mu\text{g.L}^{-1}$) concentration; B) Average surface total chlorophyll-*a* for each sector, during winter 2008. Error bars are standard deviations.

Table 4.13: Results of a series of t-tests for winter size fractionated chlorophyll-*a* data. Note: Microphytoplankton (log) and picophytoplankton (rank) required transformations, while nanophytoplankton required none.

A. Microphytoplankton				
Source of Variance	t	df	P	Significance
Surface: E vs. W	-1.95	40	0.058	NS

B. Nanophytoplankton				
Source of Variance	t	df	P	Significance
Surface: E vs. W	-3.86	40	<0.001	**

C. Picophytoplankton				
Source of Variance	t	df	P	Significance
Surface: E vs. W	-2.77	40	0.008	*

Note: * and ** indicate significant and high significant P values, respectively; df = degrees of freedom.

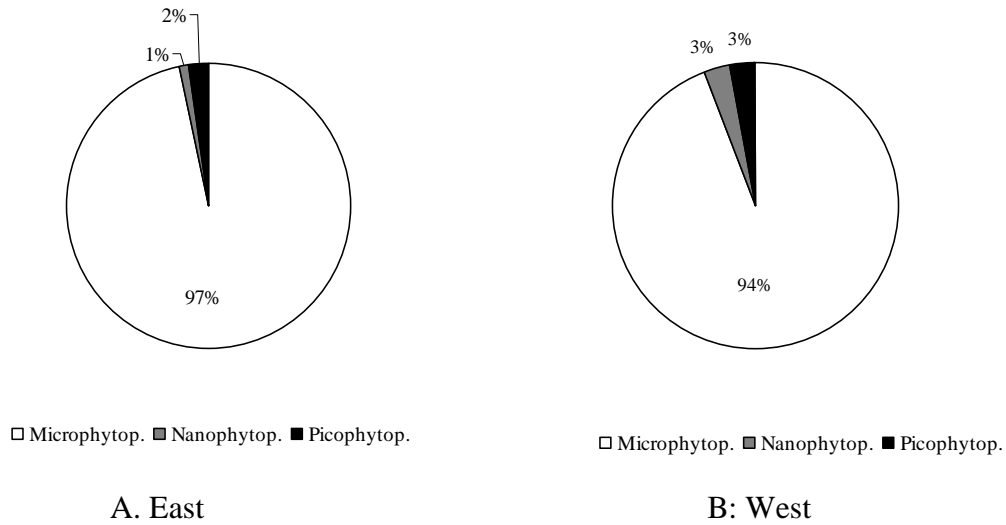


Figure 4.13: Percent contribution of SFC to total surface chlorophyll-*a* for each sector during the winter survey.

4.2.2 Integrated total chlorophyll-*a* and integrated size-fractionated chlorophyll-*a* (SFC)

The integrated total chl-*a* concentrations demonstrated no significant spatial variability during the winter survey ($P = 0.925$; Table 4.14; Figure 4.14). The highest integrated total chl-*a* concentrations were observed in the eastern sector, with an average of 13.88 mg.m^{-2} ($SD = 13.93$), compared to the western sector in which the average integrated chl-*a* concentration was 13.54 mg.m^{-2} ($SD = 8.17$) (Figure 4.14). The microphytoplankton size fraction contributed the most to the integrated total chl-*a* concentration in both the eastern and the western sectors of Algoa Bay, with 96 % (Mean = 9.20 mg.m^{-2} ; $SD = 9.48$) and 94 % (Mean = 8.72 mg.m^{-2} ; $SD = 5.69$) of the total pigment, respectively. There was no significant difference in integrated microphytoplankton concentration between the two sectors ($P = 0.699$; Table 4.15A). Integrated nano- and picophytoplankton concentrations contributed $\sim 2\%$ and $\sim 3\%$ to total integrated chl-*a*, in both sectors (Figure 4.15A and 15B).

Table 4.14: Results of a t-test for summer integrated chlorophyll-*a* concentration data

Source of Variance	df	t	P	Significance
East vs. West	40	0.09	0.925	NS

Note: NS = No Significant difference

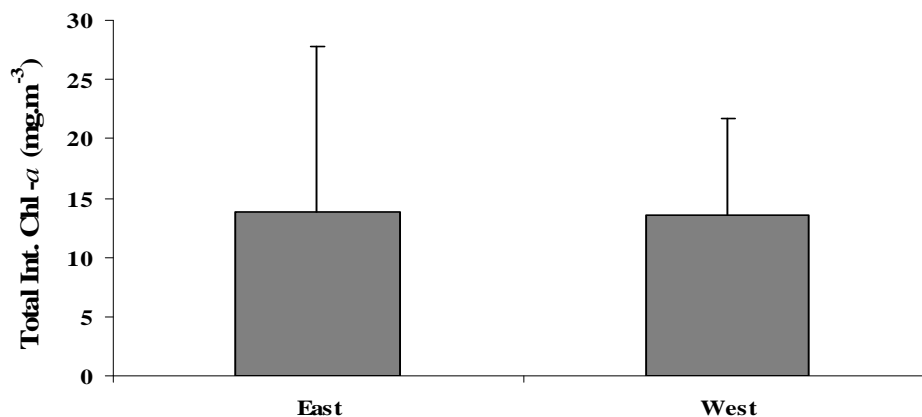


Figure 4.14: Average total integrated chlorophyll-*a* for each sector, during winter 2008. Error bars are standard deviations.

Table 4.15: Results of a series of t-tests for winter size fractionated chlorophyll-*a* data. Note: Only microphytoplankton required transformation (square root); other fractions had normal data.

A. Integrated microphytoplankton				
Source of Variance	t	df	P	Significance
East vs. West	-0.39	40	0.699	NS

B. Integrated nanophytoplankton				
Source of Variance	t	df	P	Significance
East vs. West	-3.27	40	0.002	*

C. Integrated picophytoplankton				
Source of Variance	t	df	P	Significance
East vs. West	-1.15	40	0.255	NS

Note: * indicates significant P value; NS = No Significant difference; df = degrees of freedom

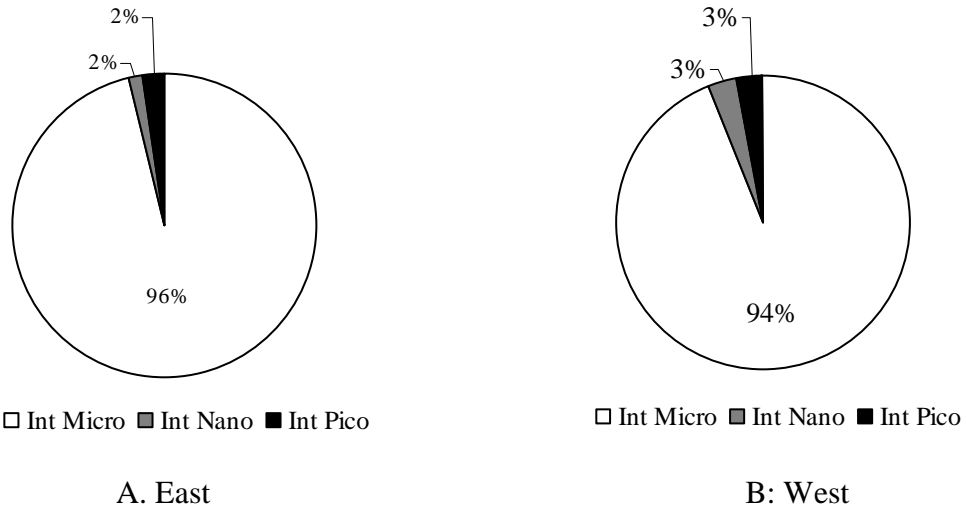


Figure 4.15: Percent contribution of integrated SFC to total integrated chl-*a* ($\text{mg}\cdot\text{m}^{-2}$) for each sector during winter 2008.

4.3 ZOOPLANKTON COMMUNITY STRUCTURE

4.3.1 Cluster Analysis

Cluster analysis identified four distinct zooplankton groupings; designated Groups A to D, at ~ 65 % similarity level during the winter survey (Figures 4.16 and 4.17). Group A, consisted of only two sites occupied in the vicinity of Cape Recife in the western sector of Algoa Bay (Figure 4.16 and 4.17). Group B, was located in the sheltered retention area of the western sector of Algoa Bay with three sites (Figure 4.16 and 4.17). Group C, comprising four sites, was located close to Cape Padrone, in the eastern sector of the Bay (Figure 4.16 and 4.17). Group D was located between the 30 m and the 50 m contours across Algoa Bay (Figure 4.16 and 4.17). ANOSIM showed no significant difference between clusters B and A, and C and A ($P > 0.050$). However, both of these pairwise comparisons showed high R statistic values (Table 4.16), which suggests that the groups compared were statistically different (Clarke and Gorley 2006). Other pairwise tests showed significant differences ($P < 0.050$) between the remaining groups (Table 4.16).

Table 4.16: Results of the ANOSIM pairwise tests of winter zooplankton abundances between clusters.

Clusters	R	P	Significance
C vs. D	0.86	0.016	*
C vs. B	1.00	0.029	*
C vs. A	1.00	0.067	NS
D vs. B	0.93	0.018	*
D vs. A	1.00	0.048	*
B vs. A	0.91	0.100	NS

Note: * indicates significant P values; NS = No Significant difference.

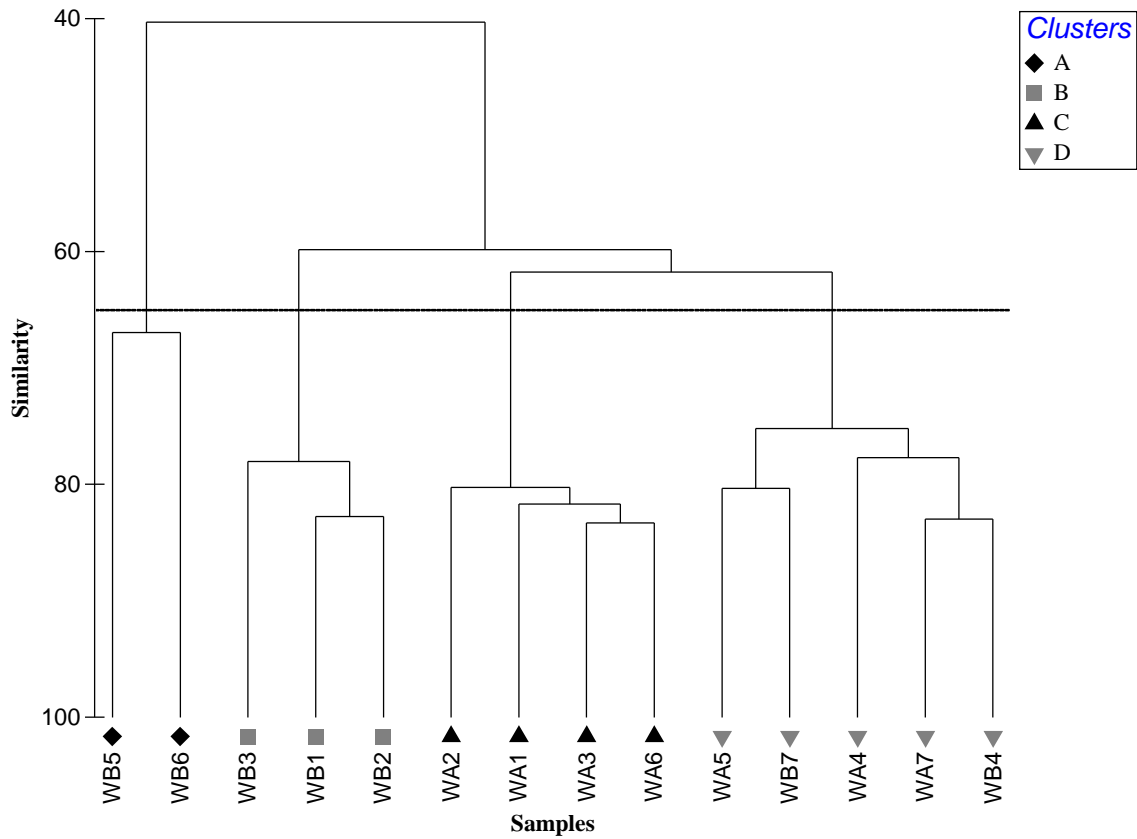


Figure 4.16: Cluster analysis dendrogram of zooplankton abundance data for Algoa Bay during winter 2008. Note: After standardisation and $\text{Log}_{10}(x + 1)$ transformation, Bray–Curtis similarity index was used on abundance data. Identified groupings are indicated by symbols shown in the legend. WA1 – WA7 = Winter eastern sector stations; WB1 – WB7 = Winter western sector stations.

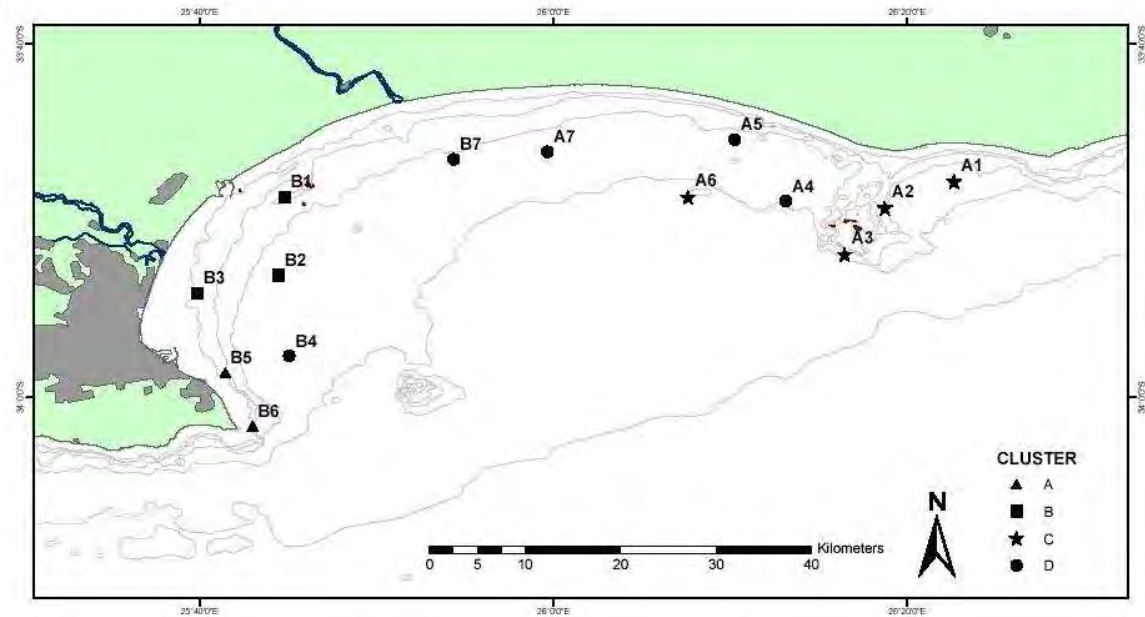


Figure 4.17: Distribution of zooplankton cluster groups in Algoa Bay during winter 2008. Note: A1 – A7 = Eastern sector stations; B1 – B7 = Western sector stations.

4.3.2 Zooplankton abundance

Total zooplankton abundances were highly variable across Algoa Bay during the winter survey. The highest average zooplankton abundances were recorded in Cluster A with a value of $11145.29 \text{ ind.m}^{-3}$ ($SD = 3375.40$), while in Cluster C the average zooplankton abundance was calculated at $2392.49 \text{ ind.m}^{-3}$ ($SD = 1230.68$) ($P < 0.050$; Table 4.17; Figure 4.18). Average zooplankton abundances in Clusters B and D were $5729.44 \text{ ind.m}^{-3}$ ($SD = 1276.51$) and $4274.44 \text{ ind.m}^{-3}$ ($SD = 1689.36$), respectively (Figure 4.18). The $1000\text{--}2000 \mu\text{m}$ size class contributed the least to total abundances in all four clusters ($P < 0.050$; Table 4.18). The greatest contribution to total abundance was made by the $200\text{--}500 \mu\text{m}$ size class in Cluster B, C and D, while both the $90\text{--}200$ and $200\text{--}500 \mu\text{m}$ size classes dominated total zooplankton abundances in Cluster A (Table 4.18; Figure 4.18).

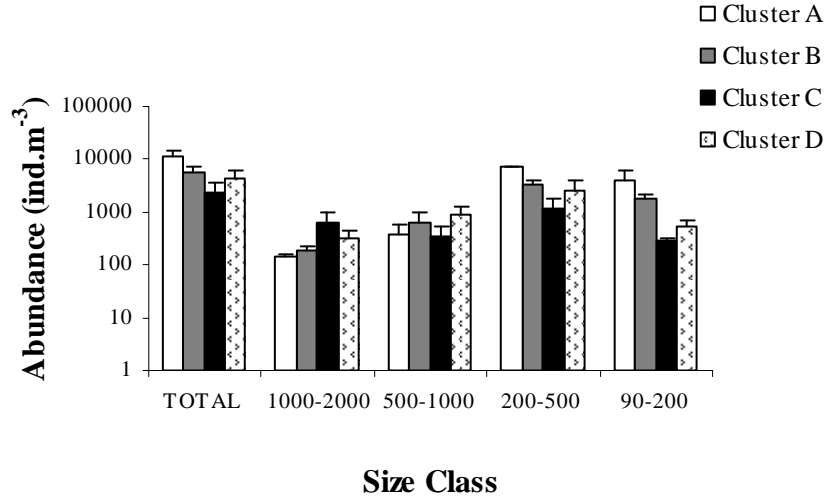


Figure 4.18: Winter total and size fractionated zooplankton abundance (ind.m⁻³) in each cluster identified with the hierachical cluster analysis. (Note: y-axis is on log scale)

Table 4.17: Results of a series of One Way Analysis of Variance (F) and the non-parametric equivalent, Kruskal-Wallis One Way Analysis of Variance on Ranks (H), statistical tests on zooplankton abundance by size class data. For tests where the main effects showed significant variability, the post-hoc Tukey Test (q; parametric) or Dunn’s Method (Q; non-parametric) was used to conduct the pairwise multiple comparison procedures. All cluster abundance data were log transformed prior to testing, except for ones which required non-parametric tests (Q).

Size Class (µm)	Source of Variance	q	H	F	df	Q	P	Significance
Total	All Clusters		51.46		3		<0.001	**
	A vs. C					6.54	<0.050	*
	A vs. D					3.78	<0.050	*
	A vs. B					1.86	>0.050	NS
	B vs. C					5.19	<0.050	*
	B vs. D					2.00	>0.050	NS
	D vs. C					3.72	<0.050	*
1000–2000	All Clusters			24.37	3		<0.001	**
	C vs. A	10.31					<0.001	**
	C vs. B	9.65					<0.001	**
	C vs. D	6.72					<0.001	**
	D vs. A	5.34					0.002	*
	D vs. B	3.93					0.032	*
	B vs. A	1.77					0.595	NS

500–1000	All Clusters		19.44	3	<0.001	**
	D vs. C	9.82			<0.001	*
	D vs. A	7.33			<0.001	*
	D vs. B	3.21			0.111	NS
	B vs. C	5.49			0.001	*
	B vs. A	4.16			0.02	*
	A vs. C	0.38			0.993	NS
200–500	All Clusters		50.53	3		
	A vs. C			6.47		*
	A vs. D			3.25		*
	A vs. B			1.97		NS
	B vs. C			5.01		*
	B vs. D			1.26		NS
	D vs. C			4.34		*
90–200	All Clusters		88.07	3	<0.001	**
	A vs. C	19.41			<0.001	**
	A vs. D	15.29			<0.001	**
	A vs. B	4.60			0.008	*
	B vs. C	16.62			<0.001	**
	B vs. D	11.85			<0.001	**
	D vs. C	5.99			<0.001	**

Note: A = Cluster A; B = Cluster B; C = Cluster C; D = Cluster D; df = Degree of Freedom; * and ** indicate significant and highly significant P values, respectively; NS = No significant difference.

Table 4.18: Results of a series of One Way Analysis of Variance (F) and the non-parametric equivalent, Kruskal-Wallis One Way Analysis of Variance on Ranks (H), statistical tests on zooplankton abundance by cluster data. For tests where the main effects showed significant variability, the post-hoc Tukey test (q; parametric) or Dunn’s Method (Q; non-parametric) was used to conduct the pairwise multiple comparison procedures. All cluster abundance data were log transformed prior to testing, except for Clusters A and C, which required no transformation.

Clusters	Source of Variance	H	F	df	Q	Q	P	Significance
Cluster A	All size classes	46.71		3			<0.001	**
	200-500 vs. 1000-2000				6.01		<0.050	*
	200-500 vs. 500-1000				4.18		<0.050	*
	200-500 vs. 90-200				0.98		>0.050	NS
	90-200 vs. 1000-2000				5.02		<0.050	*
	90-200 vs. 500-1000				3.20		<0.050	*
	500-1000 vs. 1000-2000				1.82		>0.050	NS

Cluster B	All size classes	130.10	3		<0.001	**
	200-500 vs. 1000-2000			25.78	<0.001	**
	200-500 vs. 500-1000			14.71	<0.001	**
	200-500 vs. 90-200			4.88	0.005	*
	90-200 vs. 1000-2000			20.90	<0.001	**
	90-200 vs. 500-1000			9.82	<0.001	**
	500-1000 vs. 1000-2000			11.07	<0.001	**
Cluster C	All size classes	68.53	3		<0.001	**
	200-500 vs. 90-200		7.52		<0.050	*
	200-500 vs. 500-1000		6.31		<0.050	*
	200-500 vs. 1000-2000		3.13		<0.050	*
	1000-2000 vs. 90-200		4.38		<0.050	*
	1000-2000 vs. 500-1000		3.17		<0.050	*
	500-1000 vs. 90-200		1.21		>0.050	NS
Cluster D	All size classes	82.23	3			
	200-500 vs. 1000-2000			21.23	<0.001	**
	200-500 vs. 500-1000			15.76	<0.001	**
	200-500 vs. 90-200			10.13	<0.001	**
	90-200 vs. 1000-2000			11.10	<0.001	**
	90-200 vs. 500-1000			5.62	<0.001	**
	500-1000 vs. 1000-2000			5.47	<0.001	**

Note: Sources of variance are zooplankton size classes (μm); df = Degree of Freedom; * and ** indicate significant and highly significant P values, respectively; NS = No significant difference

4.3.3 Dominant zooplankton taxa and species

The winter survey zooplankton groupings were numerically dominated by copepods in all size classes (Figure 4.19 A–D). Zooplankton groups that contributed >10 % to the total zooplankton counts were considered representative groups and included the Appendicularia, Chaetognatha and Siphonophora. In addition, copepod nauplii were listed as a separate group to highlight their importance (Figure 4.19 A–D). Groups that contributed <10 % to the total counts were combined to form “Other groups”. Important zooplankton taxonomic groups demonstrated statistical variability between the cluster groupings in some cases ($P < 0.050$). An exception was observed on certain cluster groups that reflected no statistical variability ($P > 0.050$; Tables 4.19–4.22). Representative species that contributed to group abundances are listed in Table 6 (see Appendix), including the groups that constituted “Other Groups”.

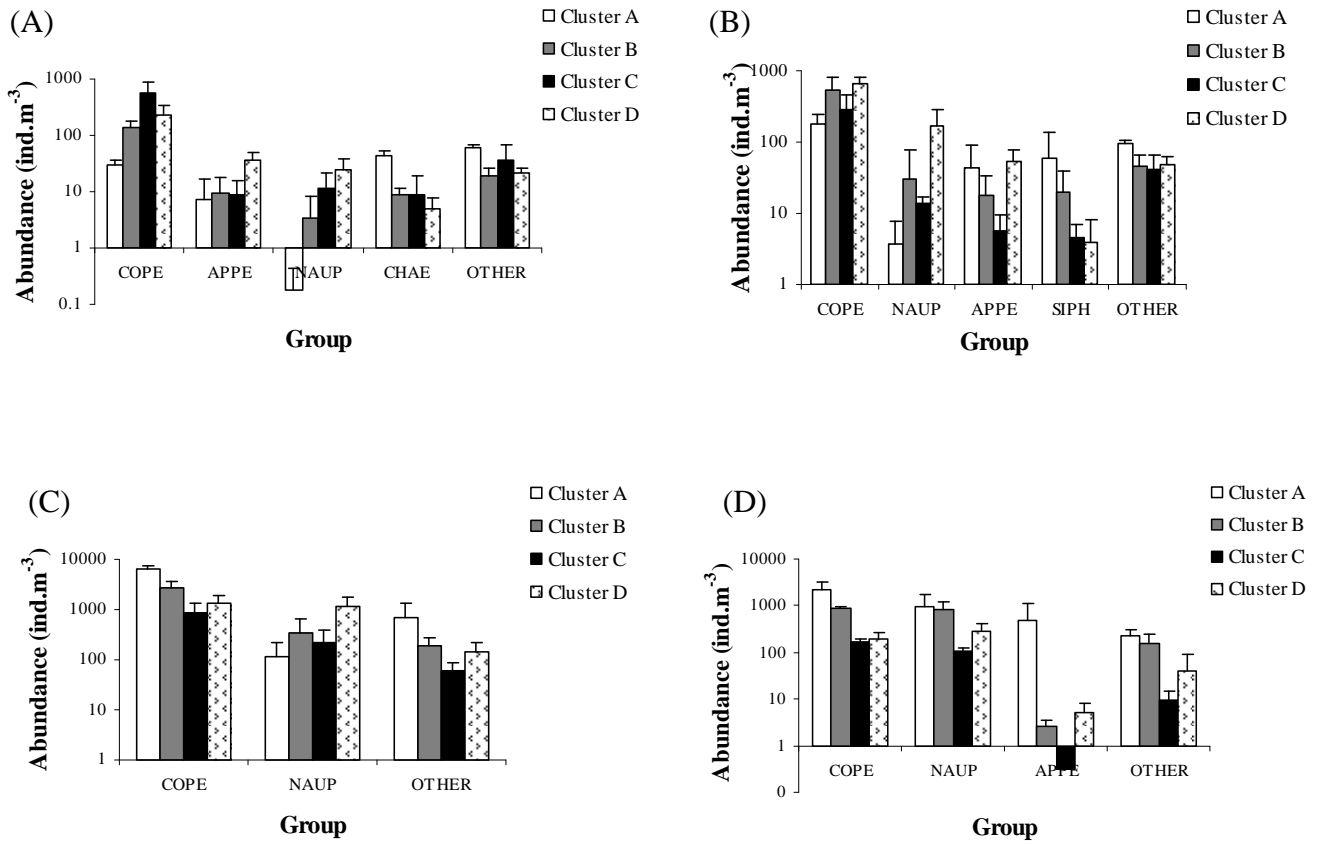


Figure 4.19: Winter dominating groups from (A) 1000–2000 μm; (B) 500–1000 μm; (C) 200–500 μm; and (D) 90–200 μm size classes. COPE = Copepoda; APPE = Appendicularia; CHAE = Chaetognatha; SIPH = Siphonophora; NAUP = Nauplii; OTHER = “Other Groups”. (Note: y-axis is on log scale)

Table 4.19: Results of a series of One Way Analysis of Variance (F) and the non-parametric equivalent, Kruskal–Wallis One Way Analysis of Variance on Ranks (H), statistical tests on the 1000–2000 μm size class dominating zooplankton groups. For tests where the main effects showed significant variability, the post-hoc Tukey Test (q; parametric) or Dunn’s Method (Q; non-parametric) was used to conduct the pairwise multiple comparison procedures. Non-parametric tests were run on data that exhibited no normality/equal variance.

Group	Source of Variance	q	F	H	df	Q	P	Significance
Copepoda	All		73.56		3		<0.001	**
	Clusters							
	C vs. A	20.66					<0.001	**
	C vs. B	10.99					<0.001	**
	C vs. D	9.14					<0.001	**
	D vs. A	14.09					<0.001	**
	D vs. B	3.13					0.125	NS
	B vs. A	10.42					<0.001	**
Appendicularia	All		25.02		3		<0.001	**
	Clusters							
	D vs. A	8.37					<0.001	**
	D vs. C	10.55					<0.001	**
	D vs. B	8.61					<0.001	**
	B vs. A	0.83					0.935	NS
	B vs. C	0.93					0.913	NS
	C vs. A	0.06					1.000	NS
Nauplii	All			50.73	3		<0.001	**
	Clusters							
	D vs. A					6.33	<0.050	*
	D vs. B					4.84	<0.050	*
	D vs. C					2.64	<0.050	*
	C vs. A					4.13	<0.050	*
	C vs. B					2.34	>0.050	NS
	B vs. A					1.96	>0.050	NS
Chaetognatha	All			43.01	3		<0.001	**
	Clusters							
	A vs. D					6.22	<0.050	*
	A vs. C					5.05	<0.050	*
	A vs. B					3.08	<0.050	*
	B vs. D					2.29	<0.050	*

	B vs. C		2.04	>0.050	NS
	C vs. D		1.28	>0.050	NS

Other Groups	All Clusters	10.84	3	<0.001	**
	A vs. B	7.14		<0.001	**
	A vs. D	6.84		<0.001	**
	A vs. C	3.92		0.028	*
	C vs. B	4.08		0.020	*
	C vs. D	3.47		0.067	NS
	D vs. B	1.08		0.869	NS

Note: A = Cluster A; B = Cluster B; C = Cluster C; D = Cluster D; df = Degree of Freedom; * and ** indicate significant and highly significant P values, respectively; NS = No significant difference.

Table 4.20: Results of a series of One Way Analysis of Variance (F) and the non-parametric equivalent, Kruskal-Wallis One Way Analysis of Variance on Ranks (H), statistical tests on the 500–1000 μm size class dominating zooplankton groups. For tests where the main effects showed significant variability, the post-hoc Tukey Test (q; parametric) or Dunn's Method (Q; non-parametric) was used to conduct the pairwise multiple comparison procedures. Non-parametric tests were run on data that exhibited no normality/equal variance.

Group	Source of Variance	q	F	H	df	Q	P	Significance
Copepoda	All Clusters		29.39		3		<0.001	**
	D vs. A	11.42					<0.001	**
	D vs. C	9.37					<0.001	**
	D vs. B	2.21					0.403	NS
	B vs. A	8.70					<0.001	**
	B vs. C	6.05					<0.001	**
	C vs. A	3.93					0.032	**

Nauplii	All Clusters			66.11	3		<0.001	**
	D vs. A					7.12	<0.050	*
	D vs. B					5.49	<0.050	*
	D vs. C					5.29	<0.050	*
	C vs. A					2.86	<0.050	*
	C vs. B					0.65	>0.050	NS
	B vs. A					2.16	>0.050	NS

Appendicularia	All Clusters			53.33	3		<0.001	**
	D vs. C					7.10	<0.050	*
	D vs. B					3.79	<0.050	*
	D vs. A					1.48	>0.050	NS

	A vs. C		3.98	<0.050	*
	A vs. B		1.65	>0.050	NS
	B vs. C		2.55	>0.050	NS
Siphonophora	All Clusters	36.09	3	<0.001	**
	A vs. D		4.45	<0.050	*
	A vs. C		3.32	<0.050	*
	A vs. B		0.28	>0.050	NS
	B vs. D		4.77	<0.050	*
	B vs. C		3.45	<0.050	*
	C vs. D		1.29	>0.050	NS
Other Groups	All Clusters	6.98	3	<0.001	**
	A vs. C	6.09		<0.001	**
	A vs. B	5.38		<0.001	**
	A vs. D	5.52		<0.001	**
	D vs. C	0.89		0.921	NS
	D vs. B	0.40		0.992	NS
	B vs. C	0.39		0.992	NS

Note: A = Cluster A; B = Cluster B; C = Cluster C; D = Cluster D; df = Degree of Freedom; * and ** indicate significant and highly significant P values, respectively; NS = No significant difference.

Table 4.21: Results of a series of non-parametric Kruskal–Wallis One Way Analysis of Variance on Ranks (H) statistical tests on the 200–500 μm size class dominating zooplankton groups. For tests where the main effects showed significant variability, the post-hoc Dunn’s Method (Q) was used to conduct the pairwise multiple comparison procedures. Non-parametric tests were run on data that exhibited no normality/equal variance.

Group	Source of Variance	H	df	Q	P	Significance
Copepoda	All Clusters	52.19	3		<0.001	**
	A vs. C			6.21	<0.050	*
	A vs. D			4.57	<0.050	*
	A vs. B			1.41	>0.050	NS
	B vs. C			5.39	<0.050	*
	B vs. D			3.50	<0.050	*
	D vs. C			2.32	>0.050	NS
Nauplii	All Clusters	61.21	3		<0.001	**
	D vs. A			6.40	<0.050	*
	D vs. C			6.30	<0.050	*
	D vs. B			4.51	<0.050	*

	B vs. A			2.28	>0.050	NS
	B vs. C			1.16	>0.050	NS
	C vs. A			1.40	>0.050	NS
Other Groups	All Clusters	31.56	3		<0.001	**
	A vs. C				<0.050	*
	A vs. D				>0.050	NS
	A vs. B				>0.050	NS
	B vs. C				<0.050	*
	B vs. D				>0.050	NS
	D vs. C				<0.050	*

Note: A = Cluster A; B = Cluster B; C = Cluster C; D = Cluster D; df = Degree of Freedom; * and ** indicate significant and highly significant P values, respectively; NS = No significant difference.

Table 4.22: Results of a series of One Way Analysis of Variance (F) and the non-parametric equivalent, Kruskal-Wallis One Way Analysis of Variance on Ranks (H), statistical tests on the 90–200 μm size class dominating zooplankton groups. For tests where the main effects showed significant variability, the post-hoc Tukey Test (q; parametric) or Dunn’s Method (Q; non-parametric) was used to conduct the pairwise multiple comparison procedures. Non-parametric tests were run on data that exhibited no normality/equal variance.

Group	Source of Variance	F	H	df	q	Q	P	Significance
Copepoda	All Clusters	98.48		3			<0.001	**
	A vs. C				20.03		<0.001	**
	A vs. D				18.80		<0.001	**
	A vs. B				6.302		<0.001	**
	B vs. C				15.26		<0.001	**
	B vs. D				13.76		<0.001	**
	D vs. C				2.33		0.354	NS
Nauplii	All Clusters		67.53	3			<0.001	**
	A vs. C					6.30	<0.050	*
	A vs. D					3.76	<0.050	*
	A vs. B					0.09	>0.050	NS
	B vs. C					7.09	<0.050	*
	B vs. D					4.23	<0.050	*
	D vs. C					3.46	<0.050	*
Appendicularia	All Clusters		39.03	3			<0.001	**
	A vs. C					5.21	<0.050	*
	A vs. B					3.98	<0.050	*
	A vs. D					3.07	<0.050	*

	D vs. C			2.92	<0.050	*
	D vs. B			1.48	>0.050	NS
	B vs. C			1.13	>0.050	NS
Other Groups	All Clusters	62.16	3		<0.001	**
	A vs. C			6.93	<0.050	*
	A vs. D			4.19	<0.050	*
	A vs. B			1.55	>0.050	NS
	B vs. C			6.01	<0.050	*
	B vs. D			2.86	<0.050	*
	D vs. C			3.73	<0.050	*

Note: A = Cluster A; B = Cluster B; C = Cluster C; D = Cluster D; df = Degree of Freedom; * and ** indicate significant and highly significant P values, respectively; NS = No significant difference.

4.3.4 Species richness and diversity

The species richness values in the 1000–2000 μm size class in Clusters B (mean = 6.1; SD = 1.59) and D (mean = 5.75; SD = 1.64) were significantly higher than those recorded in Clusters A (mean = 4.63; SD = 0.96) and C (mean = 3.47; SD = 0.80) ($P < 0.001$ in both cases, Table 4.23, Figure 4.20a). Similarly, species diversity varied with higher mean values of 3.87 (SD = 6.95) in Cluster D and significantly lower mean values of 3.15 (SD = 0.87) and 3.12 (SD = 0.36) in Clusters A and C, respectively ($P < 0.050$ in both cases, Table 4.24, Figure 4.20b).

The 500–1000 μm size class exhibited no significant variability in species richness between the clusters ($P > 0.050$ in all cases; Table 4.23). The highest species richness value was recorded in Cluster A (mean = 3.36; SD = 1.39) (Figure 4.20a). Similarly, species diversity exhibited no significant variability between clusters ($P > 0.050$ in all cases; Table 4.24). The average species diversity of this size class was 3.57 (SD = 0.47) for the whole of Algoa Bay (Figure 4.20b).

Species richness in the 200–500 μm size class was highly variable between the four clusters ($P < 0.050$ in all cases; Table 4.23). The highest values were recorded in Cluster C (Mean = 3.14; SD = 0.68) and the lowest in Cluster A (Mean = 1.37; SD = 0.39) (Figure 4.20a). Similarly, species diversity exhibited higher values (Mean = 2.83; SD = 0.33) in

Cluster C and significantly lower values in Clusters A and B (Mean = 1.99; SD = 0.59 and Mean = 2.296; SD = 0.50, respectively) ($P < 0.001$ in both cases; Table 4.24; Figure 4.20b).

In the 90–200 μm size class, species richness reflected no significant variability between the clusters ($P > 0.050$; Table 4.23). However, Cluster C had higher average values of 1.13 (SD = 0.68) for species richness, while the lowest values of 0.74 (SD = 2.11) were observed in Cluster A (Figure 4.20a). Species diversity, in contrast, was more variable, with highest average values in Cluster A (mean = 2.11; SD = 0.23) and significantly lower values in Clusters B, C and D ($P < 0.001$ in all cases; Table 4.24, Figure 4.20b).

Statistically, the 90–200 μm size class contributed the least to the species richness in all clusters ($P < 0.001$ in all cases; Table 4.25; Figure 4.20a). Highest species richness values were recorded in the 1000–2000 and 500–1000 μm size classes in Cluster A. In Clusters B and D, the 1000–2000 μm size class had highest species richness values. In Cluster C, all groups > 200 μm exhibited higher species richness (Table 4.25; Figure 4.20a). For species diversity, the 90–200 and 200–500 μm size classes exhibited significantly lower values than the 500–1000 and 1000–2000 μm size classes in Clusters A and B. In Cluster C, the species diversity was greatest in the 500–1000 μm and lowest in the 90–200 μm size class (Table 4.26; Figure 4.20b). In Cluster D, highest species diversity was observed in the 1000–2000 μm size class, with the lowest values recorded in the 90–200 μm size class (Table 4.26; Figure 4.20b).

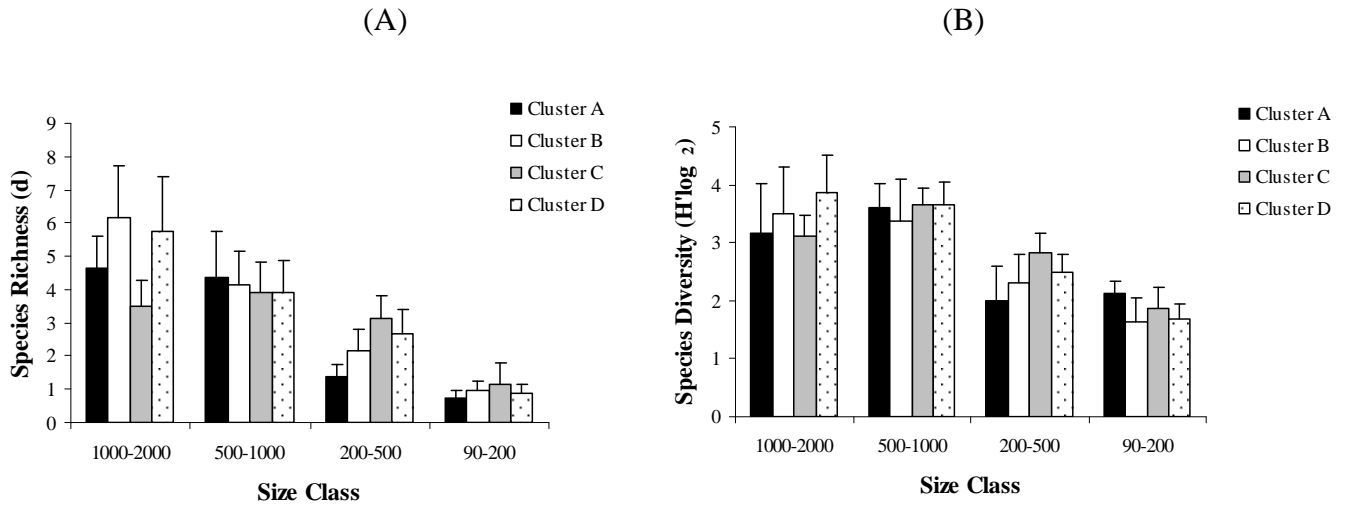


Figure 4.20: (A) Margalef's species richness (d); (B) Shannon species diversity ($H'log_2$) indices for zooplankton abundance data in Algoa Bay, during winter 2008.

Table 4.23: Results of a series of One Way Analysis of Variance (F) and the non-parametric equivalent, Kruskal-Wallis One way Analysis of Variance on Ranks (H), statistical tests on zooplankton species richness data by size class. For tests where the main effects showed significant variability, the post-hoc Tukey test (q; parametric) was used to conduct the pairwise multiple comparison procedures. Non-parametric tests were run on data that exhibited no normality/equal variance.

Size Class (μm)	Source of Variance	q	F	H	df	P	Significance
90–200	A, B, C, D			7.21	3	0.065	NS
200–500	All clusters		32.85		3	<0.001	**
	C vs. A	13.24				<0.001	**
	C vs. B	8.34				<0.001	**
	C vs. D	4.54				0.007	**
	D vs. A	10.12				<0.001	**
	D vs. B	4.55				0.007	**
	B vs. A	5.72				<0.001	**
500–1000	A, B, C, D		1.08		3	0.359	NS
1000–2000	All Clusters		26.57		3	<0.001	**
	B vs. C	10.88				<0.001	**
	B vs. A	5.06				0.003	*
	B vs. D	1.66				0.641	NS

D vs. C	10.62	<0.001	**
D vs. A	4.09	0.023	*
A vs. C	4.14	0.021	*

Note: A = Cluster A; B = Cluster B; C = Cluster C; D = Cluster D; df = Degree of Freedom; * and ** indicate significant and highly significant P values, respectively; NS = No significant difference.

Table 4.24: Results of a series of One Way Analysis of Variance (F) and the non-parametric equivalent, Kruskal-Wallis One way Analysis of Variance on Ranks (H), statistical tests on zooplankton species diversity data by size class. For tests where the main effects showed significant variability, the post-hoc Tukey test (q; parametric) or Dunn's Method (Q; non-parametric) was used to conduct the pairwise multiple comparison procedures. Non-parametric tests were run on data that exhibited no normality/equal variance.

Size Class (µm)	Source of Variance	q	df	Q	F	H	P	Significance
90–200	All Clusters		3		10.05		<0.001	**
	A vs. B	6.86					<0.001	**
	A vs. D	6.54					<0.001	**
	A vs. C	3.66					0.045	*
	C vs. B	4.02					0.023	*
	C vs. D	3.40					0.076	NS
	D vs. B	1.08					0.869	NS
200–500	All Clusters		3		18.96		<0.001	**
	C vs. A	9.96					<0.001	**
	C vs. B	7.27					<0.001	**
	C vs. D	5.36					<0.001	**
	D vs. A	6.01					<0.001	**
	D vs. B	2.68					0.229	NS
	B vs. A	3.36					0.081	NS
500–1000	A, B, C, D		3			6.41	0.093	NS
1000–2000	All Clusters		3			59.72	<0.001	**
	D vs. C			7.34			<0.050	*
	D vs. A			4.86			<0.050	*
	D vs. B			3.03			<0.050	*
	B vs. C			3.55			<0.050	*
	B vs. A			1.99			>0.050	NS
	A vs. C			1.02			>0.050	NS

Note: A = Cluster A; B = Cluster B; C = Cluster C; D = Cluster D; df = Degree of Freedom; * and ** indicate significant and highly significant P values, respectively; NS = No significant difference.

Table 4.25: Results of a series of One Way Analysis of Variance (F) statistical tests on zooplankton species richness data by cluster. For tests where the main effects showed significant variability, the post-hoc Tukey test (q; parametric) was used to conduct the pairwise multiple comparison procedures. Note: data for Clusters A, B and D were log transformed, while Cluster C data were square root transformed prior to testing.

Cluster	Source of Variance	q	F	DF	P	Significance
Cluster A	All clusters		170.60	3	<0.001	**
	1000–2000 vs. 90–200	26.60			<0.001	**
	1000–2000 vs. 200–500	17.69			<0.001	**
	1000–2000 vs. 500–1000	1.25			0.812	NS
	500–1000 vs. 90–200	25.72			<0.001	**
	500–1000 vs. 200–500	16.68			<0.001	**
	200–500 vs. 90–200	8.62			<0.001	**
Cluster B	All clusters		241.90	3	<0.001	**
	1000–2000 vs. 90–200	35.53			<0.001	**
	1000–2000 vs. 200–500	19.99			<0.001	**
	1000–2000 vs. 500–1000	7.42			<0.001	**
	500–1000 vs. 90–200	28.10			<0.001	**
	500–1000 vs. 200–500	12.49			<0.001	**
	200–500 vs. 90–200	15.86			<0.001	**
Cluster C	All clusters		115.23	3	<0.001	**
	500–1000 vs. 90–200	23.68			<0.001	**
	500–1000 vs. 200–500	5.01			0.002	**
	500–1000 vs. 1000–2000	2.81			0.192	NS
	1000–2000 vs. 90–200	20.87			<0.001	**
	1000–2000 vs. 200–500	2.20			0.402	NS
	200–500 vs. 90–200	18.66			<0.001	**
Cluster D	All clusters		378.70	3	<0.001	**
	1000–2000 vs. 90–200	44.99			<0.001	**
	1000–2000 vs. 200–500	18.37			<0.001	**
	1000–2000 vs. 500–1000	9.18			<0.001	**
	500–1000 vs. 90–200	36.01			<0.001	**
	500–1000 vs. 200–500	9.24			<0.001	**
	200–500 vs. 90–200	26.77			<0.001	**

Note: Sources of variance are zooplankton size classes (μm); df = Degree of Freedom; * and ** indicate significant and highly significant P values, respectively; NS = No significant difference.

Table 4.26: Results of a series of One Way Analysis of Variance (F) and the non-parametric equivalent, Kruskal-Wallis One way Analysis of Variance on Ranks (H), statistical tests on zooplankton species diversity data by cluster. For tests where the main effects showed significant variability, the post-hoc Tukey test (q; parametric) or Dunn's Method (Q; non-parametric) was used to conduct the pairwise multiple comparison procedures. Non-parametric tests were run on data that exhibited no normality/equal variance. Note: Cluster D data were square root transformed while the other clusters' data required no transformation prior to testing.

Cluster	Source of Variance	q	Q	H	F	df	P	Significance
Cluster A	All clusters			49.16		3	<0.001	**
	500–1000 vs. 90–200		5.53				<0.050	*
	500–1000 vs. 200–500		5.47				<0.050	*
	500–1000 vs. 1000–2000		1.25				>0.050	NS
	1000–2000 vs. 90–200		4.28				<0.050	*
	1000–2000 vs. 200–500		4.21				<0.050	*
	200–500 vs. 90–200		0.06				>0.050	NS
Cluster B	All clusters			81.48		3	<0.001	**
	1000–2000 vs. 90–200		7.61				<0.050	*
	1000–2000 vs. 200–500		5.40				<0.050	*
	1000–2000 vs. 500–1000		0.66				>0.050	NS
	500–1000 vs. 90–200		6.94				<0.050	*
	500–1000 vs. 200–500		4.73				<0.050	*
	200–500 vs. 90–200		2.27				>0.050	NS
Cluster C	All clusters				178.84	3	<0.001	**
	500–1000 vs. 90–200	31.87					<0.001	**
	500–1000 vs. 200–500	14.58					<0.001	**
	500–1000 vs. 1000–2000	9.45					<0.001	**
	1000–2000 vs. 90–200	22.42					<0.001	**
	1000–2000 vs. 200–500	5.13					0.002	*
	200–500 vs. 90–200	17.29					<0.001	**
Cluster D	All clusters				511.77	3	<0.001	**
	1000–2000 vs. 90–200	49.06					<0.001	**
	1000–2000 vs. 200–500	29.35					<0.001	**
	1000–2000 vs. 500–1000	5.85					<0.001	**
	500–1000 vs. 90–200	43.45					<0.001	**
	500–1000 vs. 200–500	23.64					<0.001	**
	200–500 vs. 90–200	19.81					<0.001	**

Note: Sources of variance are zooplankton size classes (μm); df = Degree of Freedom; * and ** indicate significant and highly significant P values, respectively; NS = No significant difference

4.3.5 Zooplankton biomass

During winter 2008, the total zooplankton biomass was variable across Algoa Bay ranging between 5.83 mg.m^{-3} (SD = 1.43) and 33.84 mg.m^{-3} (SD = 8.44). Total average zooplankton biomass was highest in Clusters A and C, with values of 42.49 mg.m^{-3} (SD = 7.38) and 34.49 mg.m^{-3} (SD = 21.21), respectively. Significantly lower total zooplankton biomass values were recorded in Cluster D, with an average of 24.16 mg.m^{-3} (SD = 2.65) ($P < 0.050$; Table 4.27; Figure 4.21).

In Clusters A and B, the 90–200 and 200–500 μm size classes significantly dominated total biomass (Table 4.28). In contrast, in Cluster C, the total zooplankton biomass was dominated by the 1000–2000 μm size class, while in Cluster D the 200–500, 500–1000 and 1000–2000 μm size classes accounted for the largest portion of total zooplankton biomass (Table 4.28; Figure 4.21).

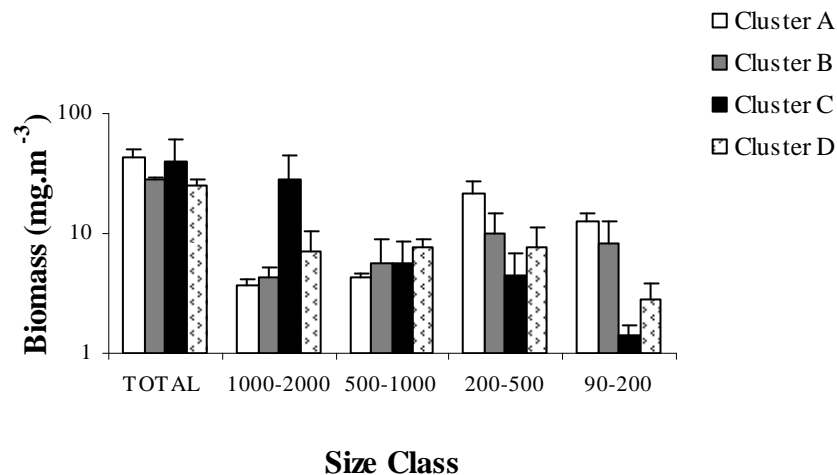


Figure 4.21: Winter total and size fractionated zooplankton biomass (mg.m^{-3}) in each cluster. (Note: y-axis is on log scale)

Table 4.27: Results of a series of One Way Analysis of Variance (F) and the non-parametric equivalent, Kruskal-Wallis One Way Analysis of Variance on Ranks (H), statistical tests on zooplankton biomass by size class data. For tests where the main effects showed significant variability, the post-hoc Tukey Test (q; parametric) or Dunn's Method (Q; non-parametric) was used to conduct the pairwise multiple comparison procedures. Biomass data were log transformed prior to testing with the exception of the 90–200 μm size class, which was square root transformed.

Size Class (μm)	Source of Variance	F	H	df	Q	q	P	Significance
Total	All Clusters	6.14		3			<0.001	**
	A vs. D					4.97	0.004	*
	A vs. B					3.27	0.101	NS
	A vs. C					1.12	0.855	NS
	C vs. D					4.83	0.005	*
	C vs. B					2.67	0.237	NS
	B vs. D					1.61	0.666	NS
1000–2000	All Clusters	70.33		3			<0.001	**
	C vs. A				6.63		<0.050	*
	C vs. B				6.92		<0.050	*
	C vs. D				5.92		<0.050	*
	D vs. A				2.16		>0.050	NS
	D vs. B				1.82		>0.050	NS
	B vs. A				0.53		>0.050	NS
500–1000	All Clusters	16.55		3			<0.001	**
	D vs. A				3.63		<0.050	*
	D vs. C				2.79		<0.050	*
	D vs. B				2.42		>0.050	NS
	B vs. A				1.40		>0.050	NS
	B vs. C				0.10		>0.050	NS
	C vs. A				1.39		>0.050	NS
200–500	All Clusters	39.15		3			<0.001	**
	A vs. C				6.02		<0.050	*
	A vs. D				3.73		<0.050	*
	A vs. B				2.58		>0.050	NS
	B vs. C				3.75		<0.050	*
	B vs. D				1.05		>0.050	NS
	D vs. C				3.13		<0.050	*

Size Class (μm)	Source of Variance	F	H	df	Q	q	P	Significance
90–200	All Clusters	62.13		3			<0.001	**
	A vs. C				6.66		<0.050	*
	A vs. D				4.62		<0.050	*
	A vs. B				1.28		>0.050	NS
	B vs. C				6.06		<0.050	*
	B vs. D				3.72		<0.050	*
	D vs. C				2.85		<0.050	*

Note: A = Cluster A; B = Cluster B; C = Cluster C; D = Cluster D; df = Degree of Freedom; * and ** indicate significant and highly significant P values, respectively; NS = No significant difference.

Table 4.28: Results of a series of One Way Analysis of Variance (F) and the non-parametric equivalent, Kruskal-Wallis One Way Analysis of Variance on Ranks (H), statistical tests on zooplankton biomass by cluster data. For tests where the main effects showed significant variability, the post-hoc Tukey test (q; parametric) or Dunn’s Method (Q; non-parametric) was used to conduct the pairwise multiple comparison procedures. Non-parametric tests were run on data that failed normality/equal variance even when transformed prior to testing, with the exception of Cluster B data, which passed normality and equal variance after Square root transformation.

Cluster	Source of Variance	F	H	df	q	Q	P	Significance
Cluster A	All size classes		36.20	3			<0.001	**
	200-500 vs. 1000-2000				5.00		<0.050	*
	200-500 vs. 500-1000				4.56		<0.050	*
	200-500 vs. 90-200				1.30		>0.050	NS
	90-200 vs. 1000-2000				3.70		<0.050	*
	90-200 vs. 500-1000				3.26		<0.050	*
	500-1000 vs. 1000-2000				0.44		>0.050	NS
Cluster B	All size classes	6.22		3			<0.001	**
	200-500 vs. 1000-2000				5.55		0.001	*
	200-500 vs. 500-1000				4.08		0.024	*
	200-500 vs. 90-200				1.53		0.7	NS
	90-200 vs. 1000-2000				4.01		0.028	*
	90-200 vs. 500-1000				2.55		0.277	NS
	500-1000 vs. 1000-2000				1.46		0.729	NS
Cluster C	All size classes		104.47	3			<0.001	**
	1000-2000 vs. 90-200					10.04	<0.050	*
	1000-2000 vs. 200-500					6.38	<0.050	*
	1000-2000 vs. 500-1000					4.58	<0.050	*

Cluster	Source of Variance	F	H	df	q	Q	P	Significance
	500-1000 vs. 90-200					5.45	<0.050	*
	500-1000 vs. 200-500					1.79	>0.050	NS
	200-500 vs. 90-200					3.65	<0.050	*
Cluster D	All size classes	49.88		3			<0.001	**
	500-1000 vs. 90-200					6.34	<0.050	*
	500-1000 vs. 1000-2000					1.54	>0.050	NS
	500-1000 vs. 200-500					0.61	>0.050	NS
	200-500 vs. 90-200					5.72	<0.050	*
	200-500 vs. 1000-2000					0.92	>0.050	NS
	1000-2000 vs. 90-200					4.80	<0.050	*

Note: Sources of variance are zooplankton size classes (μm); df = Degree of Freedom; * and ** indicate significant and highly significant P values, respectively; NS = No significant difference.

4.3.6 Indicator Species Assessment (ISA)

ISA identified a number of species/taxa within each cluster as indicator species/taxa, in other words, species with IndVals $\geq 50\%$ (Table 4.29). For Cluster A, the top five species/taxa with highest IndVals included Isopod spp.; Platyhelminthes larvae; Appendicularia spp.; Ascidian larvae and the copepod, *Centropages chierchiae* (Table 4.29). Only three taxa/species were identified as indicator species/taxa in Cluster B. These were the copepods *Labidocera minuta* and *Mecynocera clausii*, and chaetognath spp. In Cluster C, Euphausiid larvae and juveniles were important indicator taxa; as were the copepods, *Miracia minor* and *Calocalanus minutus*; and the chaetognath, *Serrosagitta* spp. In Cluster D, the top five taxa that were identified as indicator species/taxa include a thaliacean, *Doliolum nationalis*; Actinula larvae; and the copepods, *Pseudodiaptomus serricaudata*, *Subeucalanus subtenius* and *Temora discaudata* (Table 4.29).

Table 4.29: Indicator species/taxa with IndVals ≥ 50 % from clusters identified during winter 2008.

Cluster A		Cluster B		Cluster C		Cluster D	
Species/Taxa	IndVal	Species/Taxa	IndVal	Species/Taxa	IndVal	Species/Taxa	IndVal
Isopod spp.	100.00	<i>Labidocera minuta</i>	93.44	Euphausiid juvenile	76.83	<i>Doliolum nationalis</i>	85.78
Platyhemintes larvae	100.00	<i>Mecynocera clausii</i>	71.72	Euphausiid larvae	76.03	Actinula larvae	72.91
Appendicularia spp.	98.40	<i>Chaetognatha</i> spp.	54.69	<i>Calocalanus minutus</i>	75.16	<i>Pseudodiaptomus serricaudata</i>	72.82
Ascidian larvae	88.13			<i>Miracia minor</i>	75.00	<i>Subeucalanus subtenius</i>	68.41
<i>Centropages chierchiae</i>	86.69			<i>Serrosagitta</i> spp.	75.00	<i>Temora discaudata</i>	68.40
<i>Evadne</i> spp.	85.36			<i>Calanoides macrocarinatus</i>	73.66	<i>Aglaura hemistoma</i>	67.89
<i>Obelia</i> spp.	83.09			<i>Mesocalanus tenuicornis</i>	69.34	<i>Centropages orsinii</i>	67.58
<i>Oithona similis</i>	82.07			<i>Euphausea aurata</i>	66.13	<i>Candacia bradyi</i>	62.65
<i>Sagitta setosa</i>	80.49			<i>Lovenella</i> spp.	65.03	<i>Euchaeta indicus</i>	60.00
<i>Chelophyes appendiculata</i>	76.87			<i>Corycaeus ovalis</i>	61.72	<i>Corycaeus typicus</i>	57.19
Fish egg	75.66			<i>Corycaeus longistylis</i>	53.88	<i>Acartia tonsa</i>	55.99
<i>Penilia avirostris</i>	70.67			<i>Pterosagitta</i> spp.	50.00	<i>Subeucalanus crassus</i>	53.70
<i>Acrocalanus monachus</i>	70.46					<i>Paracalanus aculeatus</i>	52.03
<i>Chelophyes contorta</i>	70.44					<i>Oceania armata</i>	50.46
<i>Oikopleura</i> spp.	69.72						
<i>Pleurobranchia</i> spp.	67.70						
Decapod larvae	65.56						
<i>Lensia</i> spp.	63.40						
<i>Centropages typicus</i>	62.57						
<i>Folia</i> spp.	61.62						
<i>Oithona nana</i>	55.52						
<i>Oithona simplex</i>	53.08						
<i>Spiophanes</i> spp.	50.19						
<i>Acartia africana</i>	50.00						
Branchiostoma larvae	50.00						
<i>Clytemnestra scutellata</i>	50.00						
<i>Phiallela quadrata</i>	50.00						
Siphonophora spp.	50.00						
<i>Zanclaea</i> spp.	50.00						

4.4 ENVIRONMENTAL DRIVERS OF ZOOPLANKTON COMMUNITY STRUCTURE

Winter sample ordination analysis showed an exact replication of the four clusters defined by cluster analysis. The CCA revealed a number of environmental variables that were responsible for the patterns observed in the zooplankton community structure. These are variables with correlation coefficient values >0.65 (Table 4.30; Figure 4.22). These included surface turbidity, nanophytoplankton and picophytoplankton biomass and bottom water dissolved oxygen, nitrate, nitrite and ammonia concentrations along the first ordination axis; and surface temperature and integrated picophytoplankton biomass along the second ordination axis (Table 4.30). The majority of environmental variables showed significant variability between the clusters (Table 4.31). Bottom water nitrate and surface water ammonia concentrations, however, exhibited no significant differences between the clusters ($P>0.050$; Table 4.31). A clear pattern was observed in the species ordination plot of the CCA (Figure 4.23) where those taxa with IndVals $\geq 50\%$ were plotted. The taxa separated out well according to the cluster they were associated with, with only minor overlapping occurring between clusters (Figure 4.23).

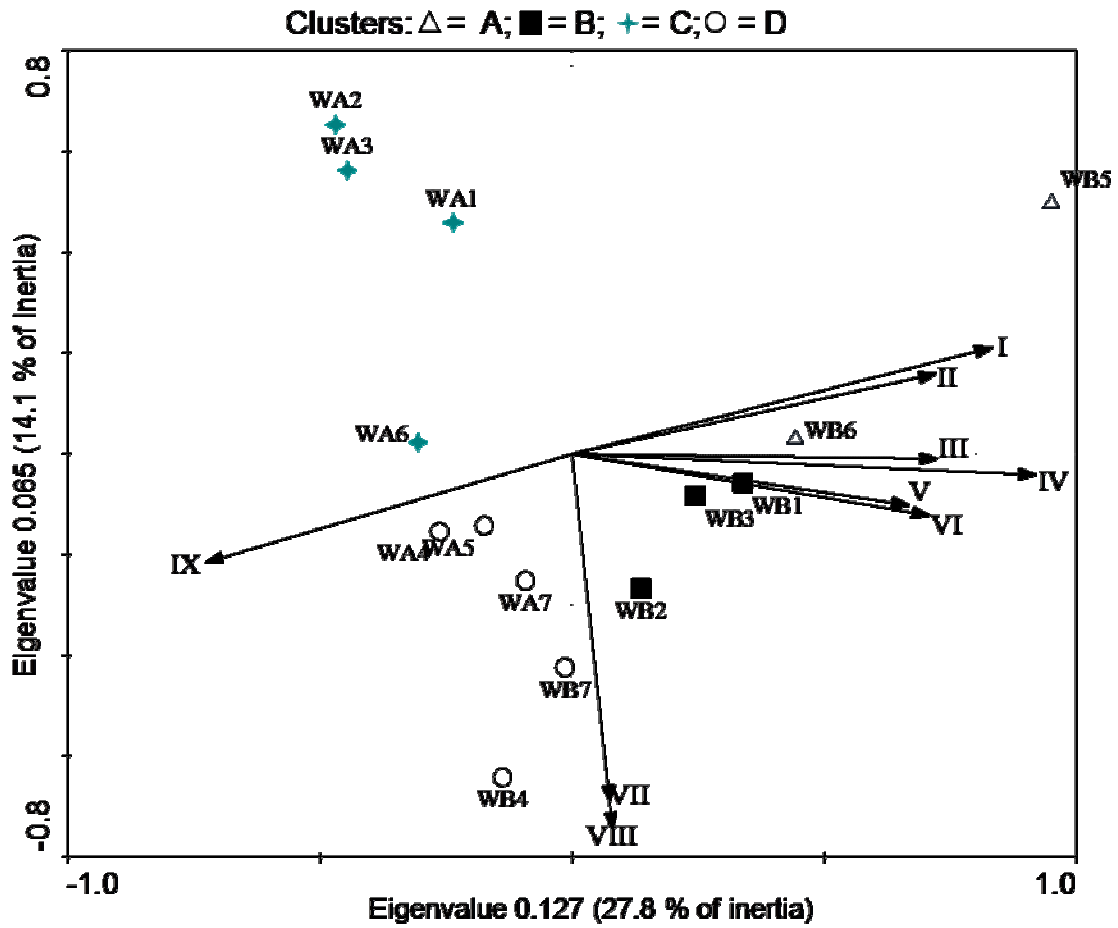


Figure 4.22: Ordination plot of samples and selected environmental variables from results of the winter CCA. Samples are presented as symbols to the cluster analysis sample groupings. The direction and length of the arrows indicate the increase in values of the particular environmental variable. Note: I = Bottom Ammonia; II = Surface Turbidity; III = Bottom Nitrite; IV = Surface Nanophytoplankton; V = Surface Picophytoplankton; VI = Bottom Dissolved Oxygen; VII = Integrated Picophytoplankton; VIII = Surface Temperature; and IX = Bottom Nitrate.

Table 4.30: Winter correlation coefficients between the environmental variables and the species-derived sample scores on Axes 1 and 2 of the Canonical Correspondence Analysis. Values marked in bold had strong correlations (>0.65) and therefore indicate the environmental variables responsible for co-variance with observed zooplankton patterns.

Environmental Variable	Axis 1	Axis2
Surface Temperature	0.07	-0.74
Surface Salinity	0.20	-0.57
Surface Dissolved Oxygen	0.38	-0.43
Surface Turbidity	0.72	0.15
Surface Chlorophyll-a	0.51	-0.07
Surface Microphytoplankton	0.50	-0.07
Surface Nanophytoplankton	0.91	-0.04
Surface Picophytoplankton	0.66	-0.10
Integrated Chlorophyll-a	0.12	-0.52
Integrated Microphytoplankton	0.11	-0.49
Integrated Nanophytoplankton	0.40	-0.61
Integrated Picophytoplankton	0.07	-0.69
Surface Nitrate	-0.34	0.43
Surface Nitrite	0.48	-0.33
Surface Ammonia	0.58	0.08
Surface Phosphate	0.42	0.26
Surface Silicate	-0.05	-0.08
Surface Seston	0.54	0.03
Bottom Temperature	0.63	0.12
Bottom Salinity	0.54	-0.29
Bottom Dissolved Oxygen	0.70	-0.12
Bottom Turbidity	0.62	0.19
Bottom Nitrate	-0.72	-0.21
Bottom Nitrite	0.72	-0.00
Bottom Ammonia	0.83	0.21
Bottom Phosphate	-0.04	0.36
Bottom Silicate	-0.14	-0.33
Bottom Seston	0.47	-0.17

Table 4.31: Winter cluster average values (with standard deviation, SD) of important environmental variables identified with the Canonical Correspondence Analysis. One Way Analysis of Variance (F) or the non-parametric equivalent, Kruskal–Wallis One Way Analysis of Variance on Ranks (H), tests were conducted to identify any significant variability in important environmental variables between the clusters. Values marked in bold represent those that are significantly higher. Note: Environmental variables required no transformation prior to testing.

Variable	Cluster A		Cluster B		Cluster C		Cluster D		F	H	df	P	Significance
	Average	SD	Average	SD	Average	SD	Average	SD					
Surface Temperature	15.552	0.19	16.43	0.07	15.61	0.09	16.25	0.26	--	30.80	3	<0.001	**
Surface Turbidity	4.45	0.71	3.54	0.44	2.83	0.06	2.76	0.05	--	32.61	3	<0.001	**
Surface Nanophytoplankton	0.02	0.01	0.01	0.008	0.002	0.003	0.009	0.004	--	26.16	3	<0.001	**
Surface Picophytoplankton	0.02	0.00	0.01	0.004	0.006	0.003	0.01	0.008	10.77	--	3	<0.001	**
Integrated Picophytoplankton	0.19	0.08	0.24	0.18	0.13	0.10	0.33	0.10	6.13	--	3	0.002	*
Bottom Dissolved Oxygen	7.98	0.44	7.59	0.28	7.04	0.29	7.50	0.55	7.13	--	3	<0.001	**
Bottom Ammonia	2.38	0.63	1.65	0.35	1.29	0.23	1.38	0.25	5.69	--	3	0.015	*
Bottom Nitrate	6.35	4.13	8.39	1.86	11.01	1.06	10.31	2.16	2.58	--	3	0.111	NS
Bottom Nitrite	0.70	0.11	0.71	0.07	0.42	0.16	0.37	0.11	6.61	--	3	0.01	*

Note: * and ** indicate significant and highly significant P values, respectively; NS = No significant difference; df = degrees of freedom; -- = not tested

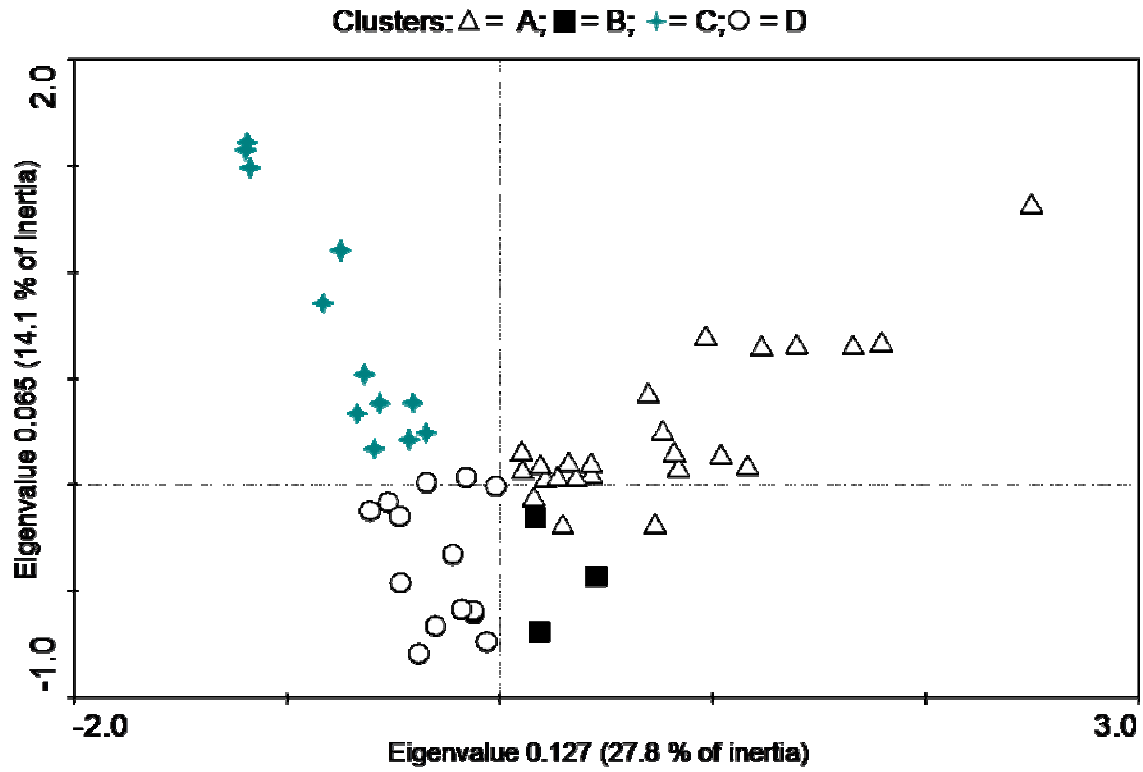


Figure 4.23: Ordination plot of species from results of the winter CCA. Only those species with indicator values $\geq 50\%$ are presented. The symbols represent the indicator species from each of the clusters.

CHAPTER 5: RESULTS – SEASONALITY

5.1 SEASONAL PATTERNS IN PHYSICAL-CHEMICAL VARIABLES

Seven of eleven measured physical-chemical variables reflected no significant seasonal variability in Algoa Bay ($P > 0.050$ in all cases; Table 5.1). These included temperature, salinity, and dissolved oxygen, nitrate, nitrite, phosphate and silicate concentrations. Relatively higher values of seawater temperature and nitrite and phosphate concentrations were recorded during the summer survey. For the remainder of the variables, however, elevated values were recorded during winter (Figure 5.1). Variables that exhibited significant seasonal variability included water column stability, turbidity, and seston and ammonia concentrations ($P < 0.050$ in all cases; Table 5.1). Highest concentrations of seston and ammonia as well as high water column stability values were recorded during the summer survey (Figure 5.1). Turbidity, on the other hand, was highest in winter.

Table 5.1: Results of a series of a One Way Analysis of Variance (F) and non-parametric Kruskal-Wallis One Way ANOVA on Ranks (H) statistical tests. For tests where main effects showed significant variability, a post-hoc Tukey Test (q; parametric) or Dunn's Method (Q; non-parametric) was used to conduct pairwise multiple comparison procedures.

Variable	H	Q	df	P	F	q	Significance
Environmental Variables							
Temperature	3.16	--	1	0.075	--	--	NS
Salinity	0.13	--	1	<0.001	--	--	**
Stability	58.06	7.57	1	<0.001	--	--	**
Dissolved oxygen	0.51	--	1	0.475	--	--	NS
Turbidity	22.11	4.67	1	<0.001	--	--	**
Seston	81.08	9.00	1	<0.001	--	--	**
Nitrate	3.04	--	1	0.081	--	--	NS
Nitrite	0.21	--	1	0.646	--	--	NS
Ammonia	4.69	2.16	1	0.03	--	--	*
Phosphate	0.94	--	1	0.33	--	--	NS
Silicate	1.64	--	1	0.199	--	--	NS
Chlorophyll-a	41.33	6.42	1	<0.001	--	--	**
Integrated chlorophyll-a	45.43	6.74	1	<0.001	--	--	**
Zooplankton							
Abundance	98.39	9.82	1	<0.001	--	--	**
Biomass	106.38	10.21	1	<0.001	--	--	**
Species Richness	77.22	8.78	1	<0.001	--	--	**
Species Diversity	--	--	1	<0.001	82.59	12.85	**

Note: * and ** indicate significant and highly significant P values, respectively, -- = not tested, df = degrees of freedom.

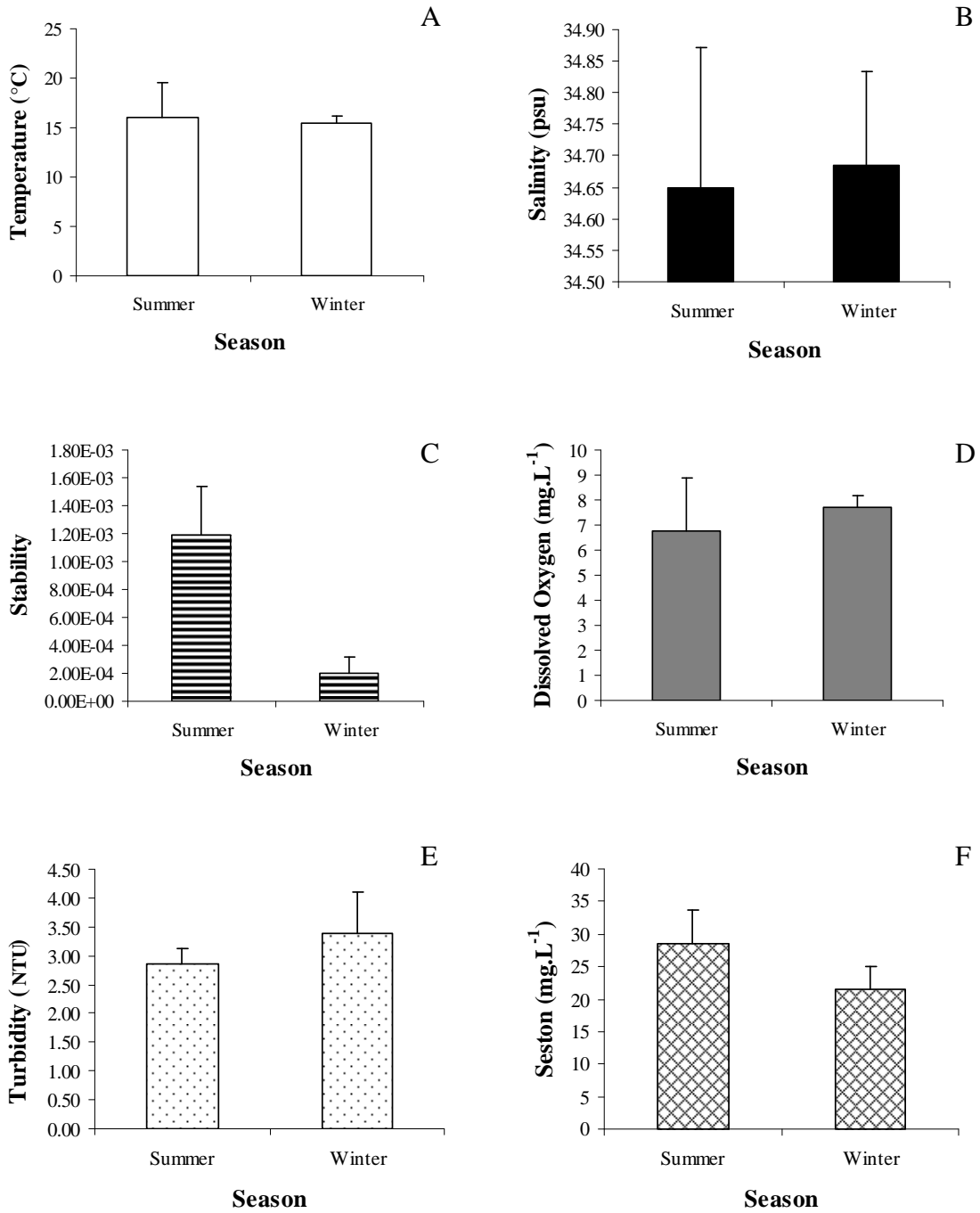


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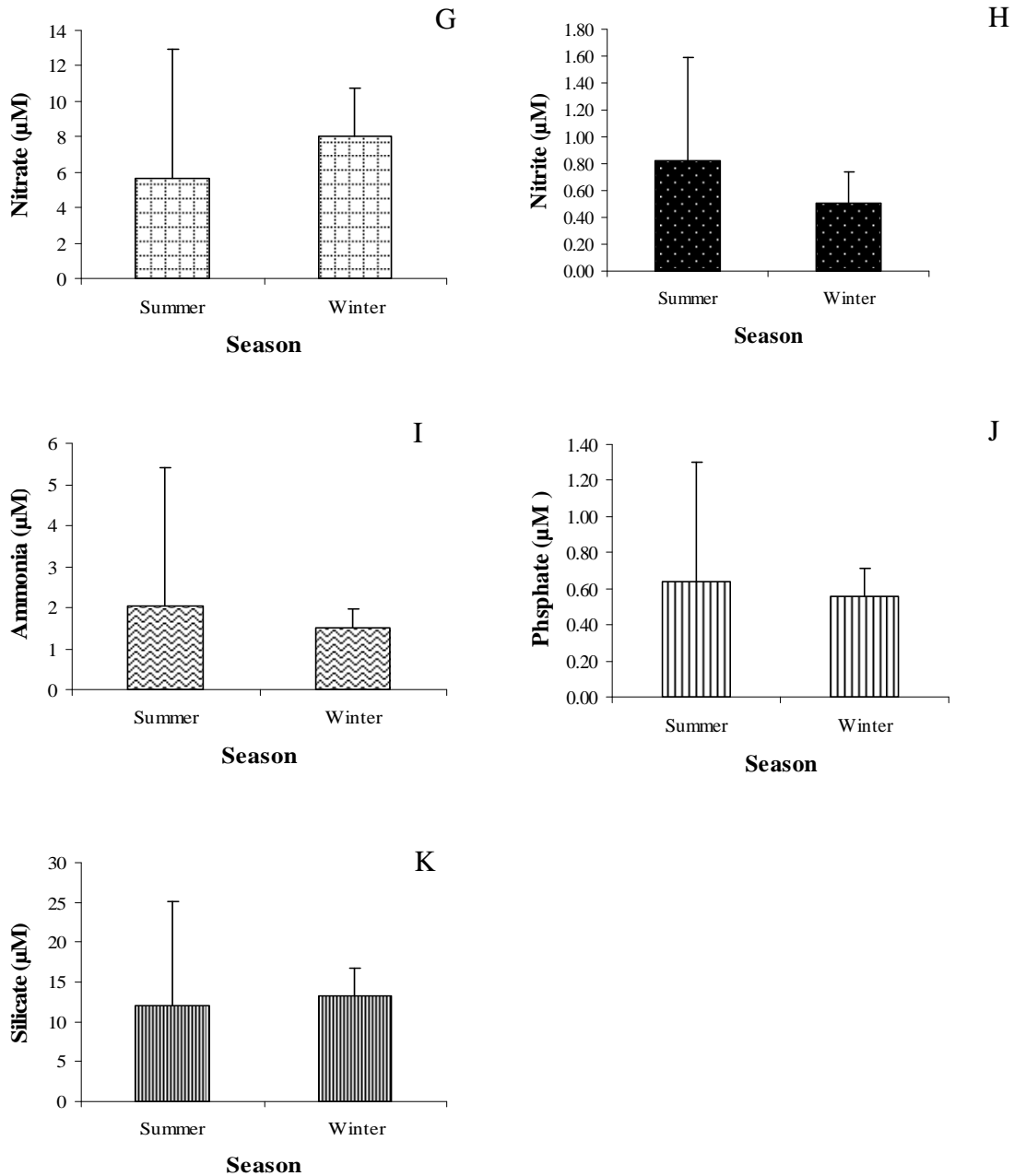


Figure 5.1: Physical-chemical environmental variable (A–K) averages between summer and winter 2008. Error bars are standard deviations.

5.2 SEASONAL PATTERNS IN PHYTOPLANKTON BIOMASS

Total chlorophyll-*a* (chl-*a*) concentrations varied significantly between the two seasons with highest values recorded in summer ($P < 0.001$; Table 5.1; Figure 5.2A). The average

summer concentration was measured at $1.66 \mu\text{g.L}^{-1}$ (SD = 1.65), while in winter an average value of $0.44\mu\text{g.L}^{-1}$ (SD = 0.48) was recorded (Figure 5.2A). Similarly, integrated chl-*a* values during summer were significantly higher (Mean = 63.29 mg.m^{-2} , SD = 47.03) than during winter (Mean = 13.71 mg.m^{-2} ; SD = 11.28) ($P = 0.001$; Table 5.1; Figure 5.2B).

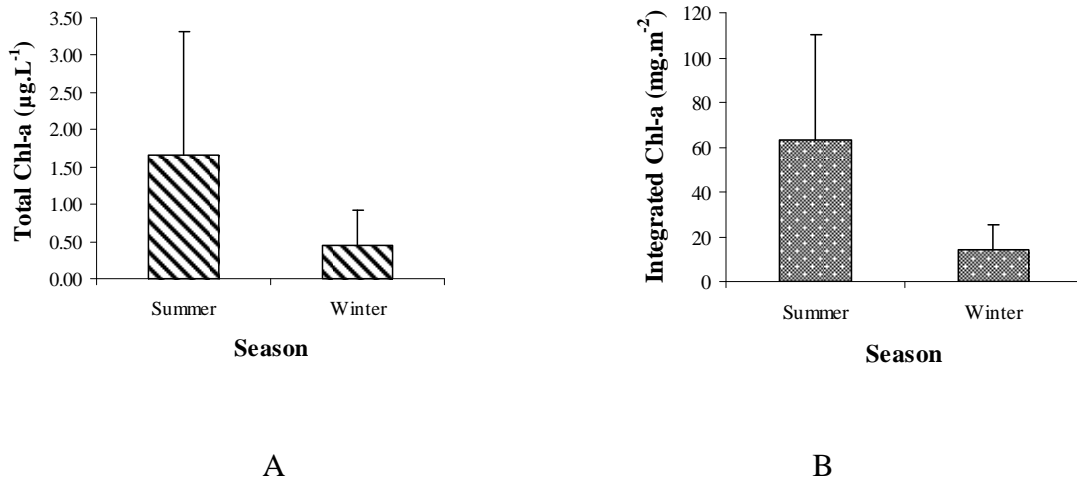


Figure 5.2: Total (A) and integrated (B) chlorophyll-*a* averages for Algoa Bay during summer and winter, 2008. Error bars are standard deviations.

5.3 SEASONAL PATTERNS IN ZOOPLANKTON ABUNDANCE AND BIOMASS

5.3.1 Zooplankton abundance and biomass

Zooplankton abundance and biomass were highly variable between the summer and winter. Zooplankton abundance exhibited significantly higher values in summer with an average of $490.02 \text{ ind.m}^{-3}$ (SD = 418.45), while in winter the average zooplankton abundance was estimated at 73.87 ind.m^{-3} (SD = 69.52) ($P < 0.001$, Table 5.1; Figure 5.3A). Similarly, the total zooplankton biomass during summer (Mean = 115.55 mg.m^{-3} ; SD = 68.46) was significantly higher than that recorded during winter (Mean = 33.28 mg.m^{-3} ; SD = 18.31) ($P < 0.001$; Table 5.1; Figure 5.3B).

During summer, the 90–200 μm size contributed the most to total abundance, with a net contribution of $\sim 60\%$. The 1000–2000 μm size class contributed $\sim 1\%$ to total zooplankton densities (Figure 5.4 A). Winter abundance, on the other hand, was dominated by the 200–500 μm size class with $\sim 58\%$ contribution to the total, while the lowest contribution to the total abundances was made by the 1000–2000 μm size class (Figure 5.4B). During summer, the highest biomass contribution of 38% of the total was recorded for the 500–1000 μm size class, with the smallest contribution being made by the 1000–2000 μm size class (Figure 5.4C). The 1000–2000 μm size class, in contrast, contributed the most (37%) to the total biomass during winter, while the 90–200 μm size class contributed the least (16%).

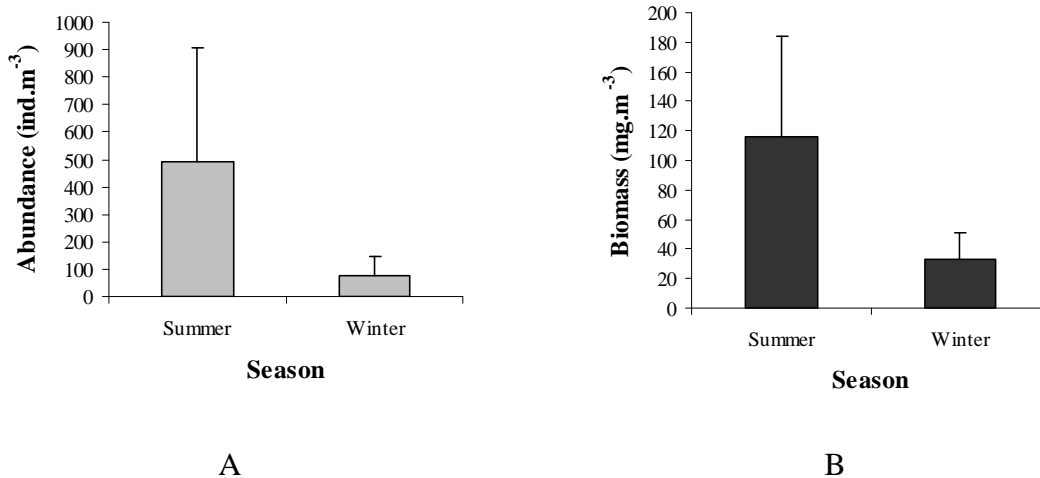


Figure 5.3: (A) Abundance and (B) Biomass averages for Algoa Bay during summer and winter, 2008. Error bars are standard deviations.

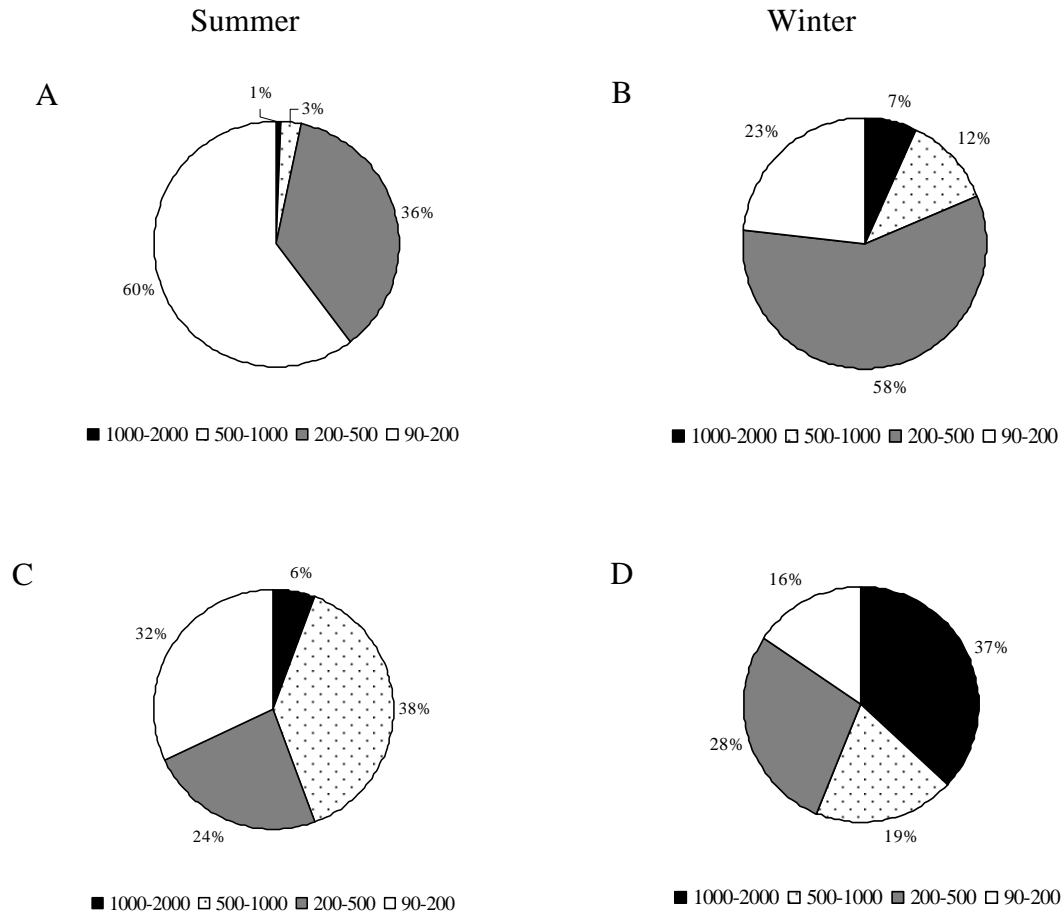


Figure 5.4: % Abundance (ind.m⁻³; A and B) and % Biomass (mg.m⁻³; C and D) contribution of zooplankton size classes to the total during summer and winter, 2008.

5.3.2 Zooplankton species richness and diversity

Species richness during the winter survey (Mean = 6.08; SD = 1.13) was significantly higher than the summer survey (Mean = 4.01; SD = 0.76) ($P < 0.001$; Table 5.1; Figure 5.5). Similarly, species diversity during winter (Mean = 3.45; SD = 0.43) was significantly higher than during the summer survey (Mean = 2.810; SD = 0.39) ($P < 0.001$; Table 5.1; Figure 5.5).

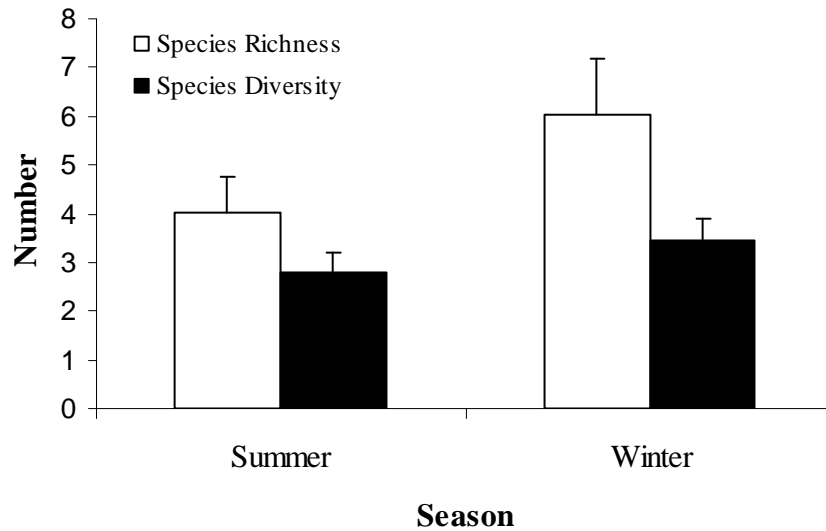


Figure 5.5: Average species richness (d) and species diversity ($H'log_2$) in Algoa Bay during summer and winter, 2008. Error bars are standard deviations.

5.4 SEASONAL PATTERNS IN ZOOPLANKTON COMMUNITY STRUCTURE

5.4.1 Cluster Analysis and Indicator Species Assessment (ISA)

The combined zooplankton data sets separated at 60 % Bray-Curtis Similarity into four zooplankton groupings (Figure 5.6). Clusters A and B comprised the summer samples, while Clusters C and D were made up of the winter samples. However, one winter site (WB 5) was similar in species composition to those in Cluster A and, as such, grouped into Cluster A (Figure 5.6). ANOSIM analysis showed significant differences between all four clusters ($P < 0.050$, in all cases; Table 5.2).

Table 5.2: Results of an ANOSIM pairwise tests between summer and winter 2008

Clusters	R	P	Significance
B vs. A	0.308	0.010	*
B vs. D	1.000	0.001	*
B vs. C	0.966	0.003	*
A vs. D	1.000	0.001	*
A vs. C	0.984	0.005	*
D vs. C	0.602	0.001	*

* indicates significant P values.

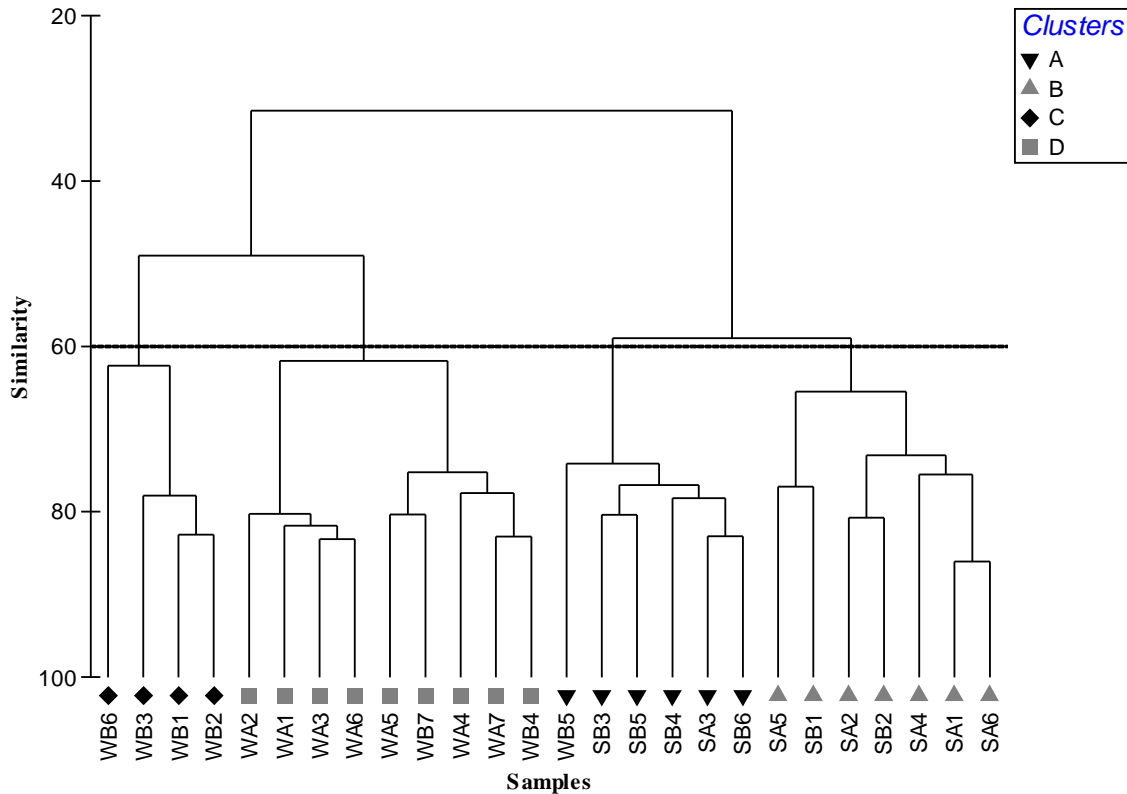


Figure 5.6: Results of a cluster analysis using data from summer and winter 2008. Note: After standardisation and $\text{Log}_{10}(x + 1)$ transformation, Bray–Curtis similarity index was used on abundance data. Identified groupings are indicated with legend symbols.

5.4.2 Dominant zooplankton groups

Zooplankton community structure was dominated by three groups during both seasons and included: Copepoda, Copepod Nauplii (listed as a separate group to highlight their abundance), Bivalvia and Appendicularia. The remaining groups that contributed <10 % to the total were combined to form “Other Groups”. Copepods contributed the most to total zooplankton counts during both seasons, with 46 % (Mean = 7856.95 ind.m⁻³; SD = 5934.49) in summer and 69 % (Mean = 3446.74 ind.m⁻³; SD = 3149.63) in winter (Figure 5.7). During summer, high copepod abundances were recorded in Cluster A, while significantly lower abundances were recorded in Cluster D ($P < 0.050$; Table 5.3) during winter. Appendicularia, on the other hand, recorded significantly lower contributions, 10 % of the total (Mean = 1671.17 ind.m⁻³; SD = 1976.55), for the most dominating groups in summer ($P < 0.050$; Table 5.3). Bivalvia had a significantly lower contribution of 1 %

(Mean = 65.429 ind.m⁻³; SD = 127.74) towards the total of the most dominant groups in winter (P<0.050; Table 5.3; Figure 5.7). “Other Groups” (which included Siphonophora, Chaetognatha, Isopoda, Amphipoda, Decapoda, Hydroidmedusae, Polychaetae, Cladocera, etc.) had significant contributions of 7 % and % 5 % in summer and winter, respectively (P<0.050; Table 5.3; Figure 5.7).

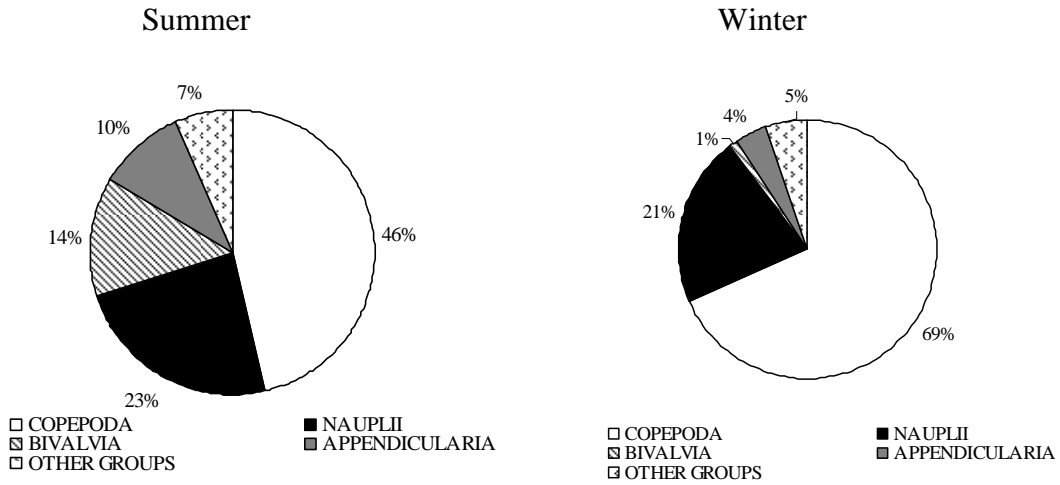


Figure 5.7: Percentage contribution of dominating zooplankton groups to total zooplankton abundance during summer and winter, 2008.

Table 5.3: Results of a series of non-parametric Kruskal-Wallis One Way Analysis of Variance on Ranks (H) statistical tests on dominating zooplankton groups between summer and winter. For tests where the main effects showed significant variability, the Dunn's Method (Q) was used to conduct pairwise multiple comparison procedures.

Group	Source of Variance	H	Q	df	P	Significance
Copepoda	All clusters	106.52		3	<0.001	**
	A vs. D	--	9.71		<0.050	*
	A vs. C	--	3.49		<0.050	*
	A vs. B	--	2.68		<0.050	*
	B vs. D	--	7.19		<0.050	*
	B vs. C	--	1.22		>0.050	NS
	C vs. D	--	4.76		<0.050	*
Nauplii	All clusters	57.62		3	<0.001	**
	A vs. D	--	6.88		<0.050	*
	A vs. C	--	5.35		<0.050	*
	A vs. B	--	2.61		>0.050	NS
	B vs. D	--	4.31		<0.050	*
	B vs. C	--	3.19		<0.050	*
	C vs. D	--	0.29		>0.050	NS
Bivalvia	All clusters	160.22		3	<0.001	**
	B vs. D	--	11.63		<0.050	*
	B vs. C	--	5.20		<0.050	*
	B vs. A	--	1.76		>0.050	NS
	A vs. D	--	9.26		<0.050	*
	A vs. C	--	3.52		<0.050	*
	C vs. D	--	4.33		<0.050	*
Appendicularia	All clusters	155.84		3	<0.001	**
	A vs. C	--	9.34		<0.050	*
	A vs. D	--	10.53		<0.050	*
	A vs. B	--	3.306		<0.050	*
	B vs. C	--	6.69		<0.050	*
	B vs. D	--	7.37		<0.050	*
	D vs. C	--	0.79		>0.050	NS
Other Groups	All clusters	127.34		3	<0.001	**
	A vs. D	--	10.56		<0.050	*
	A vs. C	--	6.34		<0.050	*
	A vs. B	--	3.31		<0.050	*
	B vs. D	--	7.38		<0.050	*
	B vs. C	--	3.58		<0.050	*
	C vs. D	--	2.45		>0.050	NS

Note: A = Cluster A; B = Cluster B; C = Cluster C; D = Cluster D; df = Degree of Freedom; * and ** indicate significant and highly significant P values, respectively; NS = No significant difference; -- = not tested.

5.4.3 Indicator Species Assessment

Taxa with IndVals $\geq 50\%$ were selected as being responsible for between cluster dissimilarity (Table 5.4). The top five indicator species/taxa in Cluster A included *Brachyura* juveniles, *Acrocalanus monachus*, *Scolecithrix bradyi*, *Pleurobranchia* spp. and *Mecynocera clausii*. In Cluster B, the top five indicator species/taxa identified were *Acartia tonsa*, Euphausiid juveniles, *Oncaea conifera*, *Corycaeus typicus* and *Oceania armata*. In Cluster C, Appendicularia spp., *Obelia* spp., *Oikopleura* spp., Ophiuroidea spp. and Siphonophorea spp. all contributed to the top five taxa in that cluster. Mussel larvae; the copepods, *Oithona plumifera* and *Centropages typicus*; Nematode spp. and *Chaetopterus* larvae were identified as indicator species/taxa in Cluster D (Table 5.4).

Table 5.4: Indicator species/taxa with IndVals ≥ 50 % in four clusters, identified by cluster analysis for combined summer and winter data.

Cluster A Species	IndVal	Cluster B Species	IndVal	Cluster C Species	IndVal	Cluster D Species	IndVal
Appendicularia spp.	76.81	Mussel larvae	80.43	Brachyura juvenile	75.00	<i>Acartia tonsa</i>	93.57
<i>Obelia</i> spp.	76.67	<i>Oithona plumifera</i>	71.87	<i>Acrocalanus monachus</i>	72.33	Euphausiid juvenile	87.56
<i>Oikopleura</i> spp.	73.97	<i>Centropages typicus</i>	67.96	<i>Scolecithriv bradyii</i>	72.13	<i>Oncaea conifera</i>	85.99
Ophiuroidea spp.	73.56	Nematoda spp.	58.90	<i>Pleurobrancia</i> spp.	67.90	<i>Corycaeus typicus</i>	84.82
Siphonophora spp.	72.19	<i>Chaetopterus</i> larvae	57.14	<i>Mecynocera clausii</i>	58.29	<i>Oceania armata</i>	80.95
Tiarospidium spp.	71.84	<i>Oithona setigera</i>	54.71	<i>Labidocera minuta</i>	57.07	<i>Corycaeus ovalis</i>	79.84
<i>Doliolum valvidae</i>	67.54	Euphausea larvae	50.91	Decapod larvae	55.55	<i>Subecalanus subtenius</i>	79.62
Egg	66.16	<i>Rhyncorella</i> spp.	50.20	<i>Euterpina acutifrons</i>	53.77	<i>Calaidea macrocarinatus</i>	76.73
Evadne spp.	65.07					<i>Subeucalanus crassus</i>	70.71
<i>Miracia minor</i>	64.72					<i>Mesocalanus tenuicornis</i>	67.62
<i>Centropages chierchiae</i>	60.71					<i>Calocalanus pavo</i>	67.45
Actinula larvae	58.39					<i>Scolecithrix danae</i>	67.36
<i>Sagitta macrocephala</i>	58.21					<i>Subeucalanus subcrassus</i>	66.97
<i>Penilia avirostris</i>	58.16					<i>Acartia negligens</i>	66.66
<i>Chelophyes contorta</i>	58.13					<i>Oncaea media</i>	66.04
<i>Folia</i> spp.	56.45					<i>Oncaea mediterranea</i>	65.56
<i>Sagitta enflata</i>	56.35					<i>Paracalanus parvo</i>	64.92
<i>Centropages brachiatus</i>	54.57					<i>Calanoides carinatus</i>	64.45
<i>Cosmocalanus darwinii</i>	53.71					<i>Acrocalanus gracilis</i>	63.25
<i>Chelophyes appendiculata</i>	52.55					<i>Subeucalanus pileatus</i>	61.57
Polychaete larvae	52.52					<i>Aglaura hemistoma</i>	59.35
<i>Pelagobia</i> spp.	50.40					<i>Paracalanus aculeatus</i>	55.86
<i>Lensia</i> spp.	50.22					<i>Calocalanus minutus</i>	52.15
Salpida_spp.	50.00					<i>Scaphocalanus brevicornis</i>	50.01

5.4.4 Environmental drivers of seasonal patterns in zooplankton community structure

Sample ordination reflected an exact duplicate of the clusters identified by the cluster analysis (Figure 5.6 and 5.8). Environmental variables, identified by the CCA as being partly responsible for this pattern (i.e., those where the correlation coefficient >0.65), were water column stability; integrated picophytoplankton concentration; surface temperature, turbidity, microphytoplankton, nitrate, and seston concentrations; and bottom dissolved oxygen and nitrite concentrations along the first ordination axis; while on the second ordination axis only surface turbidity was identified as being important (Figure 5.8; Table 5.5). Temperature, water column stability, turbidity, seston, microphytoplankton and integrated picophytoplankton concentrations exhibited significant variability between the clusters ($P < 0.050$ in all cases; Table 5.6). The dissolved oxygen, nitrate and nitrite concentrations, however, reflected no statistical variability between the identified clusters ($P > 0.050$ in all cases; Table 5.6). Taxa with IndVals ≥ 50 % also separated according to the cluster grouping (Figure 5.9).

Table 5.5: Correlation coefficients between the environmental variables and the species-derived sample score on Axis 1 and 2 of the Canonical Correspondence Analysis. Values marked in bold had strong correlations (>0.65) and therefore indicate the environmental variables responsible, in part, for the patterns observed between summer and winter 2008.

Environmental Variable	Axis 1	Axis2
Surface Temperature	-0.84	0.19
Surface Salinity	-0.44	-0.15
Water Column Stability	-0.81	0.20
Surface Dissolved Oxygen	-0.55	-0.10
Surface Turbidity	0.08	-0.72
Surface Chlorophyll-a	-0.64	-0.04
Surface Microphytoplankton	-0.65	-0.03
Surface Nanophytoplankton	-0.48	-0.06
Surface Picophytoplankton	-0.52	-0.03
Integrated Chlorophyll-a	-0.58	-0.02
Integrated Microphytoplankton	-0.63	-0.002
Integrated Nanophytoplankton	-0.61	0.00
Integrated Picophytoplankton	-0.65	0.01
Surface Nitrate	0.89	-0.09
Surface Nitrite	0.37	-0.52
Surface Ammonia	0.27	-0.34
Surface Phosphate	0.23	-0.27
Surface Silicate	0.38	-0.20
Surface Seston	-0.76	-0.03
Bottom Temperature	0.32	-0.11
Bottom Salinity	0.26	-0.35
Bottom Dissolved Oxygen	0.68	-0.27
Bottom Turbidity	0.38	-0.63
Bottom Nitrate	0.10	0.06
Bottom Nitrite	-0.71	0.08
Bottom Ammonia	-0.26	-0.02
Bottom Phosphate	-0.21	0.04
Bottom Silicate	-0.03	-0.02
Bottom Seston	-0.77	-0.08

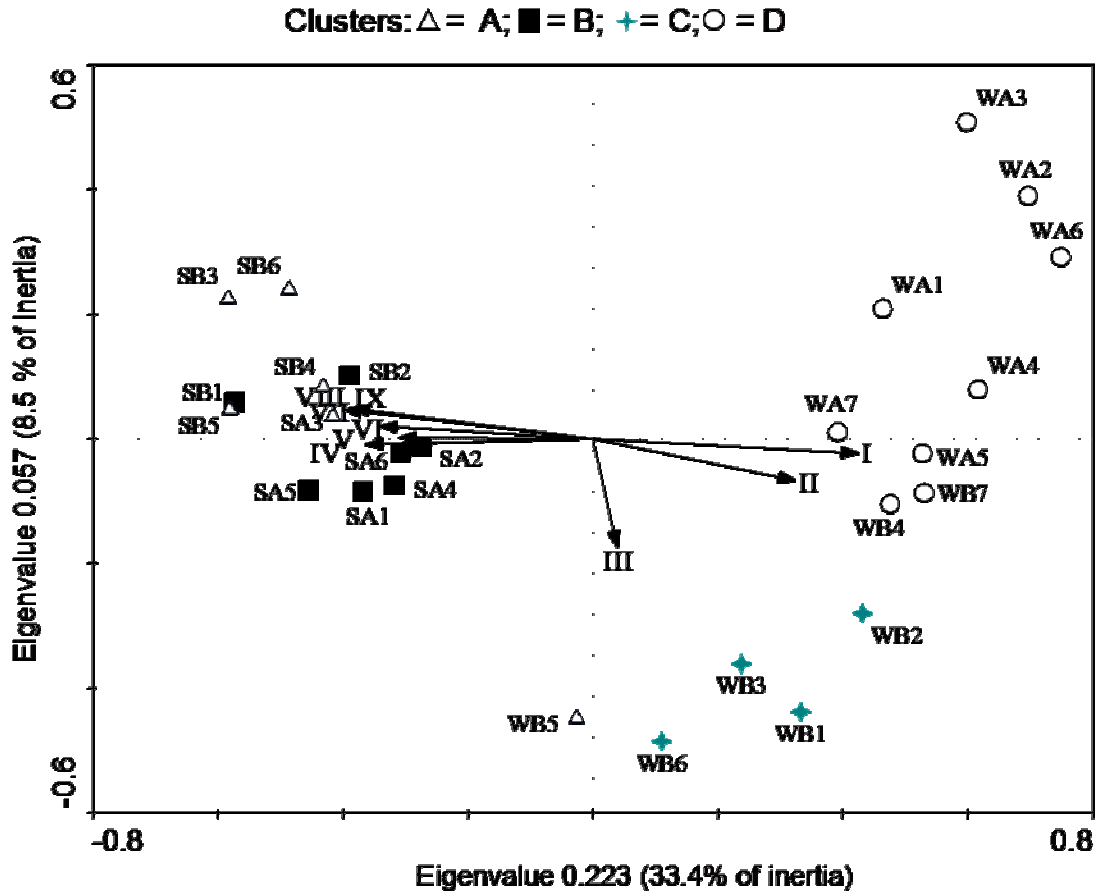


Figure 5.8: Ordination plot of samples and selected environmental variables from results of the summer and winter CCA. Samples are presented as symbols to the cluster analysis sample groupings. The direction and length of the arrows indicate the increase in values of the particular environmental variable. Note: I = Surface Nitrate; II = Bottom Dissolved oxygen; III = Surface Turbidity; IV = Surface Microphytoplankton; V = Surface Seston; VI = Integrated Picophytoplankton; VII = Bottom Nitrite; VIII = Surface Temperature; and IX = Water column Stability.

Table 5.6: Results of a series of One Way Analysis of Variance (F) and the non-parametric equivalent, Kruskal-Wallis One way Analysis of Variance on Ranks (H), statistical tests on important environmental variables (correlation coefficients >0.65). For tests where the main effects showed significant variability, the post-hoc Tukey test (q; parametric) was used to conduct the pairwise multiple comparison procedures. Non-parametric tests were run on data that exhibited no normality/equal variance.

Variable	Clusters	H	F	Df	Q	P	Significance
Temperature	All clusters	9.99	--	3		0.019	*
	A vs. D	--	--		2.99	<0.050	*
	A vs. B	--	--		1.81	>0.050	NS
	A vs. C	--	--		0.65	>0.050	NS
	C vs. D	--	--		1.92	>0.050	NS
	C vs. B	--	--		0.92	>0.050	NS
	B vs. D	--	--		1.13	>0.050	NS
Water Column stability	All clusters	48.98	--	3		<0.001	**
	B vs. C	--	--		5.63	<0.050	*
	B vs. D	--	--		5.44	<0.050	*
	B vs. A	--	--		1.42	>0.050	NS
	A vs. C	--	--		4.24	<0.050	*
	A vs. D	--	--		3.70	<0.050	*
	D vs. C	--	--		1.31	>0.050	NS
Dissolved oxygen	All clusters	0.73	--	3		0.866	NS
Turbidity	All clusters	44.64	--	3		<0.001	**
	C vs. A	--	--		6.15	<0.050	*
	C vs. B	--	--		5.44	<0.050	*
	C vs. D	--	--		5.61	<0.050	*
	D vs. A	--	--		1.12	>0.050	NS
	D vs. B	--	--		0.07	>0.050	NS
	B vs. A	--	--		1.00	>0.050	NS
Seston	All clusters	90.38	--	3		<0.001	**
	B vs. D	--	--		9.13	<0.050	*
	B vs. C	--	--		4.16	<0.050	*
	B vs. A	--	--		2.46	>0.050	NS
	A vs. D	--	--		6.13	<0.050	*
	A vs. C	--	--		1.91	>0.050	NS
	C vs. D	--	--		3.32	<0.050	*
Nitrate	All clusters	--	1.89	3		0.143	NS
Nitrite	All clusters	7.72	--	3		0.052	NS
Microphytoplankton	All clusters	57.82	--	3		<0.001	**
	B vs. D	--	--		6.37	<0.050	*
	B vs. C	--	--		4.36	<0.050	*
	B vs. A	--	--		0.38	>0.050	NS
	A vs. D	--	--		5.65	<0.050	*
	A vs. C	--	--		3.88	<0.050	*
	C vs. D	--	--		0.82	>0.050	NS
Integrated Picophytoplankton	All clusters	46.05	--	3		<0.001	**
	B vs. C	--	--		5.16	<0.050	*
	B vs. D	--	--		5.69	<0.050	*
	B vs. A	--	--		1.47	>0.050	NS

A vs. C	--	--	3.67	<0.050	*
A vs. D	--	--	3.81	<0.050	*
D vs. C	--	--	0.57	>0.050	>

Note: A = Cluster A, B = Cluster B, C = Cluster C, * indicate significant P values, NS = No significant difference; -- = Not tested.

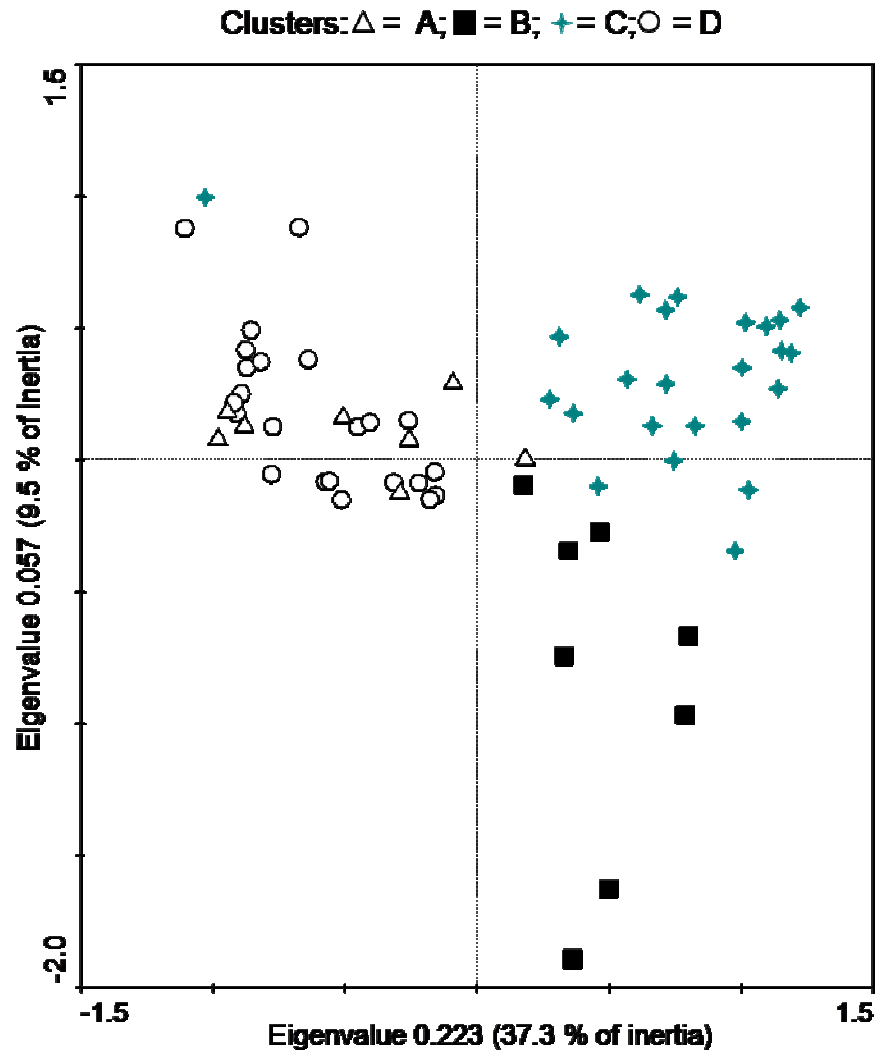


Figure 5.9: Ordination plot of species from results of the summer and winter CCA. Only those species with indicator values >50 % are presented. The symbols represent the indicator species from each of the clusters.

CHAPTER 6: DISCUSSION

Physical-chemical parameters of Algoa Bay

Previous studies have demonstrated that strong easterly component winds induce the upwelling of cold nutrient rich waters from the shelf to the surface waters along the Eastern Cape coastline (Lutjeharms 2006). The centre of an upwelling cell has been identified near the coastal town of Port Alfred, some 50 km north east of Algoa Bay (Lutjeharms 2006). During the summer survey, a distinct spatial pattern in selected physical-chemical variables was observed (Figures 3.1 and 3.2). Cold, dense seawater with high salinity, elevated seston concentrations, increased turbidity and dissolved oxygen concentrations, typical of upwelled water (Peterson et al. 1988; Escribano et al. 2004), was observed in the eastern sector of the Bay during the summer survey. Furthermore, NO₃ concentrations were significantly higher in the eastern sector during this period (Figure 3.7). The spatial pattern in the selected physical-chemical variables observed during the summer study can likely be attributed to a coastal upwelling event that occurred 3 days prior to the sampling (see Figure 1 in the Appendix for satellite imagery of the event).

During the winter survey, however, the waters in Algoa Bay appeared to be homogenous across the Bay with differences of <2 °C in temperature and less than 1 psu and 2 NTU in salinity and turbidity, respectively (Figures 4.1, 4.2 and 4.5). The physical-chemical variables that demonstrated strong seasonal variability within the Bay included: water column stability, turbidity, seston and ammonia concentrations (Figure 5.1). Water column stability during the summer survey was significantly greater than that recorded during the winter (Figure 5.1C). The observed pattern can likely be attributed both to increased solar radiation and reduced wind activity during summer, which would contribute to the formation of a stratified water column (e.g., Schumann et al. 1982; Beckley 1988; Schumann et al. 2005). It is important to note that during winter, increased wind activity and reduced solar radiation would facilitate the formation of a well mixed water column (e.g., Beckley 1988; Schumann et al. 2005). Also noteworthy are the turbidity levels during winter, which were significantly higher than during summer,

presumably the result of high wind activities and water column mixing. The strong seasonal pattern observed in water column stability is in agreement with the findings of previous studies conducted in the western sector of Algoa Bay (e.g., Schumann et al. 1982; Beckley 1988; Schumann et al. 2005). In the absence of other studies in the eastern sector of the Bay it is not possible to say whether or not the spatial patterns observed during the present study are typical for the area.

The vertical stratification of the water column largely depends on the input by solar radiation (Ruardij et al. 1997). The resultant stratification of the water column affects the vertical transport of macronutrients. The uptake of macronutrients by phytoplankton in the upper water column further contributes to a strong vertical pattern in macronutrient concentration, particularly under instances of prolonged water column stability. The absence of any significant seasonal patterns for the majority of the macronutrient concentrations (Table 5.1) suggests that the summer water column stratification within Algoa Bay was of short duration during the investigation. The virtual absence of any significant vertical patterns in the selected physical-chemical and biological variables during the winter survey provide support for this hypothesis. Seasonal and spatial variations in the nutrient concentrations observed during the study can likely be ascribed to various factors including the general hydrology of the Bay or, alternatively, to localised activities (such as agricultural practices and urban development), which would represent important allochthonous sources of nutrients within the Bay (Newman and Nel 2002).

Phytoplankton biomass

Schumann and Campbell (1999) and Campbell (2001) reported that total chl-*a* concentrations within Algoa Bay ranged from 1 to 16 µg/L with maximum concentrations recorded in summer and minimum during the winter. The estimates of total chl-*a* concentration (0.55–3.11 µg/L) recorded during this study are thus in the range reported for the Bay during different seasons. The elevated total chl-*a* concentrations recorded during the summer study can likely be attributed to a variety of factors, including elevated macronutrient concentrations (especially NO₃) derived from coastal

upwelling, increased water column stratification and elevated water temperatures (Figures 3.1 and 3.7). The predominance of large microphytoplankton during the summer survey is therefore not unexpected. The upwelling of waters in the eastern sector of the Bay contributed to a spatial pattern in the integrated chl-*a* concentration during the summer survey with values recorded in the eastern sector being significantly higher than those recorded in the west of the Bay (Figure 3.14). Numerous studies have demonstrated that upwelling events are associated with increased production rates of larger microphytoplankton, mainly diatoms (Probyn et al. 1994; Smith and Campbell 1994). The entrainment of the cooler, nutrient rich water into the Bay is thus associated with a strong biological response. The enhancement of biological activity associated with coastal upwelling has been documented worldwide (e.g., Daneri et al. 2000; Montecino et al. 2004; Largier et al. 2006).

The total chl-*a* concentrations were dominated by microphytoplankton (>20µm) during both summer and winter surveys (Figures 3.13 and 4.13). This finding is in agreement with reports by Smith and Campbell (1994), Schumann and Campbell (1999) and Campbell (2000; 2001) which demonstrated dominance of large phytoplankton cells (specifically diatoms) with no significant seasonal differences, but only regional differences within Algoa Bay. Due to their small surface area to volume ratio, large microphytoplankton cells tend to be restricted to nutrient rich waters, whereas smaller cells (nano- and picophytoplankton), which have larger surface area to volume ratios are able to more efficiently utilise available nutrients and can therefore thrive in oligotrophic waters (Bec et al. 2005). This suggests that phytoplankton growth in Algoa Bay is not nutrient limited. While microphytoplankton dominated total phytoplankton biomass during both the summer and winter surveys, it is possible that a seasonal succession exists in the phytoplankton community structure, with microphytoplankton being more dominant during summer. The succession of phytoplankton communities is typically ascribed to seasonal nutrient enrichment (e.g., Revelante and Gilmarin 1976; Huete-Ortega et al. 2010), and in Algoa Bay this might occur as a result of upwelling during the summer season. However, since Algoa Bay is influenced by agriculture and development (Newman and Nel 2002), there are likely a number of alternative allochthonous sources

of nutrient loading that might not exhibit the same temporal variability as upwelling events. It is therefore essential that further studies be conducted in the Bay in order to gain a better understanding of the various sources of nutrients and their spatial and temporal variability.

Zooplankton of Algoa Bay

Zooplankton studies conducted in Algoa Bay have been limited spatially and/or restricted to selected taxa, including mysid shrimps and penaeid prawns (Wooldrige 1983; Cockcroft and McLachlan 1986; Cockcroft et al. 1988; Schoeman 1990; Newman 2000) and fish larvae (e.g., Beckley 1986 ; Patrick and Strydom 2008). While the findings of these studies illustrate that there is high spatial and temporal variability in zooplankton abundance and biomass within Algoa Bay, they cannot readily be used as comparisons for the results from the present investigation, which focused on the entire mesozooplankton community, comprising mainly copepods. Furthermore, information in the mesozooplankton community structure in the nearshore waters to the north-east and south-west of Algoa Bay is limited (see for example Porri et al. 2007). It is therefore not possible to determine whether mesozooplankton communities inside Algoa Bay are similar to the coastal nearshore communities or whether the Bay represents an area of mesozooplankton build-up or entrainment, in which case abundances may be higher inside the Bay. It is worth noting that the estimates of total mesozooplankton abundance and biomass reported for Algoa Bay are lower than the ranges recorded in St. Helena Bay and False Bay in the Southern Benguela region (e.g. see Shannon and Pillar 1986; Painting et al. 1993; Gibbons et al. 1999). This may suggest that Algoa Bay does not necessarily contribute to the build up of zooplankton abundance and biomass. Alternatively, higher mesozooplankton densities in St. Helena Bay and False Bay may be the result of an overall increase in the plankton productivity in the Southern Benguela region. Since studies conducted in the northern hemisphere have demonstrated that coastal embayments are characterised by elevated zooplankton abundances and biomass (e.g., Okubo 1973; Poulet et al. 1996; and Archambault et al. 1998), it is possible that the same might be true for Algoa Bay. Further studies are needed to determine whether or not this is the case. The strong seasonal pattern in the total zooplankton abundance and

biomass observed during this study is in agreement with studies conducted by Hutchings (1994) and Peterson and Hutchings (1995) in the Agulhas Bank waters.

The zooplankton community identified in the present study within Algoa Bay was characterised by a diverse community, particularly copepods, Euphausiid larvae, cladocerans and copepod nauplii. This finding is consistent with the studies of Hutchings (1994), Verheye et al. (1994) and Peterson and Hutchings (1995) conducted both within Algoa Bay and in the Agulhas Bank waters. The total zooplankton community within the Bay was numerically dominated by copepod species (e.g., *Calanus agulhensis*, *Neocalanus gracilis*, *Nannocalanus minor*, *Centropages* spp.) which demonstrate wide distribution throughout warm temperate regions of the Indian Ocean (Boltovskoy 1999). The absence of any resident species can be related to the general hydrology of Algoa Bay, which seems to act as a flow through system.

Results of this study indicate that the zooplankton community structure within Algoa Bay was numerically dominated by the 200–500 and 90–200 μm size classes consisting mainly of copepods during both seasons (Figures 3.18 & 3.19 and 4.18 & 4.19). Mussel larvae also made an important contribution to the total zooplankton counts during the summer. The elevated abundances of mussel larvae during the summer survey is consistent with the investigation of Porri et al. (2006), which demonstrated that the peak in mussel recruitment within the same geographic region takes place in summer. The numerical dominance of smaller zooplankton during this study highlights the important contribution of the smaller copepods (e.g., nauplii, *Oithona* spp) to the total zooplankton counts. This finding is consistent with investigations by Morales et al. (1991), Landry et al. (1994) and Gallienne and Robin (2001). The numerical dominance of the smaller copepods to the total zooplankton counts highlights the importance of employing a small mesh size when undertaking zooplankton sampling within Algoa Bay.

It is worth noting that the smaller zooplankton fraction contribution to the total zooplankton counts attained the highest levels during the summer survey (Figure 5.4A and B). This pattern can be attributed to the predominance of the early developmental

stages of the copepods (reported as nauplii in this study) to the zooplankton counts in summer (Figure 3.19 A and C). The shift in the zooplankton community structure between the two seasons can therefore be attributed to the reproductive patterns of the numerically dominant zooplankton within the Bay, which is a function of, amongst other factors, temperature, food availability and light environment. This finding is in agreement with studies of Ianora and Buttino (1990) and Kiørboe and Nielsen (1994), which demonstrated that the peak in egg production and biomass build up of copepods in the northern hemisphere occurred in late spring and early summer.

The larger zooplankton size classes (>1000 and 500–1000 μm size classes) made the greatest contribution to the total zooplankton counts during the winter survey (Figures 4.18 and 4.19A and B). During winter, adults predominated while in the warmer summer months, when most of the species were breeding, the early developmental stages of the copepods were more conspicuous. The shift in the size composition of the zooplankton assemblages observed within the Bay is a feature that is typical of the temperate regions of the world's oceans (Landry 1977; Steele and Frost 1977; and Landry et al. 1994). The observed pattern in the size structure of Algoa Bay zooplankton may be the result of a change in food availability: Landry et al. (1994), showed that an increase in the number of the large calanoid copepod, *Calanus pacificus*, in the California Bight during winter was directly correlated with the reduction of ingested phytoplankton by this species and a shift to a more omnivorous diet. The decrease in the contribution of early developmental stages of copepods to the total mesozooplankton counts during winter may therefore be the result of both the seasonal reproductive patterns of individual species and predation. Since diet analysis was not part of the scope of the present study, it is possible that other factors may have been responsible for the shift in zooplankton community structure observed in Algoa Bay. Future studies should aim to investigate the trophodynamics of the mesozooplankton within the Bay.

Numerical analyses identified a strong seasonal pattern in the zooplankton community structure within Algoa Bay (Figure 5.4). The separation between the summer and winter surveys could largely be attributed to the elevated mesozooplankton abundances and

mussel larvae recorded during the summer survey. Spatially, although the numerical analyses did identify distinct zooplankton groupings within each season (three groupings in summer and four during winter), no consistent spatial pattern in the zooplankton assemblages within the bay was observed. Differences in the zooplankton groupings identified with the numerical analyses during both seasons could largely be attributed to shifts in the numerically abundant species within each grouping (Table 5.4 and Figure 5.7). CCA indicated that a variety of physical-chemical and biological variables co-varied with the observed patterns in the zooplankton community structure within Algoa Bay. This result is not unexpected as the distribution of zooplankton within aquatic systems reflects the complex interaction between both physical-chemical (temperature, nutrient loading and oxygen concentration) and biological (food availability and predation) factors which act synergistically with one another (Kimmel et al. 2006).

Implications towards long-term ecological monitoring

Continuous long-term monitoring of environmental change is extremely useful for documenting trends, for differentiating where possible natural from human induced change and for generating testable hypotheses on observed patterns and relationships (Wolfe et al. 1987). Recent studies have reflected on the critical role plankton plays towards marine ecosystems functioning and biogeochemical cycles (e.g. see Roemich and McGowan 1995). Changes in the inter-annual composition of the plankton community often reflect the integrated response of the ecosystem to both natural and anthropogenic forcing (Beaugrand and Ibanez 2004). Roemich and McGowan (1995) expressed global concern towards zooplankton community decline in coastal ecosystems. As a consequence, many authors have employed plankton as an indicator of global climate change (Reid and Beaugrand 2002; Beaugrand and Ibanez 2004). For instance, Dickson et al. (1988) revealed that the decreasing trend in the abundance of many zooplankton species observed in the North Atlantic Ocean in the 1980s has been linked to the decreased intensity of spring phytoplankton bloom resulting from changes in atmospheric circulation patterns. More recently, Beaugrand and Ibanez (2004) used changes in the zooplankton community structure (mainly consisting of calanoid copepod species) to investigate the hydro-climatic variability in the North Sea during the period 1958-1999.

The southern African marine environment is characterised by high levels of variability and biodiversity. The influence of global climate change on the marine ecosystems of South Africa remains uncertain. SAEON, as a framework for establishing and managing long-term ecological monitoring and research programmes, has a mandate “to develop and sustain a dynamic South African observation and research network that provides the understanding, based on long-term information, needed to address environmental issues”. The current study was undertaken to provide baseline data on the spatial and temporal patterns in the mesozooplankton community structure within Algoa Bay as part of a long-term monitoring programme. Results of the current study indicate that the zooplankton community within the Bay is numerically dominated by copepods with a wide warm, temperate distribution (Boltovskoy 1999). A strong seasonal pattern in the zooplankton abundance and biomass within the Bay is evident, presumably reflecting the influence of increased temperatures and food availability (phytoplankton) within the region during summer. Not surprisingly, the zooplankton community composition within the Bay appears to reflect the influence of various physical-chemical and biological factors which act synergistically with one another. It is suggested that global climate change will be associated with an increase in the surface water temperatures in the subtropics coupled with increased southward flow of Agulhas Current waters (Lutjeharms and Ruijter 1996; Rouault et al. 2009; Lutjeharms and Hermes in prep.). Additionally, it is likely that the current axis will lie further offshore (Lutjeharms and Ruijters 1996). Under this scenario, it is anticipated that seasonality of the Agulhas Current will also diminish. The predicted changes in the hydrology of the Agulhas Current are likely to be associated with an increased occurrence of subtropical zooplankton species and reduced seasonality in the abundances and biomass of zooplankton within the Bay region. The long-term analysis of the zooplankton community structure within Algoa Bay may therefore, provide information on the response of the coastal marine ecosystem along the Eastern Cape coastline to global climate change.

CHAPTER 7: SUMMARY

Conclusions

- Environmental analysis of the summer survey during the present study reflected a stratified (stable) system with evidence of upwelling prior to and during the sampling period. All environmental variables suggested a distinct spatial heterogeneity across Algoa Bay during summer.
- During summer, physical-chemical variables seemed not to have played a significant role in determining the zooplankton community structure during the summer survey. Zooplankton communities separated due to numerical dominance of certain taxa found in all groups and presence/absence of certain species or taxa.
- The winter survey results suggested that Algoa Bay waters were largely characterised by the absence of any horizontal and vertical patterns in the physical-chemical variables.
- During winter, no simple correlations in environmental parameters explained the observed patterns in zooplankton community patterns. However, some appeared to co-vary with the zooplankton assemblages. The zooplankton communities separated by numerical dominance of common taxa and presence/absence of certain species or taxa.
- The most important physical-chemical variables responsible for seasonal variability within Algoa Bay are water column stability, salinity, turbidity, and seston and ammonia concentrations. Chl-*a* and integrated chl-*a* also played significant roles in distinguishing between summer and winter seasons.
- Majority of taxa collected during both surveys of this study appeared to be cosmopolitan. They seem to be within the geographical range described by numerous texts.
- This study forms a baseline to the knowledge of the zooplankton community dynamics in Algoa Bay. Because zooplankton forms one of the key elements of marine ecosystems, the observations from this study provide a very important component in understanding biotic and abiotic interactions in the lower food chain levels.

Suggestions for future research:

1. Studies in Algoa Bay have shown that summer season upwelling occurring in the coastal waters off Port Alfred intrude the eastern sector of the Bay and influence processes in Algoa Bay (Lutjeharms 2006). Goschen and Schumann (1995) have also reported intrusion of cold upwelled water in the western sector of the Bay around Cape Recife with similar influence as the eastern sector upwelling inside the Bay. However, there is scant data relating to the biological response to the process and actual upwelling occurring in the Bay. Investigating such process would result in a better understanding of upwelling, onset and duration of primary productivity, and biological responses as they occur in and around Algoa Bay.
2. Trophodynamics of plankton are said to be an important factor in determining trophic positions and complex interactions between trophic groups in the food web (Richoux and Froneman 2009). Mesozooplankton trophodynamics in the Algoa Bay (with special reference to copepods as a dominating group) would give a clear insight on utilisation of available resources, influence of mesozooplankton feeding on other trophic levels, and links between the biotic and the abiotic components.
3. Several international studies have demonstrated differences in abundance between the inside and the outside of the Bay as a result of the headland effect and retention within the bay (Okubo 1973; Archambault et al. 1998). As a bay with little retention, such a study in Algoa Bay would provide insight into the retention capacity of the bay and further understanding of zooplankton communities in and around the Bay.
4. From the findings of this study it seems that there might be allochthonous and autochthonous nutrient sources that relate to the observed phytoplankton biomass and, further up the food chain, the zooplankton communities observed. Investigating spatial and temporal patterns of such factors would further illuminate nutrient variability and nutrient recycling by zooplankton in the Algoa Bay.

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APPENDIX

Table 1. Species list for samples collected during all surveys (summer and winter surveys, 2008).

Taxa	
Amphipoda	Copepoda
Gammaridae sp.	<i>Acartia africana</i>
Hyperiid sp.	<i>Acartia danae</i>
	<i>Acartia negligens</i>
Appendicularia	<i>Acartia</i> spp.
<i>Folia</i> spp	<i>Acartia tonsa</i>
<i>Oikopleura</i> spp.	<i>Acrocalanus gracilis</i>
	<i>Acrocalanus longicornis</i>
Urochordata	<i>Acrocalanus monachus</i>
Ascidian larvae	<i>Calanus agulhensis</i>
Branchiostoma larvae	<i>Calanoides carinatus</i>
	<i>Calanoides macrocarinatus</i>
Bivalvia	Other calanoid copepods
Mussel larvae	<i>Calocalanus minutus</i>
	<i>Calocalanus pavo</i>
Cladocera	<i>Calocalanus tenuis</i>
<i>Evadne</i> spp	<i>Candacia armata</i>
<i>Penilia avirostris</i>	<i>Candacia bradyi</i>
	<i>Candacia discaudata</i>
Gastropoda	<i>Candacia pachydactyla</i>
Cephalopod larvae	<i>Candacia</i> spp.
	<i>Centropages brachiatus</i>
Chaetognatha	<i>Centropages chierchiae</i>
Other Chaetognatha spp.	<i>Centropages elongatus</i>
<i>Eukrohnia</i> spp.	<i>Centropages furcatus</i>
<i>Pterosagitta</i> spp.	<i>Centropages gracilis</i>
<i>Sagitta enflata</i>	<i>Centropages orsinii</i>

<i>Sagitta macrocephala</i>	<i>Centropages typicus</i>
<i>Sagitta setosa</i>	<i>Clausocalanus arcuicornis</i>
<i>Serratosagitta</i> spp.	<i>Clausocalanus jorbei</i>
	<i>Clausocalanus minor</i>
Ctenophora	<i>Clytemnestra rostrata</i>
<i>Pleurobrachia</i> spp.	<i>Clytemnestra scutellata</i>
	Copepod nauplii
Decapoda	<i>Corycaeus longistylis</i>
Decapod larvae	<i>Corycaeus ovalis</i>
<i>Lucifer chacei</i>	<i>Corycaeus</i> spp.
<i>Lucifer typus</i>	<i>Corycaeus typicus</i>
<i>Brachyura</i> juvenile	<i>Cosmocalanus darwinii</i>
	<i>Delius nudus</i>
Echinodermata	<i>Eucalanus elongatus</i>
Ophiuroidea sp. (brittle star)	<i>Eucalanus indicus</i>
	<i>Eucalanus</i> spp.
Euphausea	<i>Euchirella amoena</i>
Juvenile Euphausiid	<i>Euchaeta indicus</i>
Euphausiid Larvae	<i>Euchaeta longicornis</i>
	<i>Euchaeta rimana</i>
Hydroid medusae	<i>Euaugaptilus affinis</i>
Actinula larvae	<i>Euaugaptilus hecticus</i>
<i>Aglaura hemistoma</i>	<i>Euterpina acutifrons</i>
<i>Amphogona apicata</i>	<i>Gaetanus minor</i>
<i>Clytia</i> spp	<i>Haloptilus oxycephalus</i>
<i>Euphysa aurata</i>	<i>Helicyclops</i> spp.
<i>Eutonina</i> spp.	<i>Labidocera acuta</i>
<i>Lovenella</i> sp.	<i>Labidocera acutifrons</i>
<i>Obelia</i> spp.	<i>Labidocera duntrata</i>
<i>Oceania armata</i>	<i>Labidocera kroyeri</i>
<i>Phiallela quadrata</i>	<i>Labidocera minuta</i>

<i>Podocoryne</i> spp.	<i>Labidocera pavo</i>
<i>Rathkea</i> spp	<i>Labidocera</i> spp.
<i>Tiaropsidium</i> spp.	<i>Lucicutia flavicornis</i>
<i>Tubellaria</i> spp.	<i>Macrosetella gracillis</i>
<i>Zanclaea</i> spp.	<i>Mecynocera clausi</i>
	<i>Mesocalanus tenuicornis</i>
Isopoda	<i>Microsetella norvegica</i>
Isopod spp. (Gnathic)	<i>Microsetella rosea</i>
	<i>Miracia minor</i>
Nematoda	<i>Nannocalanus minor</i>
Nematode larvae	<i>Neocalanus gracilis</i>
Nematode sp.	<i>Neocalanus robusitor</i>
	<i>Oithona attenuata</i>
Nemertina	<i>Oithona fallax</i>
<i>Pelagonemertes</i> sp.	<i>Oithona nana</i>
	<i>Oithona plumifera</i>
Ostracoda	<i>Oithona rigida</i>
Ostracoda spp.	<i>Oithona setigera</i>
	<i>Oithona similis</i>
Pisces	<i>Oithona simplex</i>
Fish egg	<i>Oncaea conifera</i>
Fish larvae	<i>Oncaea media</i>
	<i>Oncaea mediterranea</i>
Platyhelminth larvae	<i>Oncaea minuta</i>
	<i>Oncaea</i> spp.
Polychaetae	<i>Paracalanus aculeatus</i>
<i>Pelagobia</i> spp.	<i>Paracalanus parvo</i>
Polychaetae larvae	<i>Paracalanus parvus</i>
<i>Rhynchonerella</i> spp.	<i>Paracandacia truncata</i>
<i>Spiophanes</i> spp	<i>Pareucalanus attenuatus</i>
<i>Tomopteris</i> spp.	<i>Phyllopus aequalis</i>

<i>Chaetopterus</i> larvae	<i>Phyllopus</i> spp.
	<i>Pleuromamma abdominalis</i>
Pteropoda	<i>Pleuromamma gracilis</i>
<i>Limacina</i> spp.	<i>Pleuromamma rhobusta</i>
	<i>Pontella</i> sp.
Siphonophora	<i>Pseudodiaptomus chartei</i>
<i>Chelophyes appendiculata</i>	<i>Pseudodiaptomus gracilis</i>
<i>Chelophyes contorta</i>	<i>Pseudodiaptomus hessei</i>
<i>Eudoxoides mitra</i>	<i>Pseudodiaptomus nudus</i>
<i>Lensia</i> spp	<i>Pseudodiaptomus serricaudata</i>
	<i>Rhincalanus nasutus</i>
Thalicea	<i>Rhincalanus rostifrons</i>
<i>Doliolum nationalis</i>	<i>Scaphocalanus brevicornis</i>
<i>Doliolum valvidae</i>	<i>Scolecithricella minor</i>
<i>Cyclosalp</i> spp.	<i>Scolecithrix bradyi</i>
	<i>Scolecithrix danae</i>
Other egg	<i>Subeucalanus crassus</i>
	<i>Subeucalanus mucronatus</i>
	<i>Subeucalanus pileatus</i>
	<i>Subeucalanus subcrassus</i>
	<i>Subeucalanus subtenius</i>
	<i>Temora discaudata</i>
	<i>Temora</i> spp.
	<i>Temora turbinata</i>
	<i>Undinula vulgaris</i>

Table 2. Details of net tows conducted during the summer survey, including station number and position, date, bottom depth and recording depth. Stations with A are from the eastern sector while stations B are from the western sector.

Station	Date	Longitude [°East]	Latitude [°North]	Bottom Depth [m]	Recording depth [m]
A1a1	02/29/08	26.3777	-33.797	34.0	0.0
A1a2	02/29/08	26.3777	-33.797	34.0	15.0
A1a3	02/29/08	26.3777	-33.797	34.0	30.0
A1b1	02/29/08	26.3784	-33.796	34.2	0.0
A1b2	02/29/08	26.3784	-33.796	34.2	12.5
A1b3	02/29/08	26.3784	-33.796	34.2	26.6
A1c1	02/29/08	26.3774	-33.796	34.9	0.0
A1c2	02/29/08	26.3774	-33.796	34.9	12.6
A1c3	02/29/08	26.3774	-33.796	34.9	23.9
A2a1	02/29/08	26.3123	-33.821	30.0	0.0
A2a2	02/29/08	26.3123	-33.821	30.0	12.66
A2a3	02/29/08	26.3123	-33.821	30.0	24.9
A2b1	02/29/08	26.3138	-33.821	29.0	0.0
A2b2	02/29/08	26.3138	-33.821	29.0	12.6
A2b3	02/29/08	26.3138	-33.821	29.0	25.4
A2c1	02/29/08	26.3131	-33.822	28.0	0.0
A2c2	02/29/08	26.3131	-33.822	28.0	12.5
A2c3	02/29/08	26.3131	-33.822	28.0	25.5
A3a1	02/29/08	26.2744	-33.865	35.0	0.0
A3a2	02/29/08	26.2744	-33.865	35.0	15.6
A3a3	02/29/08	26.2744	-33.865	35.0	30.3
A3b1	02/29/08	26.2756	-33.864	32.4	0.0
A3b2	02/29/08	26.2756	-33.864	32.4	15.0
A3b3	02/29/08	26.2756	-33.864	32.4	30.2
A3c1	02/29/08	26.2737	-33.865	35.8	0.0
A3c2	02/29/08	26.2737	-33.865	35.8	15.3

A3c3	02/29/08	26.2737	-33.865	35.8	30.1
A4a1	02/29/08	26.2193	-33.815	45.0	0.0
A4a2	02/29/08	26.2193	-33.815	45.0	20.0
A4a3	02/29/08	26.2193	-33.815	45.0	40.5
A4b1	02/29/08	26.2198	-33.815	45.2	0.0
A4b2	02/29/08	26.2198	-33.815	45.2	20.2
A4b3	02/29/08	26.2198	-33.815	45.2	39.5
A4c1	02/29/08	26.2198	-33.816	45.0	0.0
A4c2	02/29/08	26.2198	-33.816	45.0	20.7
A4c3	02/29/08	26.2198	-33.816	45.0	39.0
A5a1	02/29/08	26.1711	-33.757	34.5	0.0
A5a2	02/29/08	26.1711	-33.757	34.5	15.0
A5a3	02/29/08	26.1711	-33.757	34.5	30.1
A5b1	02/29/08	26.1715	-33.757	34.0	0.0
A5b2	02/29/08	26.1715	-33.757	34.0	15.0
A5b3	02/29/08	26.1715	-33.757	34.0	30.2
A5c1	02/29/08	26.1703	-33.757	35.5	0.0
A5c2	02/29/08	26.1703	-33.757	35.5	15.1
A5c3	02/29/08	26.1703	-33.757	35.5	30.1
A6a1	02/29/08	26.1268	-33.811	54.9	0.0
A6a2	02/29/08	26.1268	-33.811	54.9	20.2
A6a3	02/29/08	26.1268	-33.811	54.9	39.2
A6b1	02/29/08	26.1268	-33.811	53.2	0.0
A6b2	02/29/08	26.1268	-33.811	53.2	19.7
A6b3	02/29/08	26.1268	-33.811	53.2	41.2
A6c1	02/29/08	26.1266	-33.812	55.0	0.0
A6c2	02/29/08	26.1266	-33.812	55.0	17.4
A6c3	02/29/08	26.1266	-33.812	55.0	33.6
B1a1	03/01/08	25.7465	-33.811	25.0	0.0
B1a2	03/01/08	25.7465	-33.811	25.0	11.7
B1a3	03/01/08	25.7465	-33.811	25.0	23.2

B1b1	03/01/08	25.7469	-33.812	25.0	0.0
B1b2	03/01/08	25.7469	-33.812	25.0	12.0
B1b3	03/01/08	25.7469	-33.812	25.0	24.0
B1c1	03/01/08	25.7461	-33.813	25.0	0.0
B1c2	03/01/08	25.7461	-33.813	25.0	11.2
B1c3	03/01/08	25.7461	-33.813	25.0	22.8
B2a1	03/01/08	25.7411	-33.885	38.0	0.0
B2a2	03/01/08	25.7411	-33.885	38.0	16.2
B2a3	03/01/08	25.7411	-33.885	38.0	34
B2b1	03/01/08	25.7399	-33.885	38.0	0.0
B2b2	03/01/08	25.7399	-33.885	38.0	17.2
B2b3	03/01/08	25.7399	-33.885	38.0	34
B2c1	03/01/08	25.7422	-33.885	38.8	0.0
B2c2	03/01/08	25.7422	-33.885	38.8	17
B2c3	03/01/08	25.7422	-33.885	38.8	34.7
B3a1	03/01/08	25.6648	-33.902	17.2	0.0
B3a2	03/01/08	25.6648	-33.902	17.2	7.5
B3a3	03/01/08	25.6648	-33.902	17.2	15.2
B3b1	03/01/08	25.6641	-33.901	17.1	0.0
B3b2	03/01/08	25.6641	-33.901	17.1	7.6
B3b3	03/01/08	25.6641	-33.901	17.1	14.7
B3c1	03/01/08	25.6667	-33.902	17.4	0.0
B3c2	03/01/08	25.6667	-33.902	17.4	7.2
B3c3	03/01/08	25.6667	-33.902	17.4	15.2
B4a1	03/01/08	25.7519	-33.96	41.0	0.0
B4a2	03/01/08	25.7519	-33.96	41.0	20.6
B4a3	03/01/08	25.7519	-33.96	41.0	39.6
B4b1	03/01/08	25.7505	-33.96	41.4	0.0
B4b2	03/01/08	25.7505	-33.96	41.4	20.3
B4b3	03/01/08	25.7505	-33.96	41.4	39.4
B4c1	03/01/08	25.7529	-33.959	41.5	0.0

B4c2	03/01/08	25.7529	-33.959	41.5	20.3
B4c3	03/01/08	25.7529	-33.959	41.5	39.8
B5a1	03/01/08	25.691	-33.977	19.3	0.0
B5a2	03/01/08	25.691	-33.977	19.3	9.3
B5a3	03/01/08	25.691	-33.977	19.3	18.2
B5b1	03/01/08	25.6897	-33.977	19.5	0.0
B5b2	03/01/08	25.6897	-33.977	19.5	9.5
B5b3	03/01/08	25.6897	-33.977	19.5	17.8
B5c1	03/01/08	25.6911	-33.975	20.0	0.0
B5c2	03/01/08	25.6911	-33.975	20.0	9.3
B5c3	03/01/08	25.6911	-33.975	20.0	18.8
B6a1	03/01/08	25.7168	-34.026	20.0	0.0
B6a2	03/01/08	25.7168	-34.026	20.0	9.2
B6a3	03/01/08	25.7168	-34.026	20.0	19.7
B6b1	03/01/08	25.7159	-34.026	18.4	0.0
B6b2	03/01/08	25.7159	-34.026	18.4	8.6
B6b3	03/01/08	25.7159	-34.026	18.4	17.4
B6c1	03/01/08	25.7181	-34.026	20.0	0.0
B6c2	03/01/08	25.7181	-34.026	20.0	9.2
B6c3	03/01/08	25.7181	-34.026	20.0	18.9

Table 3. Details of net tows conducted during the winter survey including station number and position, date, bottom depth and recording depth. Stations with A are from the eastern sector while stations B are from the western sector.

Station	Date	Longitude [°East]	Latitude [°North]	Bottom Depth [m]	Recording depth [m]
A1a1	08/06/08	26.37761	-33.79657	33	0
A1a2	08/06/08	26.37761	-33.79657	33	12
A1a3	08/06/08	26.37761	-33.79657	33	25
A1b1	08/06/08	26.37963	-33.79589	34	0
A1b2	08/06/08	26.37963	-33.79589	34	12
A1b3	08/06/08	26.37963	-33.79589	34	25
A1c1	08/06/08	26.38044	-33.79564	33	0
A1c2	08/06/08	26.38044	-33.79564	33	12
A1c3	08/06/08	26.38044	-33.79564	33	25
A2a1	08/06/08	26.31239	-33.82139	30	0
A2a2	08/06/08	26.31239	-33.82139	30	10
A2a3	08/06/08	26.31239	-33.82139	30	20
A2b1	08/06/08	26.31368	-33.82050	29	0
A2b2	08/06/08	26.31368	-33.82050	29	10
A2b3	08/06/08	26.31368	-33.82050	29	20
A2c1	08/06/08	26.31524	-33.81931	29	0
A2c2	08/06/08	26.31524	-33.81931	29	10
A2c3	08/06/08	26.31524	-33.81931	29	20
A3a1	08/06/08	26.27449	-33.86527	34	0
A3a2	08/06/08	26.27449	-33.86527	34	12
A3a3	08/06/08	26.27449	-33.86527	34	25
A3b1	08/06/08	26.27611	-33.86594	35	0
A3b2	08/06/08	26.27611	-33.86594	35	12
A3b3	08/06/08	26.27611	-33.86594	35	25
A3c1	08/06/08	26.27831	-33.86680	34	0
A3c2	08/06/08	26.27831	-33.86680	34	12
A3c3	08/06/08	26.27831	-33.86680	34	25

A4a1	08/06/08	26.21946	-33.81478	45	0
A4a2	08/06/08	26.21946	-33.81478	45	17
A4a3	08/06/08	26.21946	-33.81478	45	35
A4b1	08/06/08	26.22007	-33.81532	45	0
A4b2	08/06/08	26.22007	-33.81532	45	17
A4b3	08/06/08	26.22007	-33.81532	45	35
A4c1	08/06/08	26.22191	-33.81573	45	0
A4c2	08/06/08	26.22191	-33.81573	45	17
A4c3	08/06/08	26.22191	-33.81573	45	35
A5a1	08/06/08	26.17112	-33.75673	35	0
A5a2	08/06/08	26.17112	-33.75673	35	12
A5a3	08/06/08	26.17112	-33.75673	35	25
A5b1	08/06/08	26.17247	-33.75740	35	0
A5b2	08/06/08	26.17247	-33.75740	35	12
A5b3	08/06/08	26.17247	-33.75740	35	25
A5c1	08/06/08	26.17311	-33.75804	35	0
A5c2	08/06/08	26.17311	-33.75804	35	12
A5c3	08/06/08	26.17311	-33.75804	35	25
A6a1	08/06/08	26.12688	-33.81135	54	0
A6a2	08/06/08	26.12688	-33.81135	54	20
A6a3	08/06/08	26.12688	-33.81135	54	40
A6b1	08/06/08	26.12764	-33.81090	54	0
A6b2	08/06/08	26.12764	-33.81090	54	20
A6b3	08/06/08	26.12764	-33.81090	54	40
A6c1	08/06/08	26.12826	-33.81045	54	0
A6c2	08/06/08	26.12826	-33.81045	54	20
A6c3	08/06/08	26.12826	-33.81045	54	40
A7a1	08/05/08	25.99467	-33.76826	34	0
A7a2	08/05/08	25.99467	-33.76826	34	12
A7a3	08/05/08	25.99467	-33.76826	34	25
A7b1	08/05/08	25.99534	-33.76697	38	0

A7b2	08/05/08	25.99534	-33.76697	38	12
A7b3	08/05/08	25.99534	-33.76697	38	25
A7c1	08/05/08	25.99594	-33.76576	38	0
A7c2	08/05/08	25.99594	-33.76576	38	12
A7c3	08/05/08	25.99594	-33.76576	38	25
B1a1	08/04/08	25.74666	-33.81110	25	0
B1a2	08/04/08	25.74666	-33.81110	25	10
B1a3	08/04/08	25.74666	-33.81110	25	20
B1b1	08/04/08	25.74676	-33.81201	26	0
B1b2	08/04/08	25.74676	-33.81201	26	10
B1b3	08/04/08	25.74676	-33.81201	26	20
B1c1	08/04/08	25.74592	-33.81256	26	0
B1c2	08/04/08	25.74592	-33.81256	26	10
B1c3	08/04/08	25.74592	-33.81256	26	20
B2a1	08/04/08	25.74106	-33.88492	40	0
B2a2	08/04/08	25.74106	-33.88492	40	15
B2a3	08/04/08	25.74106	-33.88492	40	30
B2b1	08/04/08	25.73965	-33.88549	40	0
B2b2	08/04/08	25.73965	-33.88549	40	15
B2b3	08/04/08	25.73965	-33.88549	40	30
B2c1	08/04/08	25.74219	-33.88530	40	0
B2c2	08/04/08	25.74219	-33.88530	40	15
B2c3	08/04/08	25.74219	-33.88530	40	30
B3a1	08/05/08	25.6646	-33.90188	17	0
B3a2	08/05/08	25.6646	-33.90188	17	5
B3a3	08/05/08	25.6646	-33.90188	17	10
B3b1	08/05/08	25.66395	-33.90100	16.5	0
B3b2	08/05/08	25.66395	-33.90100	16.5	5
B3b3	08/05/08	25.66395	-33.90100	16.5	10
B3c1	08/05/08	25.66576	-33.89973	16.4	0
B3c2	08/05/08	25.66576	-33.89973	16.4	5

B3c3	08/05/08	25.66576	-33.89973	16.4	10
B4a1	08/04/08	25.75128	-33.96066	41	0
B4a2	08/04/08	25.75128	-33.96066	41	15
B4a3	08/04/08	25.75128	-33.96066	41	30
B4b1	08/04/08	25.75043	-33.96036	42	0
B4b2	08/04/08	25.75043	-33.96036	42	15
B4b3	08/04/08	25.75043	-33.96036	42	30
B4c1	08/04/08	25.75346	-33.95908	42	0
B4c2	08/04/08	25.75346	-33.95908	42	15
B4c3	08/04/08	25.75346	-33.95908	42	30
B5a1	08/05/08	25.69100	-33.97651	19	0
B5a2	08/05/08	25.69100	-33.97651	19	5
B5a3	08/05/08	25.69100	-33.97651	19	10
B5b1	08/05/08	25.68953	-33.97680	18.5	0
B5b2	08/05/08	25.68953	-33.97680	18.5	5
B5b3	08/05/08	25.68953	-33.97680	18.5	10
B5c1	08/05/08	25.69098	-33.97544	19.5	0
B5c2	08/05/08	25.69098	-33.97544	19.5	5
B5c3	08/05/08	25.69098	-33.97544	19.5	10
B6a1	08/05/08	25.71677	-34.02552	19	0
B6a2	08/05/08	25.71677	-34.02552	19	5
B6a3	08/05/08	25.71677	-34.02552	19	10
B6b1	08/05/08	25.71587	-34.02588	20.5	0
B6b2	08/05/08	25.71587	-34.02588	20.5	5
B6b3	08/05/08	25.71587	-34.02588	20.5	10
B6c1	08/05/08	25.71806	-34.02630	21	0
B6c2	08/05/08	25.71806	-34.02630	21	5
B6c3	08/05/08	25.71806	-34.02630	21	10
B7a1	08/05/08	25.90627	-33.77541	34	0
B7a2	08/05/08	25.90627	-33.77541	34	12
B7a3	08/05/08	25.90627	-33.77541	34	25

B7b1	08/05/08	25.90606	-33.77411	33	0
B7b2	08/05/08	25.90606	-33.77411	33	12
B7b3	08/05/08	25.90606	-33.77411	33	25
B7c1	08/05/08	25.90594	-33.77256	33	0
B7c2	08/05/08	25.90594	-33.77256	33	12
B7c3	08/05/08	25.90594	-33.77256	33	25

Table 4. Results of a series of One Way Analysis of Variance (F) and the non-parametric equivalent, Kruskal-Wallis One Way Analysis of Variance on Ranks (H), statistical tests on surface and bottom water physical-chemical variables data between summer and winter. For tests where the main effects showed significant variability, the post-hoc Tukey test (q; parametric) or Dunn's Method (Q; non-parametric) were used to conduct the pairwise multiple comparison procedures.

Variable	df	H	q	Q	F	P	Significance
Surface							
Temperature	1	52.956		7.277		<0.001	**
Salinity	1		4.789		11.467	0.001	*
DO	1	32.25		5.678		<0.001	**
Stability	1	58.062		7.577		<0.001	**
Turbidity	1	1.203				0.273	NS
Seston	1	48.457		6.961		<0.001	**
Nitrate	1	18.667		4.32		<0.001	**
Nitrite	1	8.308		2.88		0.004	*
Ammonia	1	11.54		3.395		<0.001	**
Phosphate	1				0.993	0.329	NS
Silicate	1				2.78	0.109	NS
Bottom							
Temperature	1	20.077		4.48		<0.001	**
Salinity	1	22.217		4.711		<0.001	**
DO	1	47.419		6.886		<0.001	**
Turbidity	1	31.91		5.623		<0.001	**
Seston	1	30.501		5.523		<0.001	**
Nitrate	1	2.542				0.111	NS
Nitrite	1		7.848		30.795	<0.001	**
Ammonia	1	0.0106				0.918	NS
Phosphate	1	0.0239				0.877	NS
Silicate	1	0.13				0.719	NS

Note: DO = Dissolved oxygen, * and ** = significant and highly significant P values, respectively, df = degrees of freedom.

Figure 1. Satellite image showing (A) Sea surface temperature and (B) corresponding chlorophyll-*a* concentration across Algoa Bay (blue box) 2 days before sampling. (Picture from www.rsmarinesa.org.za)

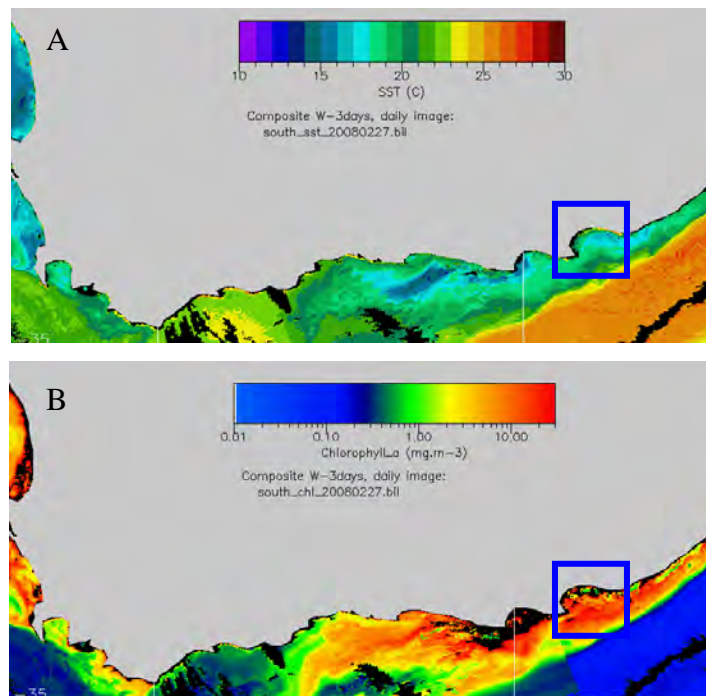


Figure 2. Schematic flow diagram showing detailed sampling design of the study

