INVERTEBRATE PLANKTON ASSEMBLAGES IN THE SURF ZONES OF THE ST. LUCIA AND MHLATHUZE ESTUARIES, KWAZULU-NATAL, SOUTH AFRICA.

by

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DECLARATION

I hereby declare that this whole thesis is my own original work, and to the best of my knowledge, it contains no material previously published or written by person nor material submitted in any form for the award of any degree at another university. Where use of the work of others was made it has been duly acknowledged in the text.

Signature:

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ABSTRACT

This study described the surf zone invertebrate plankton assemblages of the exposed sandy beaches adjacent to the St. Lucia and the Mhlathuze estuaries. The broad aims of this study were to identify the invertebrate plankton assemblages, to describe these in terms of species composition, abundance and spatio-temporal changes, and to relate these communities to adjacent estuarine fauna. Physico-chemical variables which influenced the community structure were investigated. Samples previously collected at St. Lucia between February 1992 and January 1993 by Harris (1996) were used. Additional sampling was carried out monthly from November 1998 until October 1999 in the Mhlathuze surf zone during the day and night. Invertebrate assemblages in the surf zones described in this study were compared with their adjacent estuaries to investigate the relationship between these habitats. .

In total, 171 taxa were collected from both systems. Total abundances ranged from 0.31 to 1570 and 0.17 to 106 individuals/m^3 at the St. Lucia and Mhlathuze surf zones respectively. Plankton and bentho-planktonic organisms belonging to different taxonomic types formed the major component of the assemblages in the St. Lucia and Mhlathuze surf zones. The surf zone invertebrate communities were mainly dominated by crustaceans, with the mysids *Gastrosaccus* spp. and brachyurans (megalopae) dominating the taxa at St. Lucia and the Mhlathuze estuaries respectively. Collectively copepods dominated the holoplanktonic forms. Other commonly abundant holoplankton included siphonophores, chaetognaths, cladocerans and medusae. The meroplankton composed of polychaetes and decapod larvae which dominated this group. Decapod larvae included pagurid, brachyuran and shrimp-like forms. Benthoplanktonic crustaceans sampled from these surf zones included surf zone/beach mysids of the genus *Gastrosaccus*, the isopod *Cirolana* spp. and amphipods.

Classification and ordination analyses revealed distinct day and night communities, with less seasonal and spatial (site) differences. Nine and eight faunal assemblages separated on basis of season were identified at St. Lucia and the Mhlathuze respectively. At St. Lucia four day assemblages were identified: (i) the day summer/autumn assemblage characterised by the dominance of calanoids, brachyuran megalopae and zoeae, penaeid prawns, the copepod *Corycaeus* sp.; (ii) the day summer assemblage characterised calanoids, *Sagitta* sp., *Lucifer* sp., brachyuran megalopae and *Gastrosaccus* spp.; (iii) the day autumn/winter characterised by *Sagitta* sp., calanoids, and *Cirolana* spp.; (iv) the day spring assemblage characterised calanoids, *Sagitta* sp., *Gastrosaccus* spp. brachyuran megalopae, *Lucifer* sp. and penaeid prawns. Within the night community five assemblages were distinguished: (i) the night summer assemblage characterised by *Gastrosaccus* spp., *Cirolana* spp., brachyuran megalopae and zoeae, calanoids and cumaceans; (ii) the night autumn assemblage dominated by *Gastrosaccus* spp., calanoids, *Cirolana* spp., brachyuran megalopae, and *Sagitta* sp.; (iii) the night autumn/winter assemblage characterised by the dominance of *Cirolana* spp., calanoids, *Gastrosaccus* spp. and brachyuran megalopae; (iv) the night spring assemblage characterised by *Gastrosaccus* spp., calanoids, and *Cirolana* spp.; (v) the night spring/autumn assemblage characterised by the dominance of calanoids, *Cirolana* spp., and brachyuran megalopae.

In the Mhlathuze surf zone, the day community was formed by four assemblages which included: (i) the Mhlathuze day summer/autumn assemblage dominated by brachyuran megalopae and zoeae, ctenophores, and calanoids; (ii) the Mhlathuze day winter assemblage characterised by the dominance of calanoids, ctenophores and brachyuran megalopae; (iii) the Mhlathuze day winter/spring assemblage characterised by calanoids, siphonophores and *Sagitta* sp.; (iv) the Mhlathuze day spring/summer characterised by brachyuran megalopae, *Cirolana* spp. and *Gastrosaccus* spp. Within the night community at the Mhlathuze, four assemblages were identified which included: (i) the Mhlathuze night summer assemblage characterised by the dominance of brachyuran megalopae, *Cirolana* spp., and calanoids; (ii) the Mhlathuze night autumn assemblage characterised by the dominance of *Cirolana* spp., brachyuran megalopae, *Gastrosaccus* spp. and ctenophores; (iii) the Mhlathuze night spring/summer assemblage characterised by brachyuran megalopae, *Cirolana* spp. and calanoids; (iv) the Mhlathuze night winter/spring assemblage characterised by the dominance of calanoids, brachyuran megalopae, *Gastrosaccus* spp. and *Cirolana* spp. Assemblages in these surf zones showed diverse invertebrate plankton taxa which originated from different habitats such as intertidal and offshore marine environments and nearby estuaries.

The significant differences recorded between day and night communities were attributable to the nocturnal activity of many crustacean bentho-planktonic groups including beach/surf zone mysids, isopods and decapod larvae in the St. Lucia and Mhlathuze surf zones. At St. Lucia, significant differences were found between summer and winter communities, while at the Mhlathuze significant differences were recorded between seasonal groups. With respect to site, there were no significant differences recorded at St. Lucia and Mhlathuze. This indicated that there was no apparent accumulation of planktonic invertebrates in the surf zone near the estuary mouths.

Significant differences were also recorded between the St. Lucia and Mhlathuze surf zones in terms of their community structure, abundance and diversity where higher densities were recorded at the St. Lucia estuary. These results reflected differences in physical processes and conditions that the St. Lucia and Mhlathuze surf zone communities were exposed to. These included currents, the extent of freshwater input from the estuary, wind-driven-wave action, temperature, salinity and turbidity. Significant differences between the St. Lucia and Mhlathuze communities were also ascribed to a dry period (1992/93) at St. Lucia compared with the Mhlathuze which was sampled during a wet period (1998/99). However, salinity and temperature were the most influential physico-chemical factors structuring the two communities. Although variables such as salinity and longshore currents may have influenced the surf zone communities, distinct temperature-related, seasonal patterns occurred with decreased densities in winter.

A comparison of surf zone plankton recorded in this study with estuarine communities indicated the existence of a faunal relationship between the surf zones and estuaries of the St. Lucia and Mhlathuze systems. Densities of common taxa were slightly higher in the surf zone than in the estuaries, emphasising the importance of these surf zones as habitats rather than being used as a transient area between the estuary and offshore environments. The St. Lucia and Mhlathuze surf zones were important to many faunal groups which included the mysid *Gastrosaccus* spp., brachyurans (megalopae and zoeae), the isopod *Cirolana*, copepods and chaetognaths. However, during present study it was difficult to demonstrate the utilization of these surf zones as nursery grounds due to the use of 500 µm mesh which precluded the collection some larval stages. It is therefore recommended that more detailed research be conducted with smaller mesh nets such as 60 µm in these surf zones to better understand the importance of surf zone ecosystems.

CONTENTS

CHAPTER 1

GENERAL INTRODUCTION

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1.1 Introduction

Zooplankton are defined as animals that float or swim weakly in the water column, and are consequently dependent on tides and currents for their dispersal and distribution (Meadows and Campbell 1988). Zooplankton are animals that either spend most of their lives in the plankton, or spend only a portion of their early life (as larvae) in the water column and settle on the substrata. Many estuarine and marine benthic invertebrates produce larvae that are planktonic (Giangrande and Petraroli 1991; Eckman 1996), and utilise estuaries as nursery grounds in order to make use of food resources and shelter provided by these habitats (Cyrus and Forbes 1996). These organisms either spawn at sea and their planktonic post-larvae return to the inshore nursery areas (estuaries) where they settle as juveniles, e.g. penaeid species (Cockroft and McLachlan 1986; de Villiers *et al.* 1999) or they release their larvae to the marine environment e.g. sesarmid crabs, fiddler crabs (Wheeler 1978; Christy 1982; Lambert and Epifanio 1982). As a consequence, species that migrate either into or out of estuaries have to pass through the surf zone adjacent to the estuary. However, very little is known about the structure and abundance of planktonic invertebrates in this environment.

Surf zones in southern Africa are characterised by a high wave action that causes a high degree of turbulence and creates an inhospitable environment (Dye *et al.* 1981). Generally, surf zones have a low primary production because of the unstable nature of this habitat resulting from wave action that removes substratum. The fauna consequently relies on food transported from the open ocean and land. However, a study on the role of phytoplankton in the surf ecosystem by Lewin and Schaefer (1983) showed that some beaches, together with their surf zones, have phytoplankton adapted to these environments that provide high primary production. These diatom blooms play an important role in providing an energy source for zooplankton in surf zones.

Surf zones *per se* (i.e. on their own) have been shown to be ecologically important as potential nursery grounds for zooplankton. For example, juveniles of the penaeid species *Macropetasma africanus* were found to be more abundant in the Eastern Cape surf zone than offshore (Cockroft 1982). Some juveniles of the penaeid species, *Penaeus plebejus* and *P. merguiensis* have been found to utilise the shallow beach (surf zone) for short periods before they migrate offshore (Ruello 1975; Staples 1980). Although there is very little information on invertebrate communities in the surf zones of southern Africa, they appear to be important as macroscopic food chain habitats (Brown and McLachlan 1990).

1.2 Definition and description of surf zones

Surf zones are defined as the sandy beach subsystem or environment that extends from the bottom of the beach face at mean low water to the outer breaker zone. The surf zone comprises a moving envelope of water from the break point at 1-4 m depth shorewards to the waters edge at the swash line (McLachlan *et al.* 1981). The surf zone is connected to the estuarine environment through the estuary mouth. The surf zone comprises an arrangement of bars and troughs which are continually changing due to wave action (Short 1983). Surf zones are divided into three types namely, reflective, dissipative and intermediate surf zones classified on the basis of wave action and beach gradient in which they occur (Short 1983). These types are briefly outlined as follows:

Reflective surf zones are not regarded as a true surf zones as they occurs off reflective beaches where waves surge directly up the beach face (Short 1983). There are no bars or channels, and the only circulation is associated with the uprush and backwash and surging wave action. The impact of maximum penetration of a shallow wave (swash) on the intertidal area is more intense on reflective beaches than other beach types (Short 1983).

In contrast to reflective surf zones, dissipative surf zones occur on sandy beaches which have a combination of high waves (>2.5m) and fine sand, and are characterised by low beach and surf zone gradients. Dissipative surf zones are also characterised by a longer, gentler swash and they may have multiple bars running parallel to the beach.

Intermediate surf zones form the transition from the dissipative state towards the reflective state, and are the most complex with regard to circulation and morphology. Intermidiate surf zones have sandbars and troughs usually supporting well-developed rip currents. They are found off the intermediate beaches which are characterised by high temporal variability and moderately high waves, between 1 and 2.5 m (Short 1983).

The KwaZulu-Natal coastline is characterised by long, moderately sloping beaches with a wide surf zone, especially in northern KwaZulu-Natal (Field and Griffiths 1991). There is no information on the classification of surf zones on the KwaZulu-Natal coast. However, it would appear from the high waves and moderately sloping beaches that dissipative beaches predominate on the northern KwaZulu-Natal coast. South of the Thukela Estuary the beaches are steeper and numerous rivers drain small catchments to form independent outlets at the coast (Cooper 1991). The associated high-energy surf causes a high degree of turbulence that may affect the distribution and abundance of species utilising or passing through this environment (Lasiak 1986).

1.3 The utilisation of surf zones by plankton

Surf zones are generally characterised by high wave action which results in reduced complexity of community structures as they lack attached macrophytes which would provide shelter (Lasiak 1986). This is not true in the southern and western Cape where there are extensive kelp beds in the surf zone. Despite the turbulent nature of surf zones, many invertebrate and fish species utilise them as their habitats and feeding areas (Harris 1996). For instance, zooplankton biomass and abundance appear to be far greater in surf zones than in deep water beyond them (Brown and McLachlan 1990). This situation can be due to phytoplankton blooms, which occur in the surf zone. Water circulation concentrates particulate food such as detritus in the surf zone which, in turn, attracts many zooplankton (Brown and McLachlan 1990).

Surf zones provide protection from predators as a result of turbulence and shelter provided by the accumulation of detached macrophytes (Lasiak 1986). Detached macrophytes have been reported to accumulate in the surf zone. Cockroft and McLachlan (1986) suggested that detached macrophytes came from submerged reefs 500-800 m offshore, and the prawn *M. africanus* was found to be more concentrated just behind the breakpoint than elsewhere in the surf zone. The accumulation of detached macrophytes in the surf zone has also been found to provide food and shelter for three species of juvenile fish along the coast of Western Australia (Lenanton, Robertson and Hansen 1982).

In addition to utilisation by invertebrate species, surf zones have been shown to be nursery grounds for marine larval and juvenile fish species (Harris 1996; Lasiak 1986; Lasiak 1981 and Bennett 1989). Nursery areas are habitats which provide food and shelter, for the growth of juveniles. This includes habitats such as estuaries, lagoons and semi-enclosed bays (Barnes and Hughes 1982) and harbours (Cyrus and Forbes 1996) that have been recognised as nursery grounds for juvenile teleosts. Lasiak (1981) recorded thirty species of fish utilising Eastern Cape surf zones as nursery areas. All these were zooplankton feeders.

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Cockroft and McLachlan (1986) showed that adults of the *M. africanus* migrate offshore from the surf zone to spawn. Juveniles returned to the surf zone in summer which they utilised as a nursery area to feed and for protection (Cockroft and McLachlan 1986). These studies indicate that these surf zones are important habitats which are utilised as nursery areas for juvenile fish and invertebrate species, as well as providing habitats for species that are resident in the surf zone as adults.

1.4 Physico-chemical factors affecting surf zone invertebrate assemblages.

Several studies have related zooplankton communities to physico-chemical factors using multivariate techniques (Siokou-Frangou, Papathanassiou, Lepretre and Frontier 1998; Collins and Williams 1982; Murdoch 1989 and Viitasalo 1992). The physico-chemical factors which have been shown to affect the spatial and temporal structure of zooplankton communities in coastal areas include temperature, salinity, chlorophyll-a, nutrients (Siokou-Frangou *et al.* 1998; Paula, Pinto, Guambe, Monteiro, Gove and Guerreiro 1998), currents (Murdoch 1989), pH, turbidity, dissolved gases (Kinne 1966; Siokou-Frangou *et al.* 1998) and tides (Warman, O'Hare and Naylor 1991). These factors have also been shown to cause or induce migration of marine invertebrate species, and affect the distribution of these species (Siokou-Frangou *et al.* 1998). However, information about these factors and their effects on zooplankton is limited for the surf zone environment. Beyst *et al.* (2001) studied surf zone hyperbenthos and the influence of abiotic factors on the hyperbenthic assemblages of Belgian sandy beaches. They reported that the main structuring variables that determine the occurrence of the most of hyperbenthic invertebrates in the surf zone were water temperature, wave height and turbidity. However, Romer (1986) demonstrated that combined abiotic factors such as wind, water temperature, wave height, surf zone width and salinity were the main variables structuring the zooplankton assemblages in the Sundays estuary surf zone. Studies on physico-chemical factors affecting biota in South Africa include the work on riverine (Dallas and Day 1993) and estuarine environments (Blaber and Blaber 1980; Cyrus and Blaber 1987, 1992; Mackay 1996; Cyrus *et al.* 2000).

1.5 Adaptations of surf zone zooplankton

Surf zones are extremely dynamic, turbulent habitats in which to live. Surf zone zooplankton generally possess a number of adaptive features to survive in the surf zone environment. These include large size, brood protection or migration to spawn in quieter waters, opportunism for feeding and omnivory, and the formation of swarms (Brown and McLachlan 1990). Clutter (1967) examined four inshore mysid species at La Jolla, California, and found that the largest of them dominated the community inside the surf zone. This indicated that larger sized animals are able to inhabit turbulent zone because they are able to swim continuously which helps them to remain in the surf zone (Brown and McLachlan 1990).

Surf zone zooplankton either display brood protection or leave the surf zone to spawn in quieter waters. All bentho-planktonic forms (mysids, isopods and amphipods) have brood pouches (Brown and McLachlan 1990). However, the true plankton forms display either one strategy or the other. For example, in the prawn genus *Macropetasma*, the adults move offshore to spawn, with juveniles returning to the surf zone, which they use as a nursery area to feed (Cockroft and McLachlan 1986).

Many resident surf zone zooplankton are opportunistic feeders and omnivores because they utilise whatever food becomes available, be it detritus, phytoplankton, or microzooplankton (Wooldridge 1983). Finally, most surf zone resident zooplankton have a tendency to form large swarms, which results in marked patchiness of distribution (Brown and McLachlan 1990). The reason for swarm behaviour in surf zone resident zooplankton is unknown, however, Brown and McLachlan (1990) suggest that this behaviour may be related to feeding and avoidance of predators.

1.6 Research on surf zone and offshore planktonic invertebrate assemblages.

1.6.1 Species abundance and distribution

The most detailed account of surf zone zooplankton comes from La Jolla, California, undertaken by Clutter (1967). He studied the nearshore zonation of four benthic and five pelagic mysids out to 17m depth. It was found that all these species formed swarms and occupied distinct zones occurring either on, or near to the bottom. A large number of species dominated inside the surf zone. The most abundant mysid, *Metamysidopsis elongata*, peaked in numbers where rip currents dispersed, with its outer limit of distribution occurring in this zone. He postulated that detrital food suspension decreased outside this zone and their abundance and distribution were mainly related to the nearshore, wave-induced circulation patterns that contained more food.

Other foreign studies undertaken on surf zone zooplankton include a recent study by Paula *et al.* (1998) and Beyst *et al.* (2001). Paula *et al.* (1998) studied seasonal cycles of planktonic communities at Inhaca Island in Mozambique. It was found that gastropod and decapod crustacean larvae were the most abundant organisms in the zooplankton. Seasonal trends were observed in gastropods *Pinctada capensis* and *Saccostrea cucculata* which had maximum densities in autumn. The gastropods *Modiolus phillipinarum* showed a longer period of reproduction, with a maximum in late summer, whilst the bivalve *Choromytilus meridionalis* had a maximum density in winter. Penaeid larval stages (protozoeal and mysis) were abundant in autumn, and other decapod larvae mainly represented by larval stages of brachyuran crabs in high densities were present from August to December with the highest density recorded in September (Paula *et al.* 1998). Beyst *et al.* (2001) studied surf zone hyperbenthic assemblages of Belgian sandy beaches. They recorded a total of 172 species including true hyperbenthic, endobenthic and planktonic organisms. More than 75 % of the average total composition consisted of mysids such as *Mesopodopsis slabberi*, *Schistomysis spiritus* and *Schistomysis kervillei*. It was also found that within the merohyperbenthos, postlarval decapods and fish were the dominant organisms. They also found that the main abiotic factors which determine the occurrence of most of the organisms in the surf zone were water temperature, wave height and turbidity.

In South Africa, several studies (Cockcroft 1983; Wooldridge 1983; Romer 1986) have been conducted on the surf zone zooplankton in the Eastern Cape. These studies have shown that zooplankton abundances appear to be greater in the surf zone than in deeper water. Cockcroft (1983) made a study of prawn genus, *Macropetasma*, which occurs in large numbers in Eastern Cape surf zones and uses surf zones as a nursery area. The juveniles of this species were found to occur in the inshore environment and adults out as far as 20 m depth. Shoals tended to move inshore at night and to concentrate around phytoplankton blooms by day in the surf zone.

Wooldridge (1983) studied the zooplankton of Algoa Bay from just behind the breakers to about 4 km offshore in water up to a depth of 20 m. He found that crustaceans dominated the zooplankton making up about 80 % of the biomass, while salps, medusae and ctenophores were often common. Fifteen species of mysids accounted for more than 90 % of the crustacean biomass, with copepods forming the second most important group.

1.6.2 Zooplankton communities and assemblages in the coastal areas other than the surf zone

The zooplankton communities and assemblages, as well as the influence of environmental parameters on them, were studied by Siokou-Frangou *et al.* (1998) in a Mediterranean coastal area (Saronikos Gulf, Greece). Two clearly separated communities were found. The first occurred in a semi-enclosed polluted area (Elefsis Bay) and the second in Sakonikos Gulf proper. Five assemblages were categorised on the basis of a seasonal temperature effect on species in the latter community. These were a coastal winter assemblage, a spring assemblage, a psychrophilic assemblage, a coastal thermophilic assemblage and a thermophilic assemblage. They also identified the importance of environmental factors such as eutrophication-pollution, temperature, water mass circulation, water parameters (water temperature) and topography on zooplankton community composition.

Seasonal differences in species composition were also found north of Otago Peninsula, New Zealand, by Murdoch (1989) who studied the effects of headland eddies on the surface macro-zooplankton assemblages. Three zooplankton assemblages were related to coastal hydrography and included a mixed assemblage comprising holoplankton species that was associated with waters over the outer-shelf characteristic of the Southland Current. The assemblage identified within the neritic waters that flow over the inner shelf in Bluestein Bay was dominated by mero-zooplankton, mainly benthic crustacean larvae. The zooplankton assemblage associated with low salinity neritic waters contained a relatively low density of oceanic species and was dominated by coastal species. The assemblages within neritic waters appeared to be related to the flow patterns in the topographic eddy north of the Peninsula. This eddy appeared to be not only important in bringing oceanic species into inshore waters, but also to retain larvae of benthic crustaceans and the eggs of inshore spawning of fish species within the surf zone and to recruit larvae of mid-outer shelf benthic crustaceans to the nearshore zone (Murdoch 1989).

1.6.3 Vertical and horizontal migrations

Studies have shown that some benthic mysids (Moran 1972; Wooldridge 1981), amphipods (Fincham 1970) and isopods (Warman *et al.* 1991) exhibit vertical migrations towards the surface at night in surf zones and horizontal migration behaviour. Migrations in surf zone zooplankton may be associated with spawning, with tides or with day/night regimes (Brown and McLachlan 1990). For example, the prawn *M. africanus* migrates offshore to spawn, and juveniles return to the surf zone, which they utilise as a nursery area (Cockroft and McLachlan 1986). The planktonic *Mesopodopsis* mysid species also exhibit horizontal migration behaviour. This mysid species swarms 1 - 2 km offshore near the bottom during the day and moves inshore to concentrate just behind the breakers near the sea bed after dark (Webb 1987). Here they feed on phytoplankton and detritus brought by rip currents, dispersing after daybreak and moving back offshore (Webb 1987). In the isopod species, *Eurydice pulchra*, both vertical and horizontal migrations were recorded throughout complete tidal cycles within the water column of the surf zone in North Wales (Warman *et al.* 1991). The isopod *E. pulchra* emerged from the sand just before spring high tide during the flood tide, and swam up in the water column, where they were transported onshore by wave-induced currents. At, and just after the time of high tide, individuals swam to the water/sediment interface where the predominant water movement was offshore. Isopods were retained in the surf zone by swimming near the bottom in seaward-flowing water. In the surf zone, isopods reburrowed in the sand during the ebb tide to maintain their position (Warman *et al.* 1991).

1.6.4 Diel migration

Most planktonic invertebrates display nightly vertical migrations (Moran 1972) which can be associated with feeding and diurnal fish predation pressure (Romer 1986; Rossouw 1983). An example of this migration pattern was reported in the mysid species *Gastrosaccus psammodytes* by Wooldridge (1983). *G. psammodytes* was present in low numbers (maximum 6 m^{-3}) at night. In contrast during the day it was found in the substrate in relatively high numbers (58.6 m^{-2}). Diel migration patterns were also reported by (Romer 1986) in mysid *G. psammodytes* and isopod *Eurydice longicornis* in the Sundays surf zone.

1.7 Motivation

Very few studies on surf zone planktonic invertebrate assemblages are apparent in the literature. There have been no studies undertaken on planktonic invertebrate zooplankton communities occurring in the surf zones in KwaZulu-Natal. In addition, it is evident from the generally scarce literature that surf zone planktonic invertebrates are poorly studied, with little known about their abundance, distribution and biology, as well as environmental factors influencing their abundance and distribution.

While no studies have been undertaken on the planktonic invertebrate communities in the surf zone of KwaZulu-Natal, research conducted in Japan (Kosaka 1977) and Eastern Cape (Cockroft and McLachlan 1986) have indicated the importance of surf zone habitat as a nursery area for invertebrates such as the mysid species, *Mesopodopsis slabberi*, and the penaeid species *M. africanus*.

Many studies have been conducted on the recruitment of penaeid prawns (Forbes and Cyrus 1991) and crab species into estuaries including many commercially important species. These studies have shown that estuaries are important nursery areas for these species. Forbes and Benfield (1985) looked at the penaeid prawns of the St. Lucia and Mhlathuze estuary and the larval dynamics of penaeid prawns in St. Lucia was investigated by Forbes and Benfield (1986). The St. Lucia and Mhlathuze estuaries are among the largest in KwaZulu-Natal and have been shown to be important nursery areas for many invertebrate groups such as penaeid prawns (Forbes and Benfield 1985).

This study is based on plankton samples collected by Harris (1996) in the surf zone at St. Lucia between February 1992 and January 1993, as well as additional samples collected from the Mhlathuze surf zone between November 1998 and October 19999. The samples collected by Harris (1996) were used to investigate larval fish assemblages and the invertebrate component was retained and was available for this study. Although the St. Lucia and Mhlathuze surf zones were sampled six years apart, it was decided to compare their community structures and abundance of dominance taxa.

In view of the nursery potential of southern African surf zones and lack of information on the faunal relationship between this environment and estuarine environment, this study aims to contribute to the body of knowledge by broadly undertaking the following:

- *describe the planktonic invertebrate assemblages in the surf zones adjacent to these* two estuaries,
- elucidate the importance of the surf zone to invertebrates moving in and out of these estuaries,
- determine the accumulation of planktonic invertebrates near the estuary mouth, and
- determine the importance of the surf zone as a nursery ground in these areas.

This information would help to determine any relationship between the estuaries and adjacent surf zone. Furthermore, quantification of the surf zone assemblages would give useful information on their abundance and seasonal variation, and indicate which species, if any are resident in the surf zone.

1.8 Aims and Objectives

The overall aim of this study was to investigate and describe the planktonic invertebrate assemblages in the surf zones of the St. Lucia and Mhlathuze estuaries, and to relate this information to current knowledge of invertebrate dynamics in these, and other surf zones and estuaries in KwaZulu-Natal.

This study aimed to:

- identify and describe the planktonic invertebrate assemblages including larval, post-larval and adult assemblages in the surf zones of the St. Lucia and Mhlathuze estuaries, and to determine the important taxonomic groups within these assemblages,
- determine and compare the structure and abundance of the planktonic invertebrate assemblages in the St. Lucia estuary and Mhlathuze estuary surf zones,
- relate any structural, abundance and seasonal patterns to the prevailing environmental conditions, and to
- relate the planktonic invertebrate assemblages in the two surf zones to the invertebrate communities of each estuary.

CHAPTER 2

STUDY AREA

CHAPTER 2
STUDY AREA

2.1 Geographical location

This study was conducted in the surf zones adjacent to St. Lucia and the Mhlathuze estuaries located in KwaZulu-Natal on the east coast of South Africa (Figure 2.1). The KwaZulu-Natal coast of South Africa lies between 26° 51'S and 31°10'S and extends 570 km SSW from Ponta do Ouro on the Mozambique border. The coast of KwaZulu-Natal is relatively straight and has 73 estuaries of varying size (Begg 1978). The coast can be divided into southern and northern segments with the division formed by the Thukela estuary which is approximately midway between Durban and Richards Bay (Figure 2.1). The northern segment (Zululand) consists of a sandy coastal plain which is up to 89 km wide. A result of the flat topography of the Zululand coastal plain, is that rivers drain into large coastal lakes rather than directly into the sea (Cooper 1991). South of the Thukela the topography is steeper, comprising a mixed sandy rocky shore which lacks a coastal plain (Orme 1974; Cooper 1991). Rocky and sandy beaches characterise the shoreline of the KwaZulu-Natal with expansive surf-swept beaches dominating much of the shoreline (Dye *et al.* 1981). The sediment types of beach and nearshore areas including the surf zone are mostly comprised of fine-grained sands. The beach/surf zones vary widely in physical forms owing to the combined effects of variations in coastal orientation due to prevalent winds and swell conditions. It is exposed to moderate to high wave action. The surf zone is broad and well developed (Dye *et al.* 1981), and has well-developed wave action with wave heights generally between 0.5 and 2.5 m throughout the year (Rossouw 1984).

The KwaZulu-Natal coastline is subjected to a subtropical climate with generally high temperatures and rainfall in summer. The average annual rainfall and the temperature mainly in the St. Lucia sub-region are 1,245 mm/annum and 21.8 °C respectively (Germishuyse *et al.* 1998). Rainfall is characterised by early summer rain subjected to anticyclones (Davies *et al.* 1993). Although much of the annual rainfall occurs in the summer months, the average winter rainfall still contributes about 25-30% of average summer rainfall.

The water movements or ocean currents are dominated by the warm south-west flowing Agulhas Current which runs offshore (Figure 2.1). Along the KwaZulu-Natal coast the Agulhas Current is very narrow and runs a few kilometres offshore (Schumann 1987). A temporary, colder inshore counter current also occurs which may extend up to 20 km offshore.

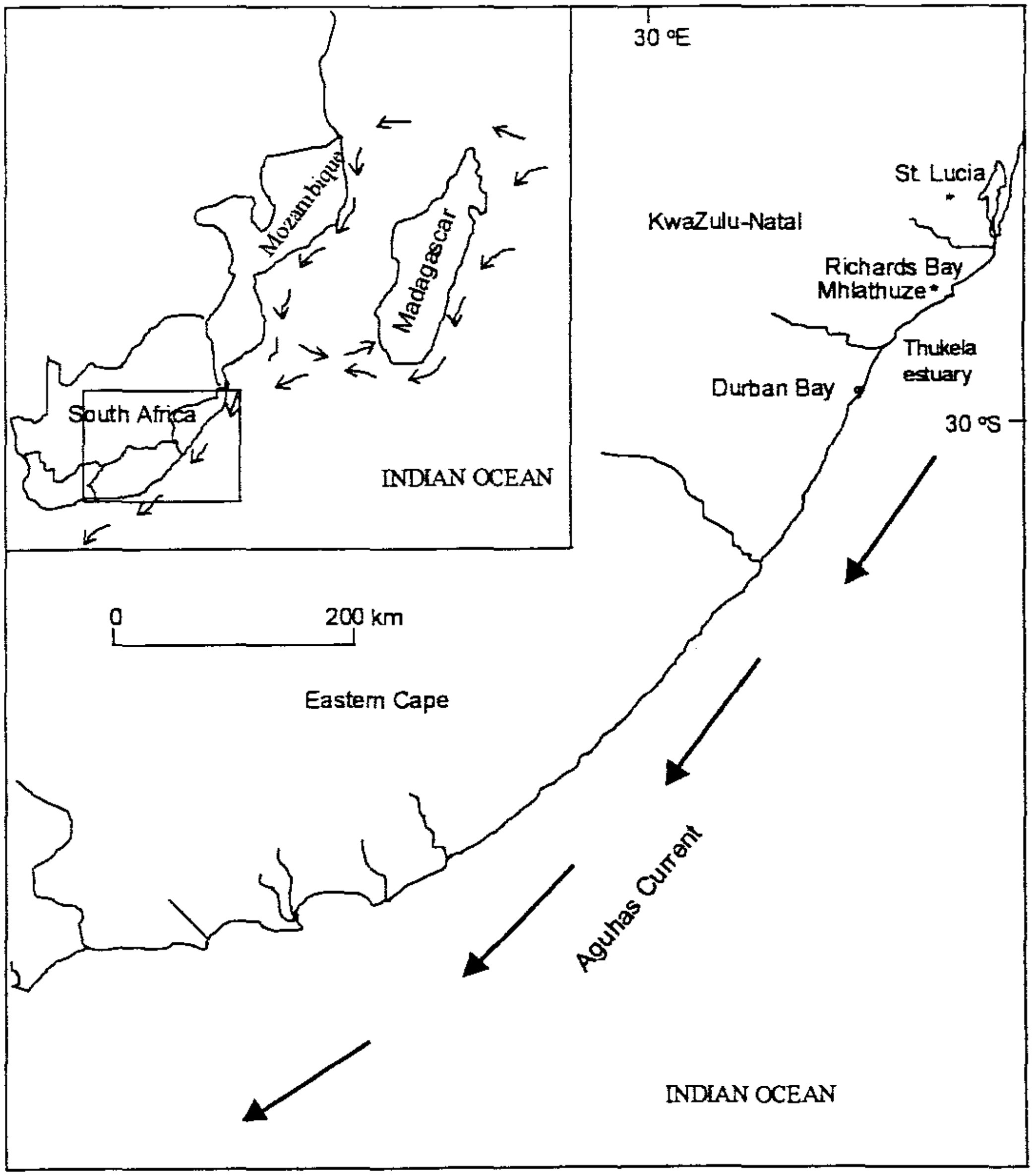

Figure 2. 1 Map of southern Africa showing the KwaZulu-Natal (KZN) region, the Agulhas Current off the South African coast and the location of surf zones adjacent to the St. Lucia and Mhlathuze estuaries (After Harris 1996).

The prevailing winds are north-east and south-west that blow more or less parallel to the coast.

The nearshore waters are subjected to small local upwelling mainly off Richards Bay (Schumman 1988). Salinities of the inshore waters along the KwaZulu-Natal, particularly in the immediate vicinity of estuary mouths, are reduced by land runoff due to the many rivers which enter the sea in this region (Pearce 1977). During the rainy season (summer) silt moved from most of rivers extends out to sea and the turbid water is distributed along the coast by inshore currents. Only north of St. Lucia, where there are no rivers, do clear water conditions occur (Wallace 1975).

2.2 The St. Lucia system

2.2.1 General description

St. Lucia is the largest estuarine system in Southern Africa (Begg 1978 and Day 1981a) and rated fifth in the South African estuaries with respect to conservation importance (Turpie *et al.* 2002). It is located between 27°53'S to 28°21'S and 32°21'E to 32°36'E on the northern KwaZulu-Natal coast of South Africa (Figure 2.1). The St. Lucia system (Figure 2.2) covers an area of approximately 300 to 350 km^2 (Begg 1978). It is referred to as an estuarine-linked lake system (Begg 1978) or estuarine lake (Whitfield 1992) comprising three shallow lake components, namely False Bay, North Lake and South Lake, connected to the sea by a 21 km long tidal channel called the Narrows (Figure 2.2). Four rivers drain into the lake and one river drains into the Narrows, making a total catchment of approximately 9 000 km^2, and they provide an estimated mean annual fresh water inflow of 295 x 106 m^3 (Begg 1978).

The St. Lucia system is known for its marked salinity regimes, which have attracted researchers to investigate the effects of salinity fluctuations on fish (Wallace 1975), benthic animals in the lake (Boltt 1975; Weerts 1993) and Narrows (Boltt 1974; Owen and Forbes 1997), and zooplankton (Grindley 1981: in Day 1981). The salinity fluctuations in the St. Lucia system are due to the combination of the volume of freshwater entering the system and high levels of evaporation in the lake compartments during dry periods. A reverse salinity gradient is established which is compounded by the flow of seawater into the lake, which is lower than mean sea level (Begg 1978). Hypersaline conditions up to 100 $^{o}/_{oo}$, and even reaching 120 ‰, have been recorded in the lake in 1970 and 1983 (Cyrus 1988, Forbes and Cyrus 1993). The hypersaline conditions (>35 %) were caused by the evaporation of freshwater from the lake combined with the continual input of sea water via the open mouth (Boltt 1975), which was maintained open by dredging between 1970 and 1992 (Owen and

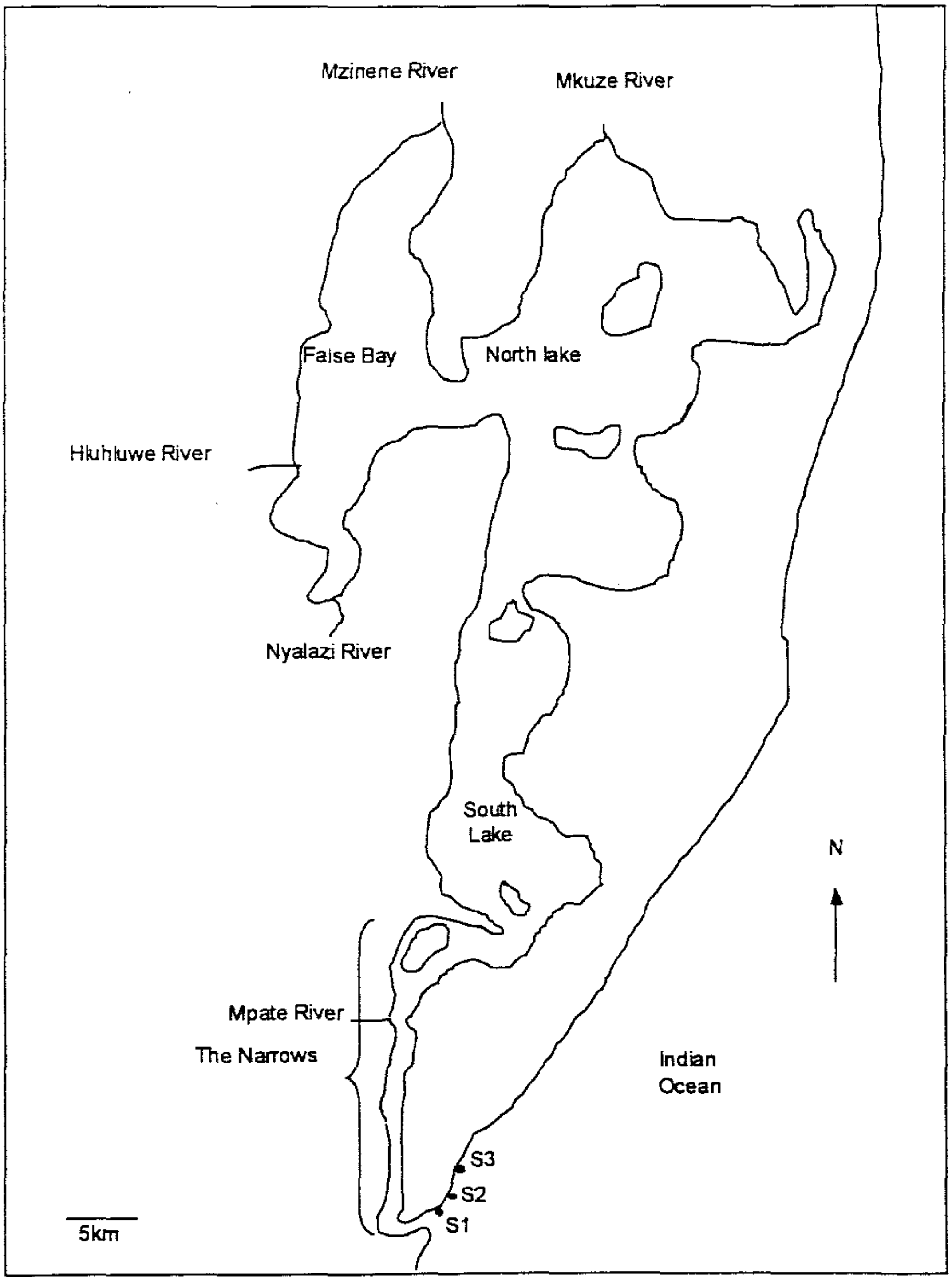

Figure 2. 2 The St. Lucia system and the surf zone study area, showing sampling sites S1, S2 and S3 located north of the estuary mouth (After Day 1981a).

Forbes 2002). Salinities in the Narrows are determined by the salinity and level of the lake, rainfall in the catchment, flooding and tidal influence (Owen and Forbes 1997). Tidal influences occur only within the 22 km of the Narrows. In the Narrows, tidal penetration is restricted by high lake levels and the associated outflows. The lake level determines salinities in the Narrows in that high lake levels during the wet season results in a net outflow with a normal salinity gradient (Owen and Forbes 1997).

2.2.2 Physical characteristics

The mean annual total rainfall recorded at St. Lucia between 1920 and 1984 is approximately 1,335 mm/annum. Temperatures along the northern Zululand coast range from warm to hot throughout the year, with the mean monthly maximum temperature of 25.1 °C and mean monthly minimum of 17 °C. Temperatures can approach 40 °C in summer while the lowest temperature recorded was 5.7 °C in 1923 (Walmsley Environmental Consultants 1993). The predominant winds are from the SW and NE/NNE sectors throughout the year. Very little wind comes from the north-westerly sector. Wind speeds usually range between 4-6 m/s, wind speeds average between 7 and 11 m/s during October to March with average wind speeds approximately 2 m/s during May to July (least windy months).

The surf zone adjacent to the St. Lucia estuary mouth is a high energy, well-developed surf zone (Orme 1973). The surf zone is influenced by swells in the nearshore zone, which are predominantly from the south-east, hence a northerly longshore surf zone current prevails (Begg 1978; Wright and Mason 1990). Offshore, in the deep water, wave height varies between 0.9 and 4 m with median height of 2.1 m. Waves originating from a more southerly direction have significant wave periods and amplitude than those originating from a more northerly direction. When the wave approaches the shore, it encounters an irregular bottom topography (submerged sandbars and troughs) particularly between 100 and 200 m offshore. Waves break on the bars, reform and continue unbroken towards the shore to break again close inshore. Extremely high energy and material transfer are involved in these breakers (Schumann 1988).

2.2.3 Biological chacteristics

The St. Lucia estuarine system is important as one of the top eco-tourism destinations in South Africa, especially for recreation including angling and boat tours (Begg 1978). It is also an important nursery ground for many marine invertebrate and fish species, and supported a prawn bait fishery in KwaZulu-Natal (Fielding *et al.* 1990). St. Lucia provides a protected habitat for a number of animal groups including crocodiles, hippo and white pelicans. It also provides breeding grounds for wetland birds (Mann *et al* 1996).

Several biological surveys have been conducted in this system. This includes surveys on the hypersaline (Day *et al.* 1954; Boltt 1975), marine (Blaber *et al.* 1983; Weerts 1993), and low salinity conditions (Millard and Broekhuysen 1970; Cyrus 1988, Weerts 1993) in the Lake and their impacts on the fauna inhabiting the lake. Boltt (1975) reported that the benthos in False Bay and North Lake were impoverished at salinities above 55 ‰ while South Lake provided the reservoir from which the northern reaches of the system were recolonised. In the Narrows, Owen and Forbes (1997) reported changes in macrobenthic infauna during which the Narrows were exposed to floods in 1984 and 1987, a net freshwater outflow following heavy seasonal rainfall in 1989/90 and hypersaline conditions following mouth closure between December 1992 and September 1993. Significant changes in species composition and density were found which indicated the overall changes in benthic community structure as a result of flooding and hypersalinity (up to 55 $^{0}/_{00}$). Information on phytoplankton, benthic fauna, avifauna and zooplankton, in the surf zone is however, lacking.

2.3 The Mhlathuze system

2.3.1 General description

The Mhlathuze Estuary (Figure 2.3) is situated in the subtropical coastal zone and is regarded as a permanently open estuarine bay based on the classification by Whitfield (1992). The estuary is located at 28° 47'S, 32° 05'E and lies 190 km north of Durban and is about 60 km south of the St. Lucia estuary (Figure 2.1). It covers an area of approximately 11.5 km^2 of the 30 km^2 of the original estuary (Begg 1978; Cooks and Bewsher 1993). According to Turpie *et al.* (2002), the Mhlathuze Estuary is rated tenth in the South African estuaries ranked in terms of their conservation importance. It was a large, shallow (± 0.9 m deep) estuary before the construction of the harbour between 1972 and 1976 (Grindley and Wooldridge 1974). The original estuary was divided into the northern Richards Bay harbour and the new estuary (now called the Mhlathuze Estuary) on the southern side separated from the harbour by a berm wall (Begg 1978). A new mouth was cut for the Mhlathuze River approximately 5 km south of the harbour entrance.

The Mhlathuze River, with a catchment of 3,936km^2 and mean annual freshwater flow of 616 x 106 m^3, was diverted to flow into the Sanctuary during harbour construction to keep silt out of the harbour (Begg 1978). Two other rivers, the Mtantatweni stream and an unnamed channel, drain the sugar cane fields planted on the floodplain (Begg 1978).

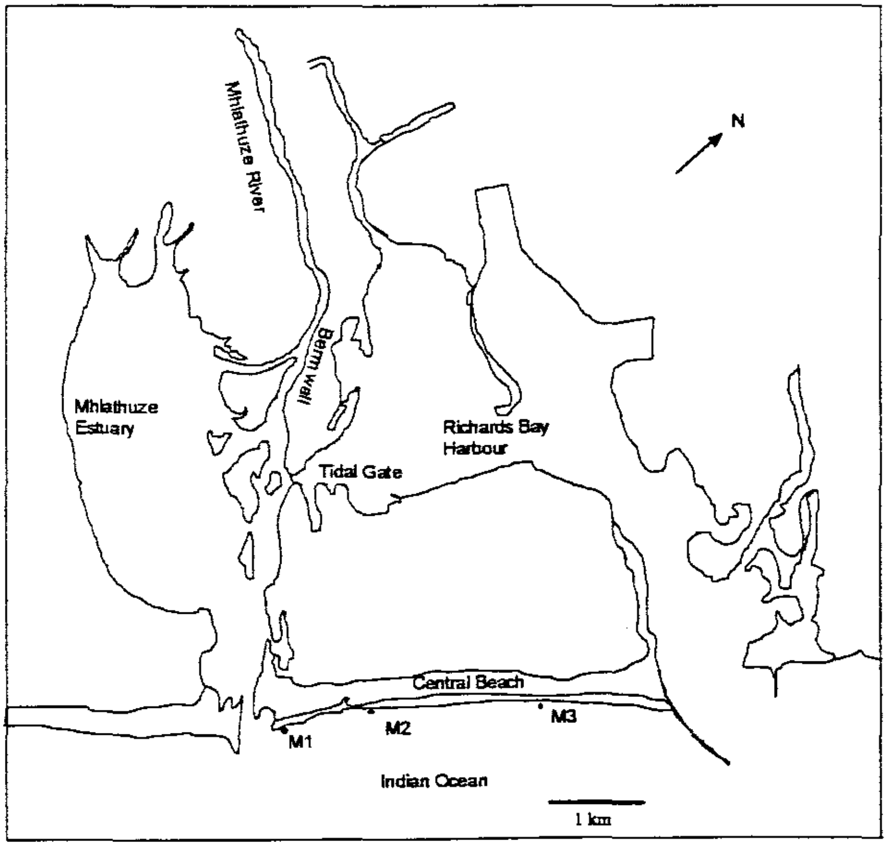

Figure 2. 3 The Mhlathuze estuary and the surf zone study area, showing sampling sites M1, M2 and M3 located north of the estuary mouth (After Mackay and Cyrus 1998/9).

The new Mhlathuze mouth has never closed, and this wide-open mouth (approximately 300 m in width) is mainly maintained by strong tidal flows related to the considerable size of the estuary (Huizinga and Van Niekerk 1998). With the opening of the new mouth (1975), the estuary area has gradually become exposed to increasing tidal ranges with estimates of a tidal rise and fall of 1.8 m (Begg 1978).

2.3.2 Physical characteristics

The mean annual total rainfall at the Richards Bay area is 1,102 mm with a mean maximum temperature of 26.7 °C and a mean minimum temperature of 16.9 °C (Begg 1978). The coast tends north east and experiences similar offshore and nearshore circulation patterns to the Thukela-Mlalazi coast, but with a reduced input of sand particle material (Orme 1973). The sea bed off Richards Bay slopes relatively gradually to the east and more gradually to the south. Whiles to the east, the 20 m contour is 4 km offshore and the 30 m contour is 5.5 km offshore; to the south, these isobaths are 7 and 12 km offshore respectively (Schumann 1988). The inshore boundary of the Agulhas current is usually situated about 20 km offshore (approximately at the 300 m isobath), with this edge meandering at distances from 10 to 30 km offshore (Pearce 1977). The offshore current is south directed, whilst the surf zone currents follow the wave direction with SSE waves driving the current northward and the ESE waves drive the current southward (CSIR 2000). Coastal currents are predominantly wind-driven (Schumann 1981) and this area is one of generally low current velocities. The currents flowing on the north east direction are stronger because they are frequently reinforced by the stronger south-westerly winds (Lord *et al.* 1988). However, south-westward flowing currents occur more frequently (Schumann 1988), and current reversals tend to occur every 2 to 5 days (NRIO 1981: in Schumann 1988).

Wave heights range from 0.5 m to 2.0 m, with the majority of wave periods ranging from 8 to 13 seconds (Schumann 1988). The majority of wave directions fall within the sector south to east, with the predominant SE (NRIO 1981: In Schumann 1988).

2.3.3 Biological chacteristics

The original Richards Bay system was divided into a harbour and "sanctuary" to form a nature reserve to maintain an estuarine habitat (Begg 1978). Following harbour development, there was an initial increase in the tidal range in the "sanctuary", now called the Mhlathuze Estuary, causing reduction in vegetation such seagrass *Zostera capensis*, the mangroves *Avicennia marina*, *Bruguiera gymnorrhiza* and *Rhizophora mucronata* on the edges of the system which had never been previously exposed to flooding by saline water

(Harris 1996). However, a large mangrove community now exists in the estuary (Begg 1978). Originally, the southern and western banks were dominated by the mangroves, *A. marina*, *R. mucronata* and *B. gymnorrhiza*. Other emergent and submerged macrophytes include the reed *Phragmites australis* and seagrass *Z. capensis* which do not occur in the majority of KwaZulu-Natal estuaries (Wepener and Vermeulen 1998/9). The tidal regime also has had an adverse effect on the Mhlathuze Estuary because the lack of water retention prevents a plankton population from building up (Begg 1978). However, it has been suggested that the increased tidal flow into the Mhlathuze Estuary has possibly increased the passive influx of juvenile fish and prawns especially post larval stages (Begg 1978).

With regard to fauna of the Mhlathuze estuary, Millard and Harrison (1954) reported prawns such as *Palaemon peringueyi*, *Penaeus indicus*, *Penaeus monodon* and *Penaeus semisulcatus* as well as crabs of genera *Sesarma*, *Dotilla*, *Macrophthalmus* and *Ocypode*. The zooplankton of the Mhlathuze estuary were studied by Grindley and Wooldridge (1974). The latest quantitative biological survey conducted in the Mhlathuze estuary includes the work on zooplankton (Jerling 1998/9) and benthos (Mackay and Cyrus 1998/9; Owen *et al.* 2000; Owen and Forbes 2002). The information on phytoplankton, benthic fauna, avifauna and zooplankton, in the surf zone is however, lacking.

2.4 Sampling sites: selection and description

This study is based on plankton samples collected between February 1992 and January 1993 by Harris (1996) in the St. Lucia estuary surf zone, as well as additional samples collected from the Mhlathuze estuary surf zone between November 1998 and October 1999. The samples collected by Harris (1996) were used to investigate larval fish assemblages and the invertebrate component was retained and was available for in this study.

At the St. Lucia surf zone, samples were collected from six sites which were located at approximately 500 m intervals north from the estuary mouth (Harris 1996), i.e. Site 1 at the mouth and site 6 was at 3 km north of the mouth (Figure 2.2). However, only samples collected from sites 1, 3 (Site S2 of this study) and 6 (Site S3 of this study) were selected and used in this study to reduce the number of samples as explained above. Samples from the Mhlathuze estuary surf zone were collected at three sites (Figure 2.3) located adjacent to the north side of the mouth (Site 1), 1 km north of the mouth (Site 2) and 3 km north of the mouth (Site 3). Sites were selected to give locations at the same distance and direction from the mouth as those sampled by Harris (1996) at St. Lucia.

Sites were chosen on basis of their distance from the estuary mouth and physical conditions they are subjected to. Site 1 (near the mouth) was considered to have a strong *estuarine/freshwater influence and much sediment dynamics due to sediment transport* through the mouth. Site 2 was characterised by sandy substrate and less riverine influence and had pools near the intertidal zone mainly at the Mhlathuze. Whereas Site 3 had coarse sandy substrate at both surf zone zones, but stones were also present at the Mhlathuze surf zone near a fossil site. It was also characterised by high wave action working the intertidal zone and less sediment deposition.

CHAPTER 3

PHYSICO-CHEMICAL VARIABLES OF SURF ZONES ADJACENT TO ST. LUCIA AND THE MHLATHUZE ESTUARIES.

CHAPTER 3

PHYSICO-CHEMICAL VARIABLES OF SURF ZONES ADJACENT TO ST. LUCIA AND THE MHLATHUZE ESTUARIES.

3.1 Introduction

A number of physico-chemical factors have been shown to influence the distribution and abundance of marine zooplankton in the sea and adjacent coastal waters. These include temperature, salinity, turbidity, pH, oxygen, currents, tides, nutrients and chlorophyll-a (Kinne 1966; Paula *et al.* 1998; Siokou-Frangou *et al.* 1998). The effects of these factors have been studied extensively in estuarine, beach and pelagic environments, but little information is available on the surf zone environment (e.g. Romer 1986; Beyst *et al.* 2001; Beyst, Hostens and Mees 2001). The effect of these factors on plankton in the nearshore environment is outlined below.

3.1.1 Physical variables

Salinity

In estuaries and surf zones, salinity usually fluctuates remarkably compared with seawater. Salinity variations in coastal waters (estuaries and surf zones) are caused by rainfall, evaporation, and fresh water inflow during flood and ebb tides. It is well documented that salinity is one of the most important physico-chemical factors affecting the distribution of aquatic animals in coastal environment (Kinne 1966 and Hughes 1969) and any fluctuation in salinity might result in stressful conditions for zooplankton. Different species have different salinity tolerance limits. However, many species migrate to the estuarine, freshwater or marine environment and *vice versa* depending on their developmental stages and food availability. During their migration, these species pass through the surf zone which is characterised by a wide range in salinity arising from tidal currents and the extent of freshwater outflow. However, there is limited information on the effects of salinity variations on the zooplankton in the surf zone (Beyst, Hostens and Mees 2001; Beyst *et al.* 2001).

Temperature

Coastal waters are also subjected to seasonal fluctuations in temperature, which might affect community structure. Increased water temperatures would lower the oxygen concentration in the water, thereby increasing oxygen levels and the energy demand for organisms (Dallas and Day 1993).

In southern Africa, ocean temperatures differ remarkably resulting in the separation of coast into three major regions. These are the subtropical, the warm-temperate and the cool-temperate regions. The subtropical region extends from the Mbashe Estuary to Maputo Bay (Figure 3.1). The upwelling of cool water created by Agulhas current seldom occurs along this region. The nearshore environment on the east coast is characterised by high input of freshwater via rivers and estuaries from catchments with a high rainfall. Estuarine water temperatures range from 14-28 °C, with sea temperature above 20 °C due to the influence of warm Agulhas current (Beckley and van Ballegooyen 1992). On the east coast mean monthly sea temperatures range from 22 °C in winter to 27 °C in summer (Field and Griffiths 1991).

The warm-temperate region extends from Cape Point to the Mendu Estuary on the Transkei coast. Annual estuarine temperatures are within the 12-26 °C range (Whitfield 1998), whilst the mean monthly sea surface temperatures range from 15 °C in winter to 22 °C in summer on the south coast. On the western part of southern Africa, the cool-temperate region extends from Walvis Bay to Cape Point. The permanently open estuaries along this coast are being influenced by cool (<14 °C) upwelled waters (Whitfield 1998). Strong river flow on this region which is associated with winter rainfall can decrease estuarine water temperatures below 12 °C (Whitfield 1998). The cool-temperate region is also characterised by low rainfall, dry coastal regions, and a harsh and inhospitable environment.

Water Currents

Water movements have been shown to play an important role in the distribution of planktonic communities (Siokou-Frangou *et al.* 1998). Currents parallel to the coast can transport planktonic communties for a long distance (Braarud and Nygaard 1980), and this can determine the zooplankton community structures and abundances in coastal waters such as gulfs, bays, surf zones and estuaries (Lindahl and Henroth 1983; Asknes *et al.* 1989).

The KwaZulu-Natal coastal ocean is influenced by the Agulhas Current, which originates from the Indian Ocean South Equatorial Current that deflects southwards (Figure 3.1). The equatorial water mass splits when it reaches Madagascar, part moving around the island and down the coast of Mozambique, where it is called the Mozambique current, while a second stream passes around the eastern coast of Madagascar (Heydorn 1978). The two currents meet again as they flow along the coast of KwaZulu-Natal, forming the Agulhas current which brings warm water to the KwaZulu-Natal coast. It is a swift, deep current, flowing at 5-10 km/hour at its core and reaching a depth of more than 1,000 m.

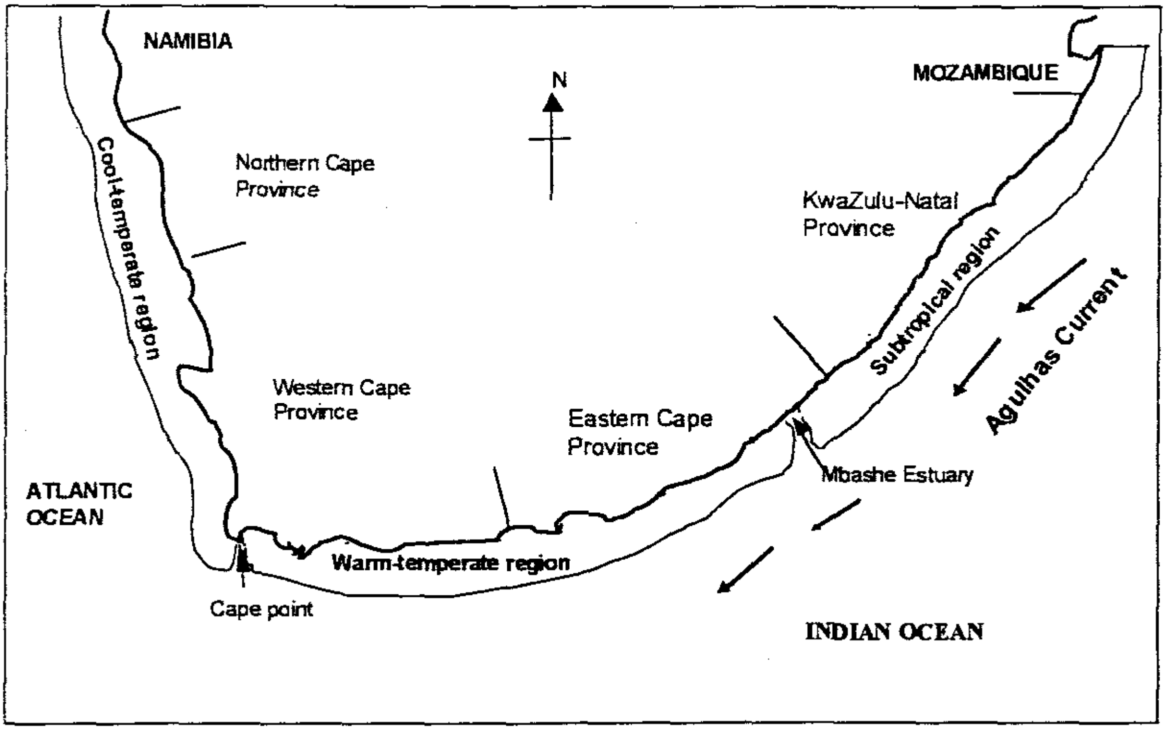

Figure 3. 1 Map of southern Africa showing the subtropical, warm-temperate and cool-temperate regions (After Whitfied 1998).

This current flows down the east coast, meanders and sheds eddies both clockwise onto the shelf and anti-clockwise offshore into the Indian Ocean. Towards the south of South Africa, the Agulhas current is deflected south-eastwards as the return Agulhas current (Figure 2.1).

The Agulhas Current is affected by seasonally prevalent winds (Heydorn 1978). In summer, the strong and constant south-east trade winds blowing over southern Africa promotes the southward movement of the Agulhas current. Periodically, warm, mixed water from the Agulhas Bank in the southern part of South Africa (around Cape Town) intrudes into the south Atlantic ocean carrying Indian ocean plankton species and larvae up the west coast as far as Saldana Bay in summer (Heydorn 1978). However, in winter, the westerly winds drive the movement of cool water of mixed origin from the Agulhas Bank region in a north-easterly direction on the inside of the Agulhas Current (Heydorn 1973).

Tides and waves

The southern African coastline is subjected to strong wave action, resulting in few sheltered beaches (Field and Griffiths 1991). Strong wave action cause a high degree of turbulence, leading to harsh conditions in the surf zone. Tides limit wave height by affecting nearshore water depth and are important in determining the volume of water within the surf zone (Brown and McLachlan 1990). The entire coast of southern Africa is subjected to a simple semi-diurnal tidal regime, with a spring-tide amplitude of 2-2.5 m and a neap-tidal range of approximaly 1 m (Field and Griffiths 1991). Tidal range is also influenced by swell and according to Duncan (1975) 50% of the swells experienced off Durban are approximately 3.5 m. Harris (1961) describes the prevailing swell as being from the south, with a breaking speed or interval of 10-12 second, so that there is continuous surf action.

Conductivity

The total amount of material dissolved in water is commonly measured as TDS (total dissolved salt) or as electrical conductivity. The electrical conductivity of water refers to its ability to conduct an electrical current and it is directly proportional to TDS. The most common dissolved ions in the sea that have a capacity to carry an electrical charge include Na^+, K^+, Ca^{2+}, HCO^{3-}, CO_3^{2-}, Cl^-, Mg^{2+}, SO_4^{2-} and NO^{3-}. Changes in electrical conductivity of water under natural conditions can be due to dissolution of rocks, soils and decomposing plant material (Dallas and Day 1993).

Turbidity

Turbidity is determined by the amount of suspended sediments such as clays and silt (particle size between 0.001 µm and 0.1 µm) which are introduced in the marine water through river run-off (DWF 1995). Turbidity may also be introduced to the water column through re-suspension of natural debris during turbulent conditions, which may be caused by strong wind and wave action. Turbidity plays an important role in activity patterns such as the distribution and behaviour of marine animals such as fish (Cyrus and Blaber 1987). In the surf zone environment, turbidity tends to vary depending on the wind direction, wave height and the distance from the mouth. Clarke *et al.* (1994) reported that turbidity was higher immediately opposite open estuary mouths of the Zandvlei and Eerste estuaries (Western Cape) in the surf zone owing to the input of turbid water from the estuary.

pH

The normal pH range of seawater is generally very small, from 7.9 to 8.2 (DWAF 1995). Water held between particles in sandy beaches may become more acidic, though the pH rarely falls below 7, while in pools and sheltered inlets on calm days the photosynthetic activity of seaweeds may remove sufficient bicarbonate to raise the pH level to 9 or more (Moore 1966). Eutrophication such as algal blooms can result in increased pH values, since excessive primary production consumes CO_2 and thus alters the equilibrium of the CO_2/HCO_3 buffering system (Dallas, Day and Reynolds 1994). However, the surf zone pH is generally constant.

Dissolved oxygen

The dissolved oxygen (DO) concentration is one of the most important abiotic factors affecting aquatic organisms (DWAF 1995). Various factors determine the amount of oxygen that can be dissolved in water. These include the rate of aeration from the atmosphere, temperature/salinity regimes, respiration by organisms, organic content and photosynthesis. In the surf zone, oxygen levels can be high due to wave action. The amount of dissolved oxygen can be reduced by an increase in temperature and salinity, O_2 consuming chemicals, effluents, high levels of organic waste and bacterial decomposition that consumes O_2. As a result, dissolved oxygen tends to vary in the surf zone owing to seasonal changes in temperature and salinity.

Sulphur

Sulphur in water occurs largely as sulphate (SO_4^{2-}) ion. Sulphate ions rarely limit the growth or distribution of the aquatic biota. In excess, however, dissolved sulphate results in the formation of sulfuric acid, which is a strong acid and can have deleterious effects on aquatic ecosystems through changes in pH (Dallas *et al.* 1994).

3.1.2 Chemical variables

Nitrogen, phosphorus and silicon

Nitrogen and phosphorus are important nutrient elements in marine systems, with nitrogen more often limiting for growth and reproduction in marine phytoplankton and benthic diatoms (Brown and McLachlan 1990). In the surf zone, nutrients are generally abundant due to freshwater inputs. Nitrogen can naturally enter surf zones and beach systems through groundwater seepage, rainfall and inputs from other systems (upwelling or from estuaries) in the form of inorganic and organic nitrogen (Brown and McLachlan 1990). High levels of nitrogen and phosphorus are caused by effluents from sewage treatment works, industry, and agricultural runoff from extensive use of fertilizers (van Vuuren *et al.* 1999). Most of these nutrients, except for nitrite and ammonia, are not directly toxic to aquatic organisms even in high concentrations (van Vuuren *et al.* 1999).

Silicon occurs as silica (SiO_2) and silicates in sand, sandstone and diatomaceous earth (Sharp 1990: in van Vuuren *et al.* 1999). Silica is a plant nutrient required for normal plant growth and reproduction. There is evidence that the source of silica and other nutrients such as nitrogen and phosphorus delivered to the coastal seas are from rivers (Justic *et al.* 1995). The importance of riverine biogenic silica to the oceanic budget has been reported (Conley 1997) and it was demonstrated that biogenic silica from rivers plays an important role to coastal sea productivity.

Nutrient distributions off the Richards Bay were studied by Carter and d'Aubrey (1988: in Schumann 1988) using data obtained from the South African Data Centre for Oceanography (SADCO). It was found that nutrient distributions in the Richards Bay area were not uniform which could be due to the vertical and horizontal gradients in nutrient concentrations found in the area. Nutrient (nitrates, silicates and phosphates) concentrations exhibited positive gradients with depth (10, 50 and 100 m) off Richards Bay, and a negative gradient with distance offshore (inner-shelf, mid-shelf and outer-shelf). These horizontal and vertical gradients were attributed to the origin (source) of the water on the continental shelf, sporadic upwelling that occurs up against the continental margin and biological modification of the nutrient levels.

Chlorophyll-a

Chlorophyll-a is the primary photochemical absorber of sunlight predominantly found in plants e.g. algae. The concentration of chlorophyll is a good indicator of primary production (since chlorophyll-a is directly proportional to the algal biomass) and living photosynthetic microorganisms present in aquatic systems. Paula *et al.* (1998) reported seasonal variation in chlorophyll-a concentrations along the coast at Inhaca Island, southern Mozambique with maximum concentrations occurring in April and September. Maximum chlorophyll-a concentrations were due to the accumulation of nutrients (nitrates, silicates and phosphorus) measured during the summer, rainy period. They also demonstrated that chlorophyll-a variations matched increased zooplankton (mainly herbivorous species collected by the 125 µm net) abundance during the early warm season, from September to November, except in March when the abundance of zooplankton was low.

In view of the physico-chemical variability of the surf zone and nearshore environment, the information on the effects on the zooplankton is, however, lacking in KwaZulu-Natal.

3.1.3 Aims and objectives

The aims of this chapter were to investigate the seasonal, spatial (site) and diel (day/night) patterns in physico-chemical variables measured in the St. Lucia and Mhlathuze surf zones.

3.1.4 Hypotheses and Null Hypotheses

The following null (HO) and alternate (HA) hypotheses were tested with reference to the physico-chemical variables in the two surf zones.

HO_1–There are no temporal and spatial differences in physico-chemical variables.

HA_1–There are temporal and spatial differences which are due to variations in physico-chemical variables.

HO_2–There are no significant differences between two systems (the St. Lucia and Mhlathuze surf zones) in terms of the measured physico-chemical variables.

HA_2–There are significant differences between the physico-chemical variables or conditions measured in the St. Lucia and Mhlathuze surf zones.

3.2 Methods

3.2.1 Sampling in the St. Lucia and Mhlathuze surf zones.

At St. Lucia and the Mhlathuze estuaries, the physico-chemical parameters were measured *in situ* during the day and night of each sampling date. Sampling was carried out during the new moon at spring low tide of each month from February 1992 to January 1993 at St. Lucia (Harris 1996) and November 1998 to October 1999 at the Mhlathuze surf zone. This was done because the sea is rough at high tide which made sampling difficult and dangerous. The physico-chemical parameters measured were temperature (°C), salinity (°/₀₀), dissolved oxygen (mg/l), oxygen saturation (%), pH and conductivity (μS). Oxygen, pH and conductivity were, however, not measured at the St. Lucia surf zone by Harris (1996) because a Hydrolab Datasonde logger was not available.

Temperature, salinity, oxygen, water pH and conductivity

At St. Lucia, the water temperature (°C) at each sampling site was measured using a WTW OXI 96 Microprocessor Oximeter. Salinity was measured using an American Optic Refractometer-temperature compensated (Harris 1996). At the Mhlathuze surf zone, the water temperature (°C), salinity (‰), dissolved oxygen (mg/l), oxygen saturation (%), pH and conductivity (μS) at each sampling site were measured using a Hydrolab Datasonde Multiprobe logger.

Turbidity

Water samples from the field were collected in numbered turbidity bottles and brought to the laboratory. Turbidities were measured using a Hach Turbidometer and expressed in Nephelometric Turbidity Units (NTU). At St. Lucia, Harris (1996) measured turbidities using a Hellige Nephelometer.

3.2.2 Data Analysis

Temporal and spatial variation in the physico-chemical variables of each surf zone were shown by calculating and plotting the mean and ranges for each season, site and time of day. The physico-chemical (normalised) data were subjected to Principal Component Analysis (PCA) to elucidate trends within and between sampling sites during the study period. This analysis was done in order to determine temporal and spatial patterns resulting from variations in physico-chemical factors.

(i) within each site

(ii) among sites at each surf zone

(iii) within each season

(iv) among seasons at each surf zone

(v) within each time of day

(vi) between times

(vii) between the two surf zones.

The PCA technique is widely applied to the interpretation of environmental variables such as physical, chemical, physiographical, morphometrical or climatological variables in ecological studies (Clarke and Warwick 1994).

The Principal Component Analysis results in a 2-dimensional ordination of the first two axes which represent a plane of "best fit" giving the maximum amount of variation in sample points (Clarke and Warwick 1994). The degree to which a 2-dimensional PCA succeeds in representing the full picture/information is seen in the percentage of total variance explained by the first two PCs. If PC1 and PC2 explain less than 40 %, then a 2-dimensional PCA ordination may give an inadequate and potentially misleading picture of the relationship between the samples. But if the PC1 and PC2 account for as much as 70-75 % of the original variation, a 2-dimensional ordination is likely to describe the overall structure well (Clarke and Warwick 1994).

Any significant differences between systems were tested using the Student t-test (Zar 1996), while the significance of any differences among seasons, sites and time of day were tested using Tukey's multiple range analysis (Anova) at 95% confidence intervals in Stagraphics® programme (Manugistics 1993). A multifactor analysis of variance (MANOVA) test at a 95 % confidence limit was also used to test for any significant differences between temperature, salinity and turbidity with regard to season, site and time of day. However, parametric statistical analyses were performed on appropriately transformed physico-chemical data in order to conform to normality and homogeneity of variances (Sokal and Rohlf 1981).

3.3 Results

Temporal and spatial changes in physico-chemical variables at St. Lucia and the Mhlathuze.

The mean and ranges of physico-chemical factors measured over the study period are shown in Figure 3.2 for St. Lucia and Figures 3.3 and 3.4 for the Mhlathuze surf zone. The actual physico-chemical measurements are shown in Appendix 1 for St. Lucia and Appendix 2 for the Mhlitathuze surf zone.

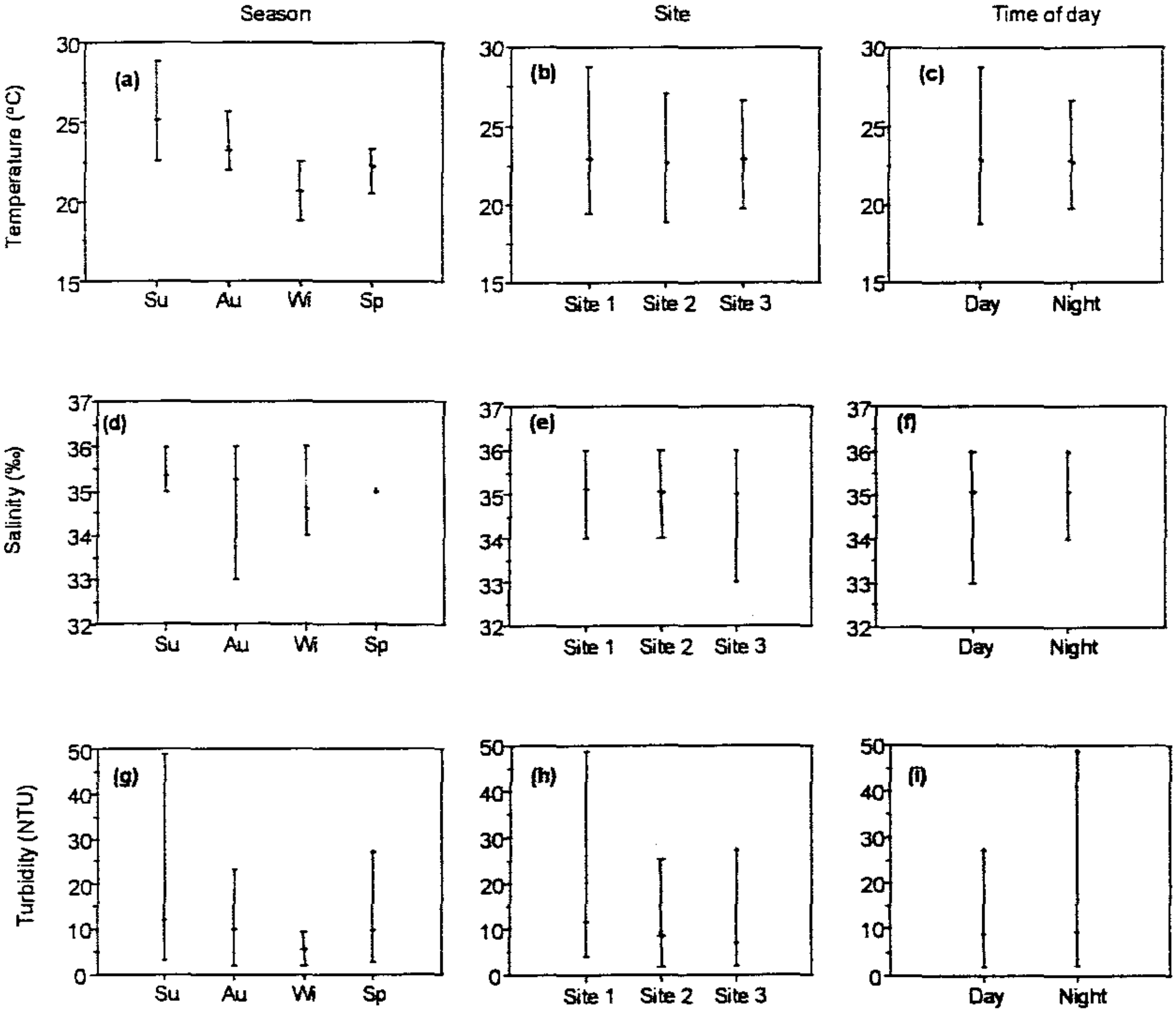

Figure 3. 2 Mean and range of temperature, salinity and turbidity measured in the St. Lucia surf zone between February 1992 and January 1993 averaged across all sites for each season (a, d and g), averaged over the study period for each sampling site (b, e and h) and averaged across sites and season for each time of day (c, f and i). Su=summer, Au=autumn, Wi=winter and Sp=spring.

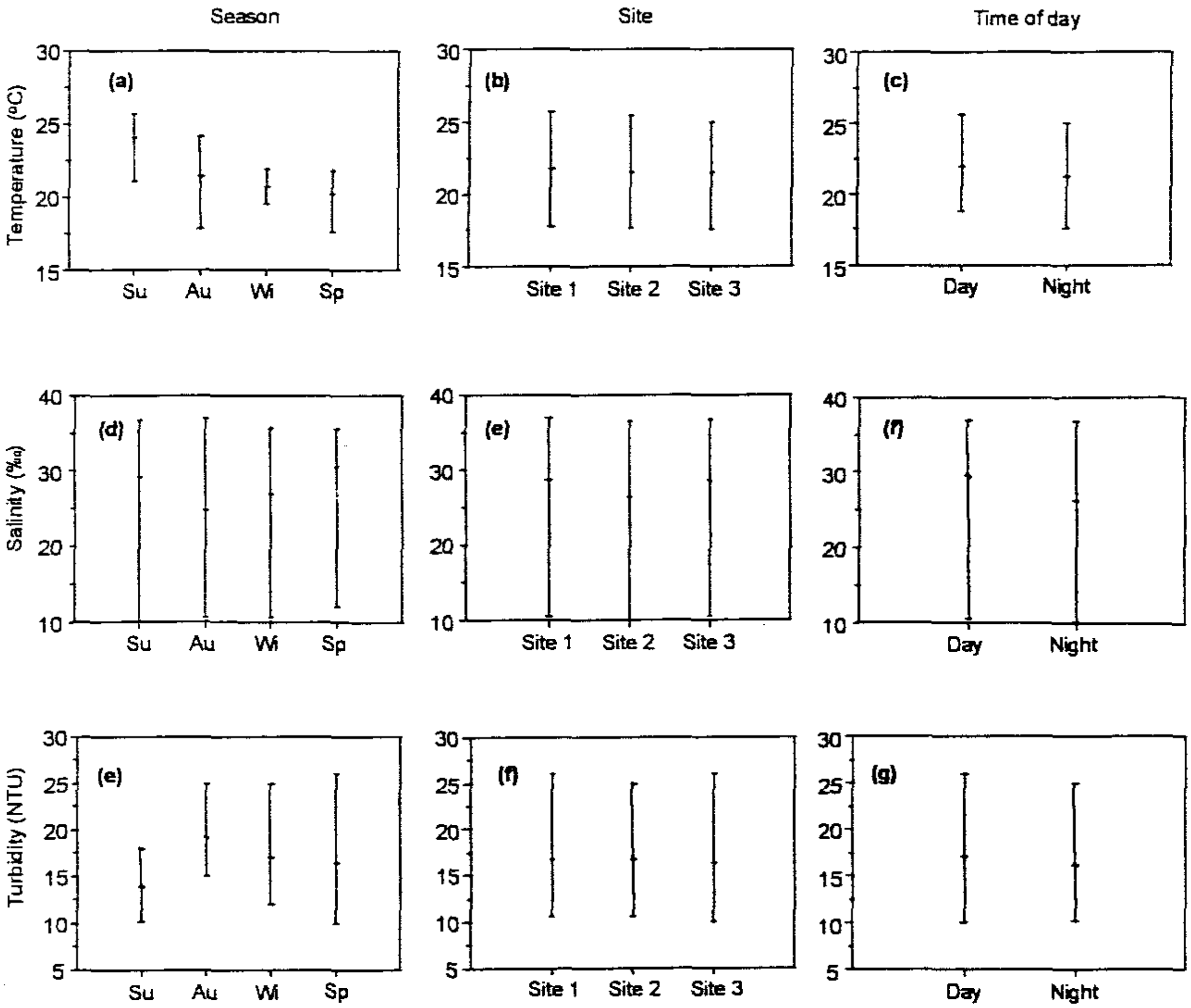

Figure 3. 3 Mean and range of temperature, salinity and turbidity measured in the Mhlathuze surf zone between November 1998 and October 1999 averaged across all sites for each season (a, d and g), averaged over the study period for each sampling site (b, e and h) and averaged across sites and season for each time of day (c, f and i). Su=summer, Au=autumn, Wi=winter and Sp=Spring.

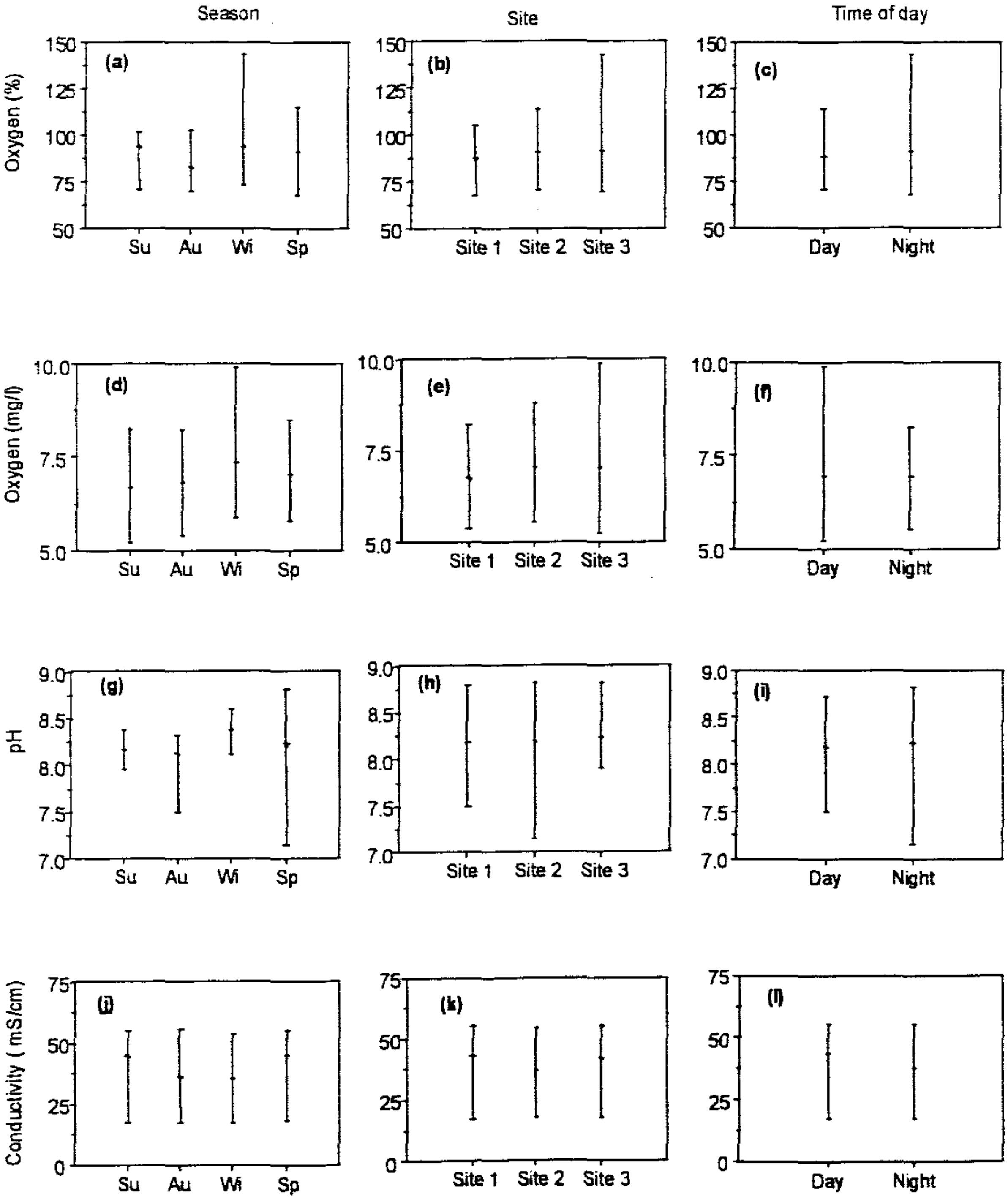

Figure 3. 4 Mean and range of oxygen, pH and conductivity measured in the Mhlathuze surf zone between November 1998 and October 1999 averaged across all sites for each season (a, d g and j), averaged over the study period for each sampling site (b, e, h and k) and averaged across sites and season for each time of day (c, f, i and l). Su=summer, Au=autumn, Wi=winter and Sp=Spring.

Temperature

At St. Lucia, temperatures recorded in the surf zone are given in Figure 3.2(a)-(c). They showed a typical subtropical seasonal range with a maximum summer temperature of 28 °C and a minimum winter value of 19 °C (Figure 3.2a). Mean temperatures were higher in summer, autumn and spring than in winter. Spatially, sites near the mouth (Site 1 and 2) showed higher fluctuations in temperature than Site 3, particularly in the St. Lucia surf zone. At St. Lucia, a maximum temperature of 28 °C was recorded at Site 1 and a minimum value of 19 °C recorded at Site 2 while there were no marked differences among sites in the surf zone (Figure 3.2b).

Figure 3.3(a)-(c) shows temporal and spatial variation in temperatures at Mhlathuze. The temperature at the Mhlathuze surf zone ranged from a minimum spring temperature of 16 °C to a maximum summer temperature of 26 °C (Figure 3.3a). At the Mhlathuze surf zone, seasonal differences in temperatures measured were apparent, with autumn, winter and spring lower than summer. There were no marked differences among sites in the surf zone at the Mhlathuze (Figure 3.3b). Higher temperatures in both surf zones were generally measured during the day (Figures 3.2c and 3.3c).

Salinity

Temporal and spatial variation in salinity are shown in Figure 3.2(d)-(f) for St. Lucia and Figure 3.3(d)-(f) for Mhlathuze. Salinity levels in the surf zone at St. Lucia showed less seasonal variation compared with the Mhlathuze. At St. Lucia, salinity levels ranged from 33 ‰ in autumn to 36 ‰ in summer, autumn and winter (Figure 3.2d). In the Mhlathuze surf zone, salinity levels reflected the influence of estuarine conditions with a minimum salinity value of 10.1 ‰ in summer and a maximum value of 36 ‰ recorded in and autumn. However, mean salinities measured in the Mhlathuze surf zone showed seasonal differences, with summer and spring higher than autumn and winter. With respect to site, mean salinity levels showed no marked differences between sites in both surf zones. However, in Mhlathuze surf zone, mean salinity values were higher at Site 1 and 3 than at Site 2 (Figure 3.3e). Low salinity levels at sampling sites indicated the inflow of freshwater through the estuary mouth or from rainfall.

Turbidity

Turbidities in the surf zone at St. Lucia showed a seasonal pattern with increased levels in summer and low levels in winter (Figure 3.2g). Turbidity was high in summer (up to 48 NTU in January 1993), but the surf zone cleared at Site 2 in winter and spring to below 10 NTU.

There were no marked differences among sites and between day/night in turbidity values measured in the St. Lucia surf zone, with high turbidity values recorded at Site 1 mainly at night (Figure 3.2h-i).

Turbidity levels measured in the surf zone at the Mhlathuze ranged from 10 to 26 NTU in spring mainly at Site 3 during the day (Figure 3.3g-i), and remained above 10 NTU. Turbidities at the Mhlathuze did not show the seasonal variation recorded at St. Lucia (Figure 3.2g). However, turbidity values increased markedly between summer and autumn followed by a slight decrease in winter and spring in the surf zone at the Mhlathuze. There were no marked differences among sites and between day and night in turbidity values measured in the Mhlathuze surf zone (Figure 3.3h-i).

Dissolved oxygen

Dissolved oxygen in the Mhlathuze surf zone ranged from 67% in spring to 143% in winter mainly at Site 3 (Figure 3.4a-c). Seasonally, oxygen levels decreased slightly between spring and autumn and increased slightly in winter reflecting the influence of seasonal changes in temperature. Decreased oxygen levels in summer and autumn corresponded to higher temperatures and suggested that temperature reduced the ability of water to hold oxygen. Dissolved oxygen also ranged between 5.2 in summer and 9.9 mg/l in winter at site 3 during the day (Figure 3.4d-f).

pH

The pH of the Mhlathuze surf zone followed a similar seasonal pattern to oxygen saturation and ranged from 7.1 to 8.8 in spring at Site 2 (Figure 3.4g-i). Seasonally, the pH decreased between summer and autumn, slightly increased in winter and decreased again in spring (Figure 3.4h). Seasonal variations in pH reflected the influence of freshwater inflow and photosynthetic activity in the surf zone with the marine influence at Site 1, 2 and 3 resulted in the relatively stable pH.

Conductivity

The conductivity of the Mhlathuze surf zone ranged from 17.6 to 55.9 mS/cm and showed slight differences with reference to site, season and time of day. However, the conductivity at Site 1 decreased between spring and autumn mainly at night (Figure 3.4j-l). Low conductivity at the Mhlathuze also coincided with low salinities over the study period. The drop in conductivity was due to high level of freshwater inflow from the Mhlathuze River and rainfall mainly in summer. The low conductivity and salinity levels at Site 1, 2 and 3 also suggested that mixing of marine and freshwater that occurs in the estuary was extended to the surf zone at the Mhlathuze estuary.

Ordination of physico-chemical variables

PCA plots showing the relationship (correlation) between physico-chemical variables and differences between seasons, sites and times at St. Lucia and Mhlathuze are presented in Figures 3.5(A-D) and 3.6(A-D) respectively. All physico-chemical variables were log transformed. Seasonal patterns in physico-chemical variables such as temperature, salinity and turbidity were evident in both the St. Lucia and the Mhlathuze surf zones.

Both components revealed obvious seasonal patterns in the combination of temperature, salinity and turbidity (Figure 3.5C and 3.6C), but not for site or time of day, with PC 1 and PC 2 accounting for 82 % and 72.77 % of the variance at St. Lucia and the Mhlathuze surf zones respectively. The first two components at both St. Lucia and the Mhlathuze estuaries accounted for greater than 70 % of total variation, resulting in a 2-dimensional ordination that gives useful information on the relationship between samples and reflects the actual situation. The PC1 component represented an axis of increasing physico-chemical variable levels with low values recorded in winter and high levels being recorded in summer in both surf zones. The second component (PC 2) showed increased physico-chemical levels from autumn through to summer at the Mhlathuze estuary. There was less change observed at St. Lucia except for one sample that was separated on basis of a high turbidity level (49 NTU) measured in summer at Site 1 at night.

Analysis of significant differences between samples using the Student t-test (Zar 1996) revealed that both systems were significantly different in terms of temperature, salinity and turbidity (Table 3.1). As a result the null hypothesis stating that the measured physico-chemical variables were similar in both systems was rejected and the alternate hypothesis stating that the physico-chemical conditions in the two surf zones are different was accepted. Mean temperatures at St. Lucia were significantly higher than at the Mhlathuze (Table 3.1).

Table 3.2 shows the result of the multifactor analysis of variance of physico-chemical variables measured in the St. Lucia and Mhlathuze surf zones for season, site and time of day factors. In both surf zones, there were significant differences in temperatures among seasons (Table 3.2). At St. Lucia, temperatures recorded in summer were significantly different from temperatures measured in autumn, winter and spring. Winter temperatures were significantly different from temperatures recorded in spring and autumn (Table 3.3).

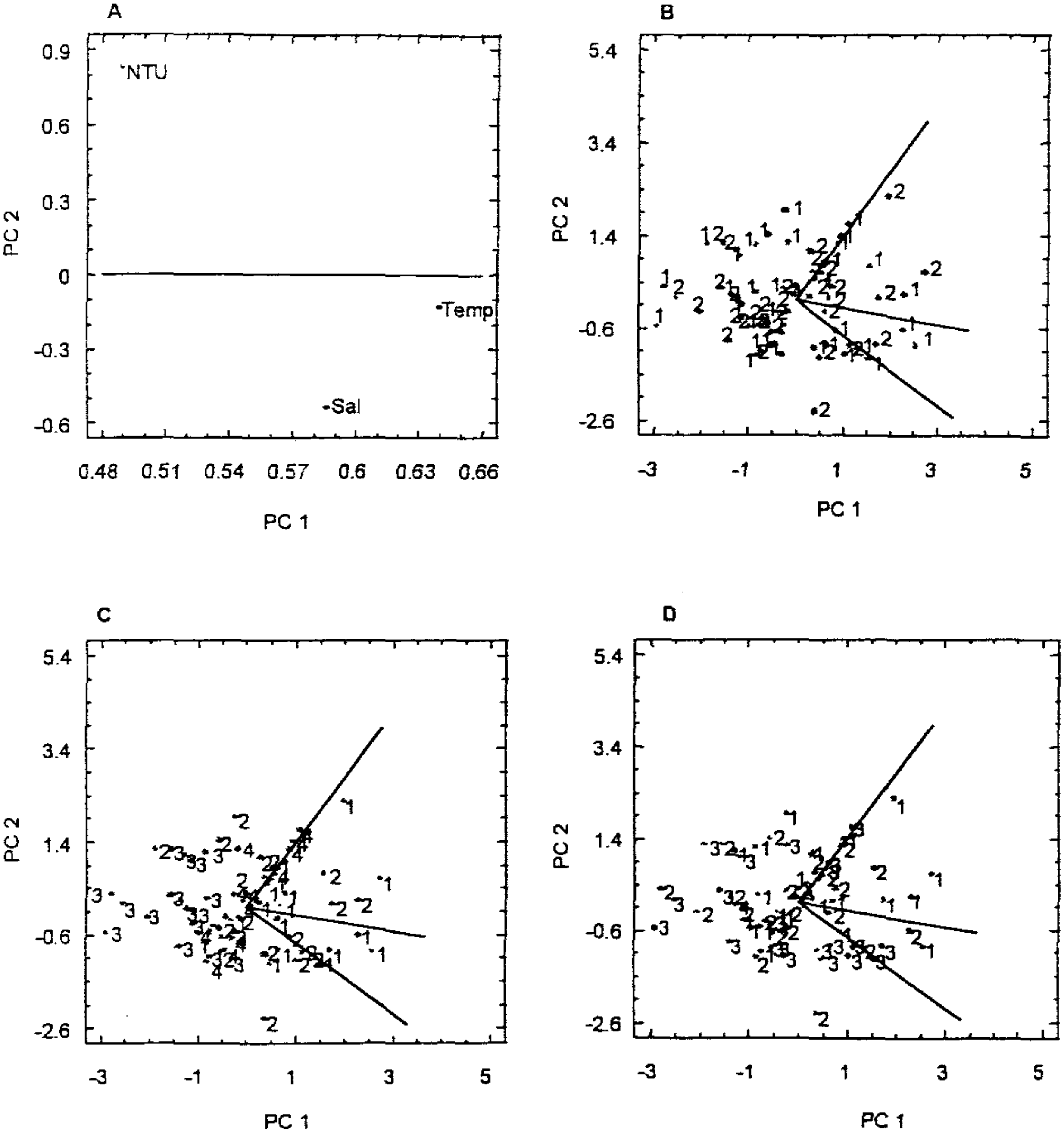

Figure 3. 5 Standard centred PCA of physico-chemical variables (A) and samples for the first two axes of Principal Component analyses for the data set from February 1992 to January 1993 at St. Lucia, illustrating patterns in time (B), season (C) and sites (D). Time 1=day and time 2=night, season 1=summer, season 2=autumn, season 3=winter and season 4=spring.

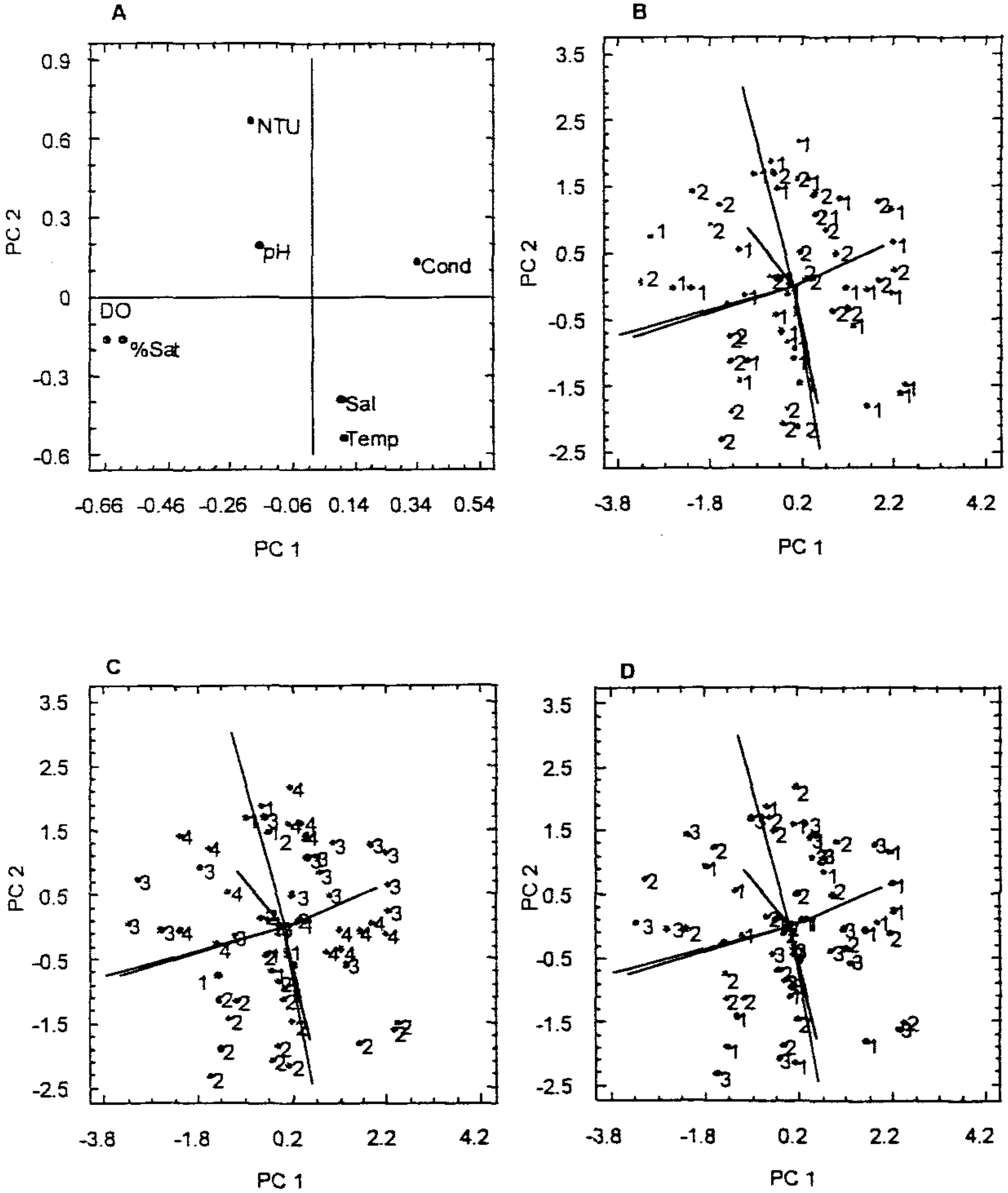

Figure 3. 6 Standard centred PCA of physico-chemical variables (A) and samples for the first two axes of Principal Component analyses for the data set from November 1998 to October 1999 at the Mhlathuze, illustrating patterns in time (B), season (C) and sites (D). *Time 1=day and time 2=night, season 1=spring, season 2=summer, season* 3=autumn and season 4=winter.

Mhlathuze surf zone temperatures measured in summer were significantly different from all other seasons including autumn, winter and spring (Table 3.4).

Salinities in the surf zone at St. Lucia differed significantly seasonally but not significantly among sites (Table 3.2). Multiple range analysis of salinity values showed that summer and autumn salinities differed significantly from winter (Table 3.3). In the Mhlathuze surf zone, there were no significant differences in salinity levels among seasons and sites (Table 3.2). The multifactor analysis of variance (MANOVA) indicated that there were no significant differences in turbidities among seasons, sites and between day and night in the surf zone at St. Lucia, while there were significant seasonal differences in turbidities measured in the Mhlathuze surf zone (Table 3.2). At the Mhlathuze, multiple range analysis of turbidity values showed that summer turbidities were significantly different from turbidities measured in autumn (Table 3.4). At both the St. Lucia and Mhlathuze surf zones, no significant interactions were found between time of day and site; season and site; and time of day, season and site for any of the physico-chemical variables measured (Table 3.2) which confirmed the results of Principal Component Analysis.

Table 3.1: Results of Student's t-test at P<0.05* showing differences between the St. Lucia and Mhlathuze surf zones in terms of temperature, salinity and turbidity. DF= degree of freedom.

System	DF	Temperature (°C)	Salinity (‰)	Turbidity (NTU)
Comparison		P	P	P
St. Lucia vs Mhlathuze	142	<0.001*	<0.001*	<0.001*

Table 3.2: Multifactor analysis of physico-chemical variables (temperature, salinity and turbidity) measured in the St. Lucia and Mhlathuze surf zones for sampling season, site and time factors at a confidence limit of 95% (P<0.05*). F-ratios are based on the residual mean square error. DF= degree of freedom.

		Temperature (°C)		Salinity (‰)		Turbidity (NTU)	
	DF	F	P	F	P	F	P
The St. Lucia surf zone							
Source of Variation							
tod	1	0.116	0.735	0.001	0.982	0.41	0.54
season	3	31.393	<0.001*	3.538	0.021*	2.65	0.05
site	2	0.139	0.870	0.183	0.834	3.12	0.05
tod x season	3	0.434	0.730	0.0746	0.973	1.20	0.33
tod x site	2	0.0884	0.916	0.0728	0.930	0.90	0.41
season x site	6	0.0282	1.000	0.112	0.995	1.04	0.42
tod x season x site	6	0.126	0.993	0.141	0.990	0.42	0.91
The Mhlathuze surf zone							
Source of Variation							
tod	1	3.580	0.065	1.597	0.212	0.684	0.412
season	3	15.762	<0.001*	0.876	0.460	4.399	0.008*
site	2	0.118	0.889	0.307	0.737	0.0657	0.936
tod x season	3	0.0718	0.975	0.496	0.687	0.125	0.945
tod x site	2	0.140	0.870	0.1000	0.905	0.0021	0.998

Table 3.2 continued...

season x site	6	0.0302	1.000	0.326	0.920	0.268	0.949
tod x season x site	6	0.0463	1.000	0.274	0.946	0.0786	0.998

Table 3.3: Analysis of variance (Tukey's ANOVA) at a confidence of 95% (P<0.05*) of temperature and salinity measured in the surf zone at St. Lucia between February 1992 and January 1993.

St. Lucia: seasons	**Temperature**		**Salinity**	
Pair-wise comparison	q	P	q	P
summer vs. winter	15.186	<0.001*	4.785	0.006*
summer vs. spring	9.557	<0.001*	2.208	0.407
summer vs. autumn	6.214	<0.001*	0.368	0.994
autumn vs. winter	8.972	<0.001*	4.417	0.014*
autumn vs. spring	3.343	0.094	1.840	0.565
spring vs. winter	5.629	0.001	2.576	0.272

Table 3.4: Analysis of variance (Tukey's ANOVA) at a confidence of 95% (P<0.05*) of temperature and turbidity measured in the surf zone at the Mhlathuze between November 1998 and October 1999.

Mhlathuze: seasons	**Temperature**		**Turbidity**	
Pair-wise comparison	q	P	q	P
summer vs. spring	10.729	<0.001*	5.861	0.196
summer vs. winter	9.286	<0.001*	3.026	0.067
summer vs. autumn	7.333	<0.001*	2.311	<0.001*
autumn vs. spring	3.396	0.087	3.550	0.151
autumn vs. winter	1.953	0.516	0.715	0.367
winter vs. spring	1.443	0.738	2.835	0.958

3.4 Discussion

Salinity, temperature and dissolved oxygen

Surf zones are characterized by fluctuations in saline conditions which are due to changes in freshwater input from rivers and through rainfall. At St. Lucia, salinity levels were typical of marine saline conditions with a summer maximum of 36 ‰ and autumn minimum of 33 ‰ which lies within the target values according to South African Guidelines for Marine Waters (DWAF 1995). Salinity increased due to high temperatures and high evaporation rates during summer and occasionally in winter and spring. Although rainfall is expected to be the main factor influencing salinity in the St. Lucia surf zone, the Agulhas Current running close to the shelf (Shannon 1989) seems to have a major influence in changing salinity conditions. This is due to intrusion of Agulhas water, which has a typically warm, saline condition (35.2-35.5 ‰ particularly surface and subsurface waters of tropical and subtropical origin), causing increased salinity levels in the surf zone. However, decreased salinities, mainly in autumn, reflect high inland rainfall conditions in autumn/late summer and subsequent runoff.

The slight spatial changes in salinity recorded along the surf zone at St. Lucia were due to near-shore currents mixing estuarine and sea water, resulting in similar salinity conditions between sites in the study area. However, at the Mhlathuze surf zone, a wide range of salinities were recorded with the fresh water influence much more pronounced than at St. Lucia. Differences in salinities between the two surf zones reflected the influence of current systems off the two estuaries and freshwater outflow via the estuary mouths. At St. Lucia, there are no major rivers entering the estuary compared with the Mhlathuze which has a greater tidal exchange volumes and freshwater input from the Mhlathuze River (Owen and Forbes 2002). Differences between the St. Lucia and Mhlathuze surf zones, in terms of salinity, can also be accounted for by the presence of a dry period (1992/93) at St. Lucia and a high rainfall period (1998/9) when the Mhlathuze surf zone was sampled (Figure 3.7).

In the surf zone at Mhlathuze, salinities at times were as low as 10.5 ‰ which is not within the target values to be met for coastal waters (DWAF 1995). The Mhlathuze estuary mouth was opened throughout the study period, and it is unlikely that it will close because of the strong tidal flow related to the size of the estuary (Huizinga and Van Niekerk 1998), resulting in an exchange of about 80% of estuarine water at each tidal cycle. The freshwater pulses from the Mhlathuze River have been reported in the Mhlathuze estuary which enter the estuary on the north eastern corner, and the greater part of this freshwater flows along the northern border (the berm wall) out to sea without dispersing into the larger estuary basin (Jerling: In DWAF 2000). Reduced salinity levels in the surf zone during this study were attributed to such increased freshwater outflow via the mouth from the estuary and high runoff/seepage as a result of high rainfall in the spring, summer, autumn and winter months. As a result brackish conditions developed in the surf zone suggesting that mixing of fresh water from the Mhlathuze River and the oceanic water occurred in the surf zone. The general increased mean salinities during spring and summer during the day can be due to high temperatures recorded in the surf zone. Beyst, Hostens and Mees (2001) recorded a maximum salinity value of 34 ‰ during winter in the surf zone of the Belgian coast.

Temperature changes generally followed typical subtropical conditions in both surf zones with higher temperatures being recorded from spring through to autumn, reflecting atmospheric temperature conditions. High temperatures during the day were due to the increased summer insolation. Clarke *et al.* (1994) recorded lower mean summer (22 °C) and winter (13.5 °C) water temperatures in Muizenberg and Macassar surf zones (South-Western Cape) than those recorded during this study.

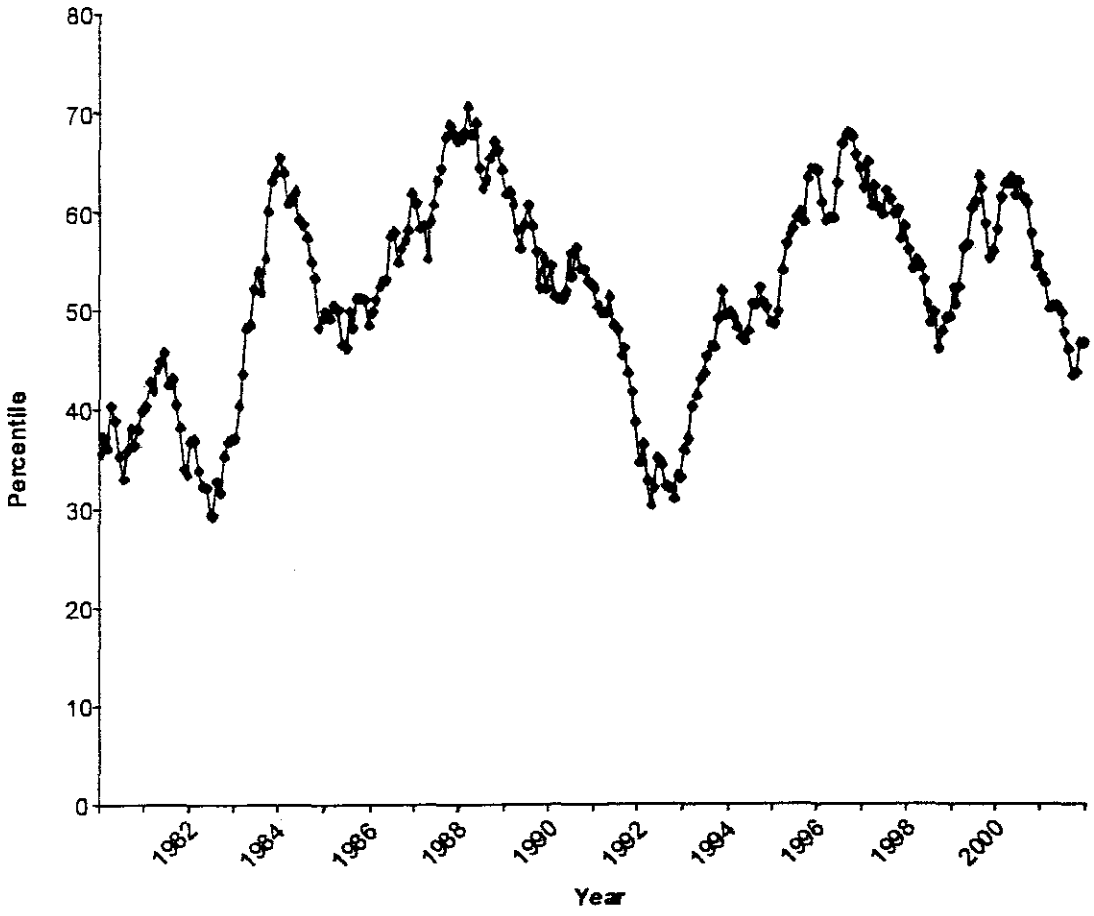

Figure 3. 7 Percentile (e.g. 50%=normal) of the mean monthly rainfall (mm/day) data for the Zululand region (27.5° to 30° S; 30° to 32.5°E) starting from January 1980 to December 2001 (National Weather Service Climate Prediction Centre website[1]).

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[1] www.nws.noaa.gov

Beyst, Hostens and Mees (2001) reported a maximum water temperature during early summer (21.3 °C) in the surf zone of the Belgian coast which is lower than those recorded in the St. Lucia and Mhlathuze surf zones. Water temperatures measured during this study were lower than those recorded by Paula *et al.* (1998) off the Inhaca Island (Mozambique) at 1 m depth levels, which reflected the subtropical conditions and evaporation due to higher levels of insolation in Maputo Bay.

High temperatures have been reported to reduce the capacity of water to hold oxygen, resulting in reduced dissolved oxygen concentrations. However, the surf zone was well oxygenated due to aeration, resulting from wave action and mixing caused by wind and water currents. Another factor that can lead to reduced oxygen levels in the nearshore zone is high levels of nitrates and phosphates which results in the occurrence of algal blooms (Paipai and Brooke 1993). This could not be a factor in the Mhlathuze surf zone because the water was well–oxygenated and there were no algal blooms observed during this study.

Turbidity and pH

The surf zone is characterized by high wave action and longshore currents, which increase the potential for resuspension of sediment. As a result turbidities may be increased. Turbidities at St. Lucia were ascribed to high wave action and longshore currents. The strong prevailing northeasterly or southwesterly winds and wave action would also bring fine sediment and detritus into suspension. The increased turbidities near the mouth suggested that particulate matter was transported with the current, and ultimately washed into the estuary by incoming tide.

Turbidities in the Mhlathuze surf zone, in contrast, did not follow the same pattern as St. Lucia, with lower turbidities recorded in summer than in winter. Dredging activities in Richards Bay Harbour would deposit spoil onto the beach north of the estuary mouth and dissipation through wave action resulted in sediment being carried and washed into the estuary with incoming tide (Wepener and Vermeulen 1998/99). However, the estuary had deepened and large amounts of fine sediment were brought to suspension by wind and wave action and probably transported out to sea with the ebb current (Huizinga: In DWAF 2000). During the ebb tide, sediments would be flushed out of the estuary and carried northwards in the surf zone with the inshore current in summer. The reduced turbidity during this period could not be explained during this study. The seasonal patterns in turbidity in the Mhlathuze surf zone reflected the wind-driven inshore currents which exhibited no major seasonal patterns (Schumann 1988). At both St. Lucia and Mhlathuze, there were no significant differences among sites which might be due to inshore currents which ensure that the turbidity is distributed along the coast (Cooper *et al.* 1993). Turbidities measured during this study were higher than those recorded by Clarke *et al.* (1994) who reported that turbidities ranged from 2-3 NTU during summer to 3-5 NTU during winter in the Muizenberg and Macassar surf zones (South-Western Cape). Beyst, Hostens and Mees (2001) recorded higher maximum value of turbidity (774 NTU) during winter in surf zone of the Belgian coast than those measured during this study.

Sea water is a solution of various salts, most of them fully ionized, with a concentration varying from 30 to 35 $^{0}/_{00}$ on most shores, sometimes rising to 40 $^{0}/_{00}$ in certain conditions. The most important dissolved substance in seawater is bicarbonate, as it has a substantial buffering action (Moore 1966). The mean pH values in the Mhlathuze surf zone were within normal sea water pH range (7.9 to 8.2), with the exception in spring at Site 2 when a minimum and a maximum values of 7.1 and 8.8 were measured respectively. High pH values can reflect the photosynthetic activity of phytoplankton that may remove sufficient bicarbonate, leading to increased pH levels of approximately 9. Whereas slightly reduced pH, probably resulting from increased carbonic acid suggested that photosynthetic activity of phytoplankton was low.

3.5 Conclusions

The following conclusions were drawn with respect to physico-chemical variability of surf zones at St. Lucia and the Mhlathuze:

- Seasonal changes in the physico-chemical variables were recorded in both surf zones, with temperature reflecting "typical" subtropical conditions.
- All physico-chemical variables showed no significant differences between the day and night sampling conditions.
- Seasonal differences were found in the St. Lucia surf zone with respect to turbidity and salinity. Turbidity increased from late spring to early autumn due to high rainfall during these seasons.
- Increased temperature values in summer corresponded with high salinities that were attributed to increased evaporation rate.
- Both surf zones showed no significant differences among sites in terms of temperature, salinity and turbidity indicating interference resulting from the local circulations and near-shore currents.

- Both systems were significantly different from each other with respect to temperature, salinity and turbidity. This was attributed to current systems and the nature of the estuary mouth.
- Differences between the two surf zones can also be due to the time difference for sampling these surf zone since the St. Lucia surf zone was sampled in 1992/93 and the Mhlathuze surf zone in 1998/99, probably dry and wet cycles respectively.

CHAPTER 4

ZOOPLANKTON ASSEMBLAGES IN THE SURF ZONES ADJACENT TO THE ST. LUCIA AND MHLATHUZE ESTUARIES

CHAPTER 4

ZOOPLANKTON ASSEMBLAGES IN THE SURF ZONES ADJACENT TO THE ST. LUCIA AND MHLATHUZE ESTUARIES.

4.1 Introduction

Many invertebrate plankton and fish species utilise inshore and coastal areas (harbours and estuaries) as feeding grounds as well as shelter for protection against predation (Odum 1983; Forbes, Demetriades and Cyrus 1996). The KwaZulu-Natal coastline has few sheltered bays and these areas, together with estuaries, are important nursery areas for juvenile invertebrate species, e.g. prawns (Forbes *et al.* 1996). Many marine and estuarine fish and invertebrate species as such penaeid prawns, caridean shrimps and brachyuran crabs migrate from estuaries to spawn at sea and return to the estuarine environment as postlarvae or juveniles to utilise food sources and shelter provided by this environment. Other species of fish and invertebrates such as the bream *Acanthopagrus berda*, gobies and sesarmid crabs spawn in estuaries and release their larvae to the marine environment followed by a return of postlarvae to estuaries (Whitfield 1989). During such migrations, species have to pass through the surf zone. Surf zones in southern Africa are characterised by a high degree of turbulence caused by wave action (Dye *et al.* 1981). However, surf zones have been shown to function as nursery areas and provide a habitat for many fish and invertebrate species (Lasiak 1981, 1986; Cockroft and McLachlan 1986; Harris 1996).

Many studies have been undertaken on individual invertebrate species of taxonomic importance (e.g. Clutter 1967, Wooldridge 1981 and 1983), while few studies have focused attention on zooplankton assemblages in the surf zone. However, workers such as Elmhirst (1931), Watkin (1941) and Coleman and Segrove (1955) have recognised the distinction between those infaunal species performing vertical migrations into the surf water from the beach sands, and those moving in passively from adjacent waters by tide and wave action. Work on zooplankon assemblages of coastal areas has included studies by Leis (1982), Siokou-Frangou *et al.* (1998) and Chiba *et al.* (2001), which showed that zooplankton groups of different origin can be characterised on basis of their association with habitats.

Studies in surf zones in South Africa have been conducted on the recruitment and assemblages of fish species. Work done in the Eastern Cape includes the surf zone fish assemblages of Kings Beach (Lasiak 1981, 1983, 1986). In KwaZulu-Natal, Harris (1996) studied the surf zone larval fish assemblages adjacent to St. Lucia estuary mouth. These studies have demonstrated the ecological importance of surf zones as nursery areas for juvenile fish.

With regard to invertebrates, however, most of the attention has focused on infaunal beach crustaceans such as amphipods and isopods that occur both in the sediments and water column (Fincham 1970, Hughes 1982, Wooldridge 1981, 1983 and Warman *et al.* 1991). Studies on plankton in surf zones in South Africa include work by Clutter (1967), Cockroft (1982) and Wooldridge (1983) which examined transient macrozooplankton of the surf zone and nearshore zone off beaches. In South Africa, Romer (1986) examined the faunal assemblages and food chains associated with surf zone phytoplankton blooms. Comprehensive information on surf zone zooplankton assemblages is lacking in KwaZulu-Natal.

Given the general lack of information on the invertebrate communities of surf zones in South Africa, and KwaZulu-Natal in particular, the present study was conducted in the surf zones adjacent to the St. Lucia and Mhlathuze estuaries to provide quantitative information on zooplankton community structures from these surf zones. This chapter is aimed at describing the zooplankton assemblages in the surf zones of these systems to help understand the relationship between these estuaries and the adjacent surf zones and to further elucidate the importance of the surf zone.

4.1.1 Aims and objectives

The present study aimed to:

- Identify, describe and compare the planktonic invertebrate communities in each surf zone in terms of community structure, abundance and diversity,
- determine the spatial, temporal and diel variations and
- relate the zooplanktonic assemblages of these systems to the physico-chemical conditions of each surf zone.

<u>Hypotheses</u>

The following null (HO) and alternate (HA) hypotheses were tested with respect to the community structure, abundance and diversity.

- HO_1 – There is no significant difference between the species composition, abundance and structure of the two systems.
- HA_1 – The two surf zones are different in terms of community structure, abundance and diversity.

- HO_2 – There are no differences among seasons, sites and time of day in terms of species composition, abundance and structure in the two surf zones.
- HOA_2 – There are significant differences among sampling seasons, sites and time of day in terms of species composition, abundance and structure in the two surf zones.
- HO_3 – Zooplankton community structures in both systems are not related to any of the environmental variables measured during this study.
- HA_3 – Physico-chemical factors measured during this study affect community structures in the two surf zones.

4.2 Methods

4.2.1 Plankton sampling

All zooplankton samples were sampled using a plankton net with a 1 x 0.6 m rectangular opening and 500 µm mesh net, and equipped with a General Oceanics 2030R flowmeter and collecting bottle fitted to the end of the net. During each trawl the net was pulled, keeping it submerged, by two people through the inner surf zone for approximately 10 minutes (time noted for each trawl). Counts were recorded and used in the calculation of the water volume filtered for each trawl. The volume of water filtered in each tow was determined using the following equation:

volume (m^3) = $[{}^{\text{revs x 51020}}/_{999999}]$ xL,

where L is the area (m^2) of the rectangular opening and $[{}^{\text{revs x 51020}}/_{999999}]$ = distance covered in *each trawl in meters.*

Samples in the St. Lucia surf zone were collected monthly from February 1992 to January 1993 (Harris 1996) and from November 1998 to October 1999 in the Mhlathuze surf zone. These samples were collected during the day and following night during the new moon (spring low tide) at each site, except in July 1999 where sampling was conducted during the full moon due to the unavailability of assistants during the new-moon period. All plankton samples were immediately preserved in 4% formaldehyde. In both systems, replicate samples were not taken to reduce the number of samples to be sorted in the time available and, as this study was to provide a baseline study, it was decided not to replicate samples in favour of completing the study in the prescribed time. Three sites were sampled at each location as described in Chapter 2 (Figures 2.2 and 2.3).

Field preserved samples were brought to the laboratory for sorting, identification and counting. In the laboratory, the planktonic invertebrates, including larval, post-larval and adult stages were sorted and identified to the lowest possible taxon with the aid of a dissecting microscope and identification keys (Newell and Newell 1977; Day 1967a, 1967b, 1969; Griffiths 1976; and Kensley 1978). However, where specific identification was not possible within a reasonable time frame, zooplankton were grouped under broader taxonomic categories. For example copepods belonging to the genera *Corycaeus* were not identified further. The symbol sp. indicates that there was only one species in a particular genus, whilst spp. denotes that there were more than one species. Samples in which the numbers of invertebrates were too high to allow counting of whole samples were sub-sampled as follows:

Sub-samples were taken by means of a wide-mouthed pipette from a well-mixed suspension of known volume (200 ml) in a measuring cylinder. The dilution volumes were noted; and the animals in each sub-sample counted using a Bogorov counting tray under a dissecting microscope. The counting tray comprised a plate of glass approximately 12 cm long and 9 cm that has three grooves (Newell and Newell 1977). In all cases three sub-samples were counted to determine a mean for each sub-sample. After the number of each group for each sample has been recorded, it was converted to a density and expressed as the number of individuals per volume of water filtered.

4.2.2 Surf zone zooplankton composition

Zooplankton were grouped into two broad categories based on the information given by Brown and McLachlan (1990) according to their presence in the surf zone. These categories include resident and non-resident forms and are described as follows:

Resident forms

This group of surf zone zooplankton consists of true planktonic forms and bentho-planktonic forms, which include species that regularly, rather than permanently, occur in the surf zone. True planktonic forms include mysid shrimps, small prawns and the larval stages of sandy beach animals. Bentho-planktonic forms include aquatic isopods, amphipods and mysids that occur in the sand but migrate into the plankton, particularly during nocturnal high tides.

Non-resident forms

The non-resident holoplankton of surf zone is divided into two sub-categories – the micro-zooplankton, such as tintinnid ciliates and copepod nauplii, which pass through a 200 μm mesh. The meso- and macro-zooplankton, including copepods, cladocerans, chaetognathans and even jelly-fishes that may be transported from open ocean into the surf zone by winds and surface currents. Finally, the meroplankton, or temporarily resident zooplankton, comprises the larval stages of non-planktonic animals from estuaries, rocky shore and sandy beaches, e.g. larvae of crabs, bivalves and polychaetes from nearby estuaries or offshore ecosystems.

4.2.3 Data Analysis

Samples were grouped and analysed according to season, site and time of day. Seasons included summer (December to February), autumn (March to May), winter (June to August) and spring (September to November). However, at both systems sampling months that formed the seasons were not consecutive due to logistical reasons of the sampling programme. Consequently, at St. Lucia summer was formed by samples collected in February 1992, December 1992 and January 1993, whereas at Mhlathuze spring was formed by *samples* collected in November 1998, September 1999 and October 1999. The mean and indication of the confidence interval were calculated and plotted to show temporal, spatial (site) and diel (day/night) variation of zooplankton densities in each surf zone.

Test for normality and data transformation

The biological data were tested for *normality and heterogeneity of variances using the* Kolmogorov-Smirnov and test in SigmaStat software package in order to determine which technique to use in analysing data between parametric and non-parametric methods. The appropriate transformations were used to remove skewness in data. The appropriate transformation can be determined by plotting $\log_{10}$ of mean against the $\log_{10}$ of corresponding standard deviation and estimate the slope of this relationship (Clarke and Warwick 1994). Clarke and Warwick (1994) suggest that if λ is set equal to 1-β in the equation $y^{*}=y^{\lambda}$ to (1-β), the transformed data will have constant variance, where β is the slope of the graph. A slope of zero implies no transformation, 0.5 implies the square root, 0.75 the fourth root and 1 the log transformation (Clarke and Warwick 1994).

Clustering and Ordination

Densities of all taxa were subjected to multivariate statistical analyses using the PRIMER (Plymouth Routines in Multivariate Ecological Research) software package (Clarke and

Warwick 1994) to determine patterns and differences in community structure within and among sampling locations over time. Hierarchical clustering (Bray-Curtis similarity) and ordination (non-Metric Multidimensional Scaling, NMDS) were performed on appropriately transformed biotic data to determine the relationship between samples with respect to season, time of day and sites. Cluster analysis aims to find "natural groupings" of samples such that samples within a group are more similar to each other than samples in different groups (Clarke and Warwick 1994). NMDS ordination, on the other hand, is a map of samples in two or three dimensions, in which the placement of samples reflects the similarity of their biological communities (Clarke and Warwick 1994). The NMDS analysis also gives a calculated stress value, which provides information to assess the usefulness and reliability of the NMDS ordination. According to Clarke and Warwick (1994), a stress value of <0.05 gives an excellent representation with no prospect of misinterpretation. A stress value of <0.1 corresponds to a good ordination with no prospect of a misleading interpretation of the similarity of samples to each other. A stress value of <0.2 gives a potentially useful two-dimensional picture. Conclusions should not, however, be based only on the ordination and should be complemented by alternative techniques such as clustering (Clarke and Warwick 1994). Biotic data were subjected to appropriate statistical methods to determine if differences between groups identified by clustering and NMDS were statistically significant.

Characteristic species of each site, season and time of day group were determined using the SIMPER program in Primer software package. Clarke and Warwick (1994) caution that this is an exploratory analysis, not a statistical testing framework. The number of species was reduced, retaining only those species that contributed greater than 3% of the total abundance at any one site when both CLUSTER and SIMPER analyses were performed, as recommended by Clarke and Warwick (1994).

Community diversity indices

Diversity indices were used to reflect changes in the community richness and evenness in terms of species-abundance relations with respect to space and time. The assumption here was that an undisturbed community would be characterised by high diversity and an even distribution of individuals among species. The Shannon-Wiener index was chosen because it incorporates both species richness (number of species present) and evenness (the distribution of individuals among species). The Shannon-Wiener diversity index is expressed according to Clarke and Warwick (1994) as

$H' = -\Sigma_i p_i(\log p_i)$

where p_i is the proportion of the total count arising from the *i*th species. The logarithms to the base of 2 were used in the calculation in the biological data of the St. Lucia and Mhlathuze surf zones. Due to the fact that the response of community to environmental stresses is not always linear, the difficulty of interpreting this diversity index was, however, acknowledged. As a result the Shannon-Wiener diversity index was used together with other indices such as species richness ***Margalef's index*** (d) and ***Pielou's evenness indices*** (J') as well as clustering and ordination. Margalef's (1961) index: is given as D_{mg}=(S-1)/ln*N* where S=number of species recorded, and *N*=total number of individuals summed over all S species. The Pielou' (1986) index is given as: J'=H'ln(S)=ln(N1)/in(N0), where H'=Shannon diversity index and S=number of species. N1 and N2, correspond to Hill's family numbers. This index shows the evenness at which individuals are distributed over the species in a sample (Clarke and Warwick 1994). During this study diversity indices were calculated using the PRIMER program, DIVERSE. The means and 95 % confidence intervals for Shannon diversity, species richness and evenness were plotted using the Statgraphics® programme (Manugistics 1993) to show changes in zooplankton community between sites over the study period.

Testing for the significance of differences between sites, seasons and day/night.

Any significance of differences between sites, seasons and day/night were tested using the appropriate methods (parametric or non-parametric) depending on the normality and homogeneity of the data.

Relating biological data to physico-chemical data

The BIOENV procedure in PRIMER was used to investigate which of the measured physico-chemical variables were related or responsible for structuring any observed zooplanktonic community patterns. The assumption made here was that if the suite of environmental variables responsible for structuring the community is known, then samples having similar values for these variables would be expected to have similar species compositions. The weighted Spearman rank correlation coefficient (ρ_w) was used to measure the match between the pattern resulting from the ordination of the biotic and abiotic data respectively. The correlation coefficient (ρ_w) takes values in the range (-1,1) with ρ_w=1 implying perfect agreement and ρ_w=0 if there is no match.

Since many variables are highly inter-correlated and including all of them in the analysis could do nothing in the way of improving the BIOENV conclusion (Clarke and Warwick 1994). All variable subsets were then reduced to a single representative. Physico-chemical variables that contained missing values were also excluded in the analysis. The resultant maximum variable combinations were noted. The RELATE program in Primer was used to test the significance match between the abiotic and the biotic patterns.

4.3 RESULTS

4.3.1 Test for normality and data transformation

The results of the normality test are shown in Table 4.1. The Kolmogorov-Smirnov test showed that abundances (counts/m^3) were not normally distributed. The non-normality was not removed completely in these data after using different transformations such as root (√), double square root (√√) and log transformations since they were collected quantitatively. At St. Lucia, Pielou's (1986) evenness and Shannon-Wiener diversity indices were normally distributed whereas Margalef's (1961) species richness index was not normally distributed (Table 4.1) which was then double square root transformed. At the Mhlathuze surf zone, all community diversity indices passed the normality test (i.e. they were normally distributed). Parametric methods (e.g. ANOVA and t-test) rely on assumptions that the data are sampled from a normally distributed population. According to Underwood (1997) many types of biological data, particularly those involving counts per units are distributed as approximately Poisson distributions, with one characteristic being that their variances equal their means and the root transformation is used to validate use of parametric methods. Due to difficulties to validate assumptions for parametric techniques, non-parametric methods or representations were used and parametric methods are restricted to univariate tests (diversity indices) during this study.

Table 4. 1: Normality Test (Kolmogorov-Smirnov) performed on the diversity indices for the St. Lucia and Mhlathuze surf zones.

Variables	K-S Distance	P	
The St. Lucia surf zone			
Number of species (S)	0.0955	0.0196	Failed
Density (ind./m^3)	0.3681	<0.0001	Failed
Margalef species richness (d)	0.0767	0.0569	Failed
Pielou evenness index (J')	0.0847	0.0608	Passed
Shannon Wiener diversity index (H')	0.0677	0.2701	Passed
The Mhlathuze surf zone			
Number of species (S)	0.0907	0.1472	Passed
Density (ind./m^3)	0.2534	<0.0001	Failed
Margalef species richness (d)	0.0712	0.4615	Passed
Pielou evenness index (J')	0.0801	0.2923	Passed
Shannon Wiener diversity index (H')	0.0787	0.3168	Passed

According to Clarke and Warwick (1994) transformation is important to weight the contribution of common and rare species in the non-parametric methods. The double square-root transformation was chosen in the present study in order to retain the information but down-weigh the contribution of dominant species (Clarke and Warwick 1994).

4.3.2 Community structure, abundance and diversity in the St. Lucia and Mhlathuze surf zones.

Figures 4.1A and 4.2A show percentage contribution of major groups and taxa within the major taxonomic groups to the total zooplankton density at St. Lucia. Figures 4.1B and 4.2B show percentage contribution of major groups and taxa within the major taxonomic groups to the total zooplankton density at the Mhlathuze surf zone.

The St. Lucia surf zone

Abundance, dominance and distribution of taxa

In total, 132 taxa were recorded in the St. Lucia surf zone (Appendix 3), 13% were common to abundant and 87% rare and were mainly dominated by crustaceans. Volumes (m^3) of water trawled at each site are shown in Appendix 4. The numerical abundance of the total zooplankton density varied from 0.31 to 1570 ind.m^{-3} (mean ± SD: 103 ± 272). The most numerical abundant major group of zooplankton sampled in the St. Lucia surf zone during the study period (February 1992-January 1993) was the Mysidacea, which contributed approximately 36% to the total zooplankton assemblage, followed by the Brachyura (25%), Copepoda (24%) and the Isopoda (10%). Each of the following groups of zooplankton contributed less than 3% to the total zooplankton assemblage: Coelenterata, Siphonophora, Polychaeta, Penaeidea, Bivalvia and Gastropoda (Figure 4.1A).

The most dominant genus of mysids species was *Gastrosaccus*, which accounted for 99% of the total mysid contribution. The members of this genus also dominated the zooplankton assemblage composition by contributing about 35% to the total zooplankton species assemblage. The other important taxa, in order of their relative contribution to the total zooplankton composition, included calanoid copepod (21%), brachyurans in the megalopal stage (13%), isopods *Cirolana* spp. (11%), brachyurans in the zoeal stage (6%) and *Sagitta* sp. (6%) (Figure 4.2A).

Figure 4.3 shows changes in contribution (%) of taxa to the overall zooplankton abundance at the St. Lucia surf zone. The zooplankton community at St. Lucia was dominated by six taxa, which made up nearly 90% of the total abundance.

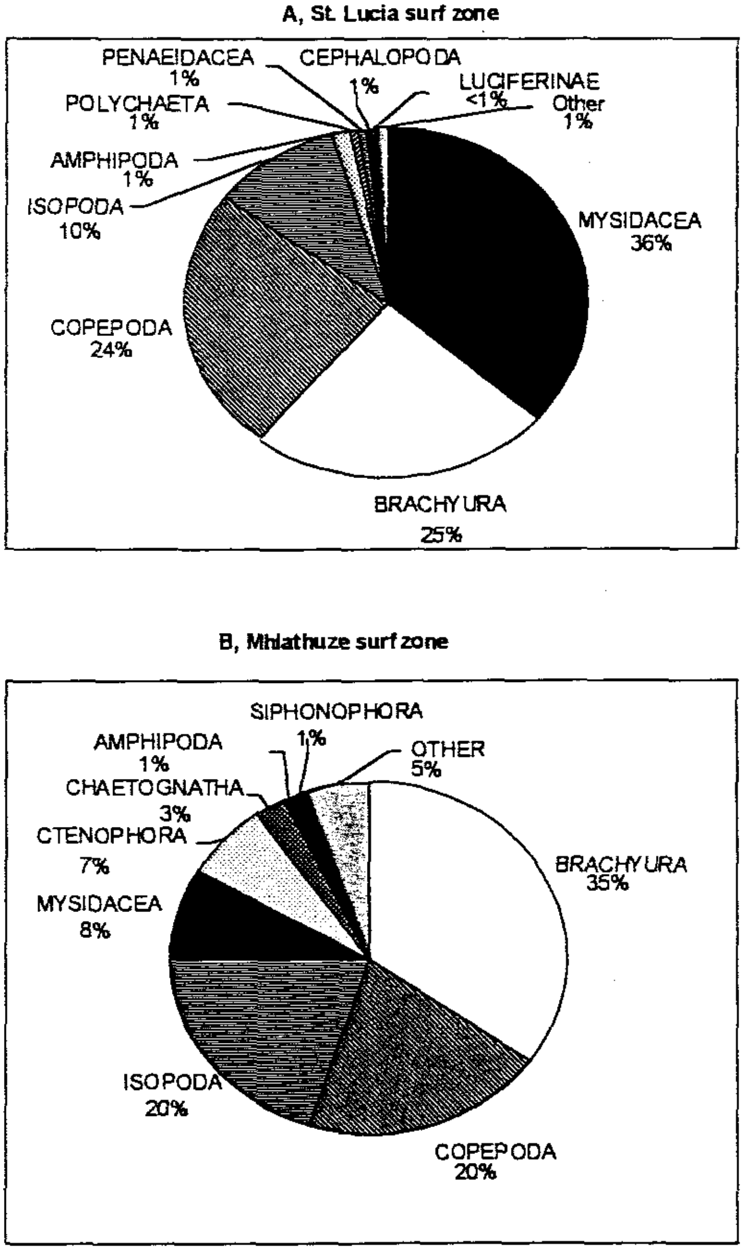


Figure 4. 1 Percentage contribution of major taxonomic groups sampled at Sites 1, 2 and 3 in the St. Lucia (A) and Mhlathuze (B) surf zone.

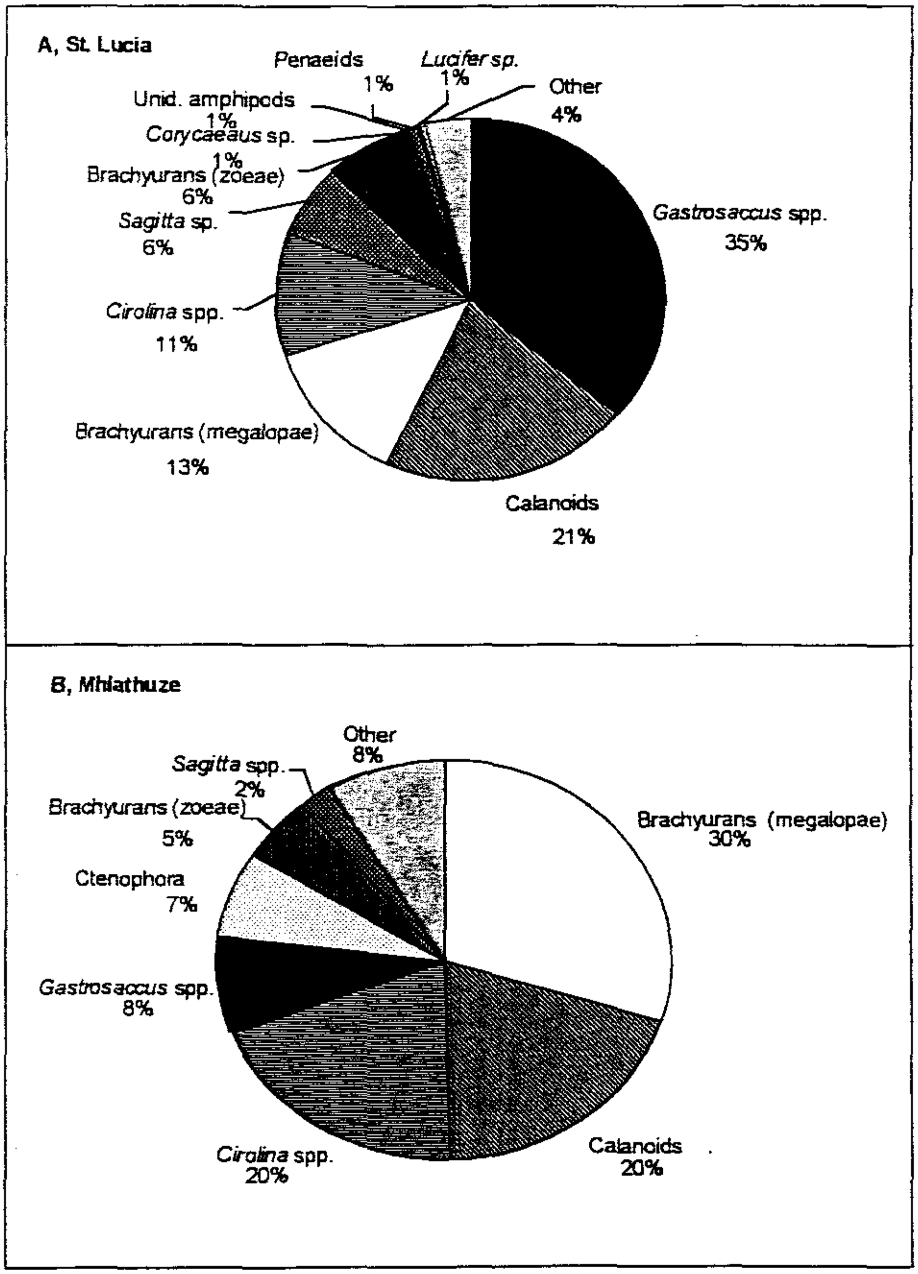


Figure 4. 2 Percentage contribution of taxa within major taxonomic groups sampled at Sites 1, 2 and 3 in the St. Lucia surf zone (A) and Mhlathuze surf zone (B).

The dominance of these taxa varied seasonally, with summer zooplankton dominated by surf zone mysids *Gastrosacccus* spp., brachyuran megalopa, calanoid copepods and *Cirolana* spp. This season was marked by the increased number of zoeae larvae. During autumn, brachyurans (megalopa) and *Gastrosaccus* spp. dominated the zooplankton collected from the St Lucia surf zone. The zooplankton sampled in winter were mainly dominated by calanoid copepods and *Sagitta* spp., which increased markedly during this period. This pattern of dominance, however, changed in spring when *Gastrosaccus spp.* became dominant.

The dominance of taxa such as calanoid copepods and *Sagitta* spp. occurred mainly at Site 1 during the day, whilst *Gastrosaccus* spp., *Cirolana* spp., and brachyuran megalopa and zoeae larvae dominated the surf zone at Sites 2 & 3, mainly at night. Although the St. Lucia zooplankton community was dominated by *Gastrosaccus* spp., it did not dominate throughout the study (i.e. it was not constantly dominant with regard to season, site and time of day).

The mean numerical abundance of zooplankton shown in Figure 4.3 (B, D & F) did not show any marked variation with respect to season, site and time of day. The significance of differences could not be determined using parametric methods due to the non-normality of the abundance data. The highest mean numerical abundance was recorded in autumn mainly at Site 3 at night, with lowest abundances being recorded in spring, mainly at Sites 1 and 2 during the day (Figure 4.3). High numerical abundances observed during autumn and summer were attributed to the high numbers of *Gastrosaccus* spp., brachyuran megalopa, *Cirolana* spp. and brachyuran zoeae collected mainly at night (Figure 4.3).

Special attention was also focused on the most numerical abundant group, *Gastrosaccus* spp., with respect to temporal and spatial distribution (Figures 4.2 and 4.3). Spatially, the mean density of *Gastrosaccus* spp. varied from Site 1 to Site 3 over the sampling period (February 1992 – January 1993) in the St. Lucia surf zone. The mean density ranged from 2.21 – 70.57 ind.m^{-3}, with a maximum being recorded at Site 3 and a minimum at Site 1. High densities observed at St. Lucia were recorded mainly at night.

Gastrosaccus spp. were particularly abundant in the early autumn, dropped between late autumn and winter, and decreased again in spring and summer. The high total densities of *Gastrosaccus* spp. were recorded at night. A maximum *Gastrosaccus* spp. density of 994 ind.m^{-3} was recorded during summer (January 1993) over the study period.

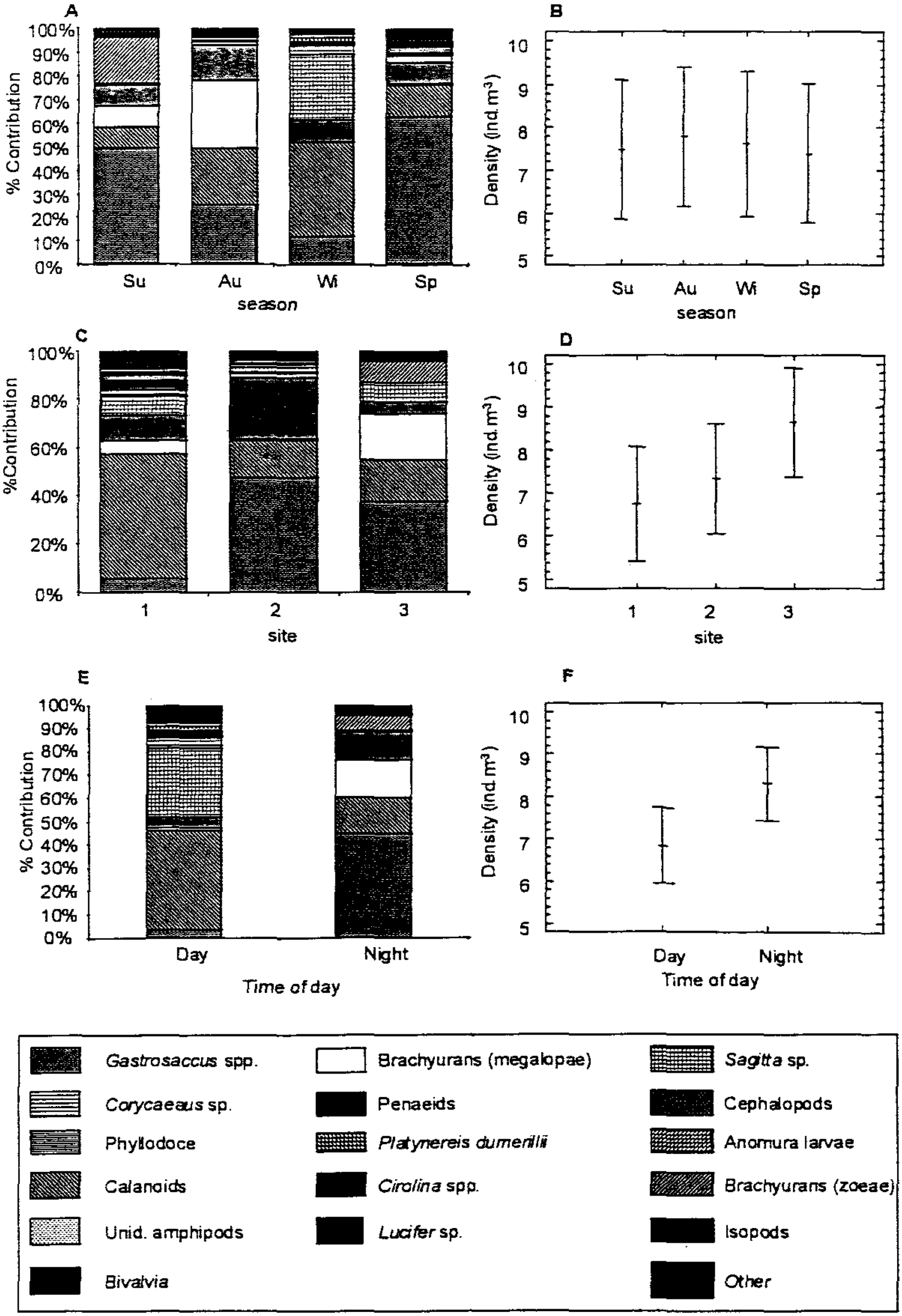


Figure 4.3 Variation in dominance and mean ± 95%CL of total zooplankton abundance sampled at the St. Lucia surf zone. A and B=seasons, C and D=sites, E and F=time of day.

During the day sampling, the total densities of *Gastrosaccus* spp. were very low such that a maximum density of 28 ind.m^{-3} was recorded, which was recorded in December 1992.

Patterns in community structure and abundance (Clustering and ordination)

To show spatial, seasonal and diel patterns in the zooplankton community, Bray-Curtis similarity matrices and dendrograms were created. The matrices were then used as an input to NMDS ordination to confirm the existence of any relationships among samples. The dendrograms and NMDS plots in Figures 4.4 to 4.8 illustrate relationships between samples at St. Lucia

Cluster analysis revealed four distinctive faunal groups from St. Lucia identified at the 25% similarity level (Figure 4.4). Group 1 and Group 2 were characterised by the dominance of day samples, whereas Group 3 and 4 were characterised by the dominance of night samples. Group 2 and 4 were further divided into three and four sub-groups respectively at a 32 % similarity level (Figure 4.4). The representative planktonic groups formed clusters on the NMDS 2-dimensional plot (Figure 4.5), validating the results of the cluster analysis. The stress value for the NMDS plot was 0.27 which was considered insufficient on its own to summarise the similarity of planktonic invertebrate community structure between groups and it was complimented with cluster analysis.

Group 1 was characterised by the dominance of calanoid copepods, brachyuran megalopae and zoeae, penaeds , *Corycaeus* sp., *Cirolana* spp. Group 1 appeared at Site 2 during the day in summer and autumn. Group 2a occurred at Sites 1, 2 and 3 during summer and at Site 1 during autumn. This was designated as the St. Lucia day summer assemblage which was characterised predominantly by calanoids, *Sagitta* sp., *Lucifer* sp., brachyuran megalopae and *Gastrosaccus* spp. Group 2b was characterised by the dominance of calanoids, *Sagitta* sp. and *Cirolana* spp. Group 2b appeared at Sites 1, 2 and 3 during autumn and winter. This assemblage also occurred at Site 3 during spring. This group was designated as the St. Lucia day autumn/winter assemblage, whereas Group 2c consisted of fauna sampled at Sites 1 and 2 during spring, at Site 1 during summer and at Site 2 during winter. Group 2c was designated as the St. Lucia day spring assemblage since it occurred mainly in spring and was dominated by calanoids, *Sagitta* sp., *Gastrosaccus* spp., brachyuran zoeae, *Lucifer* sp. and penaeids.

Group 3 was observed at Sites 2 and 3 in summer at night, and was regarded as the St. Lucia night summer assemblage.

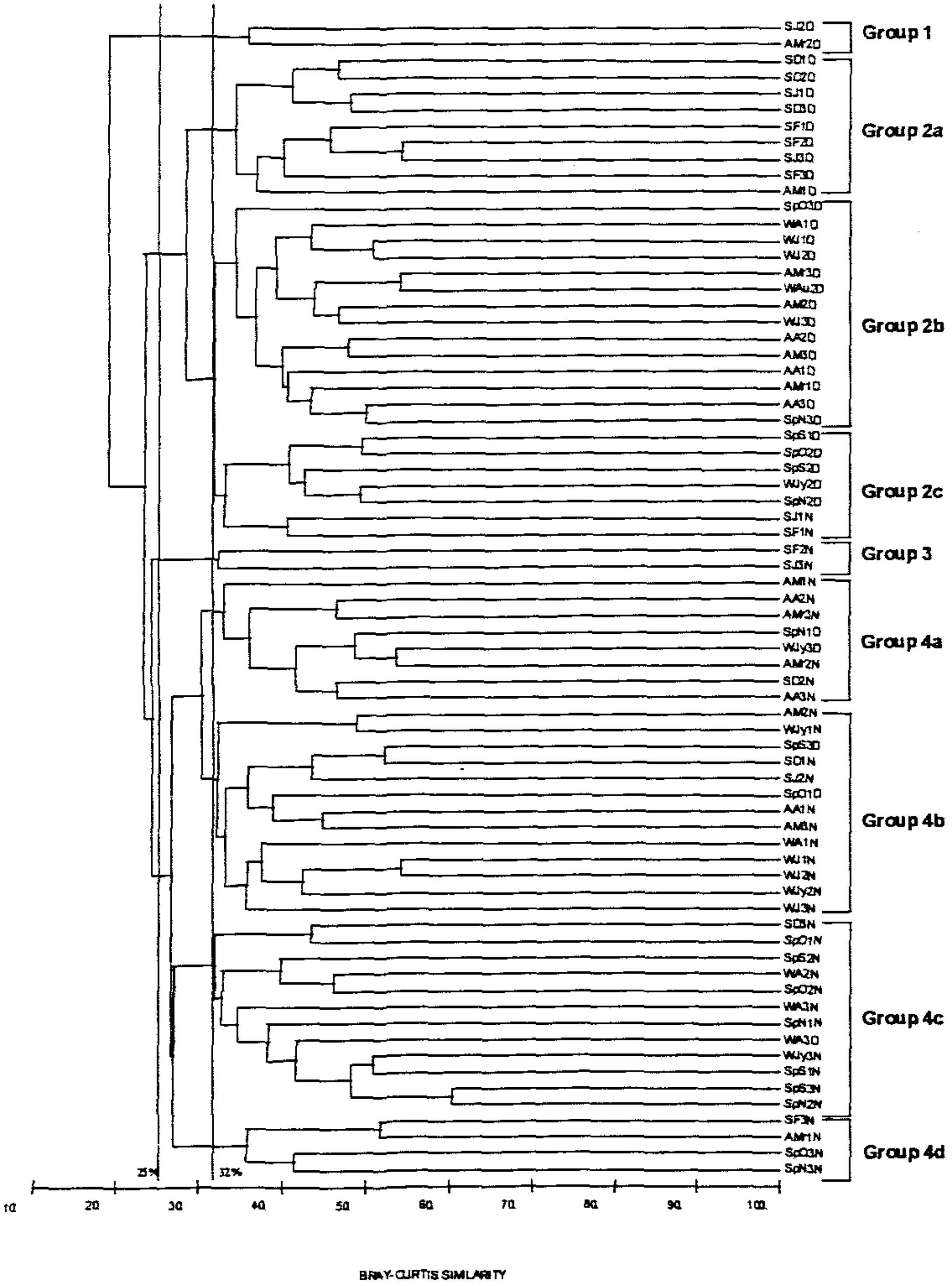
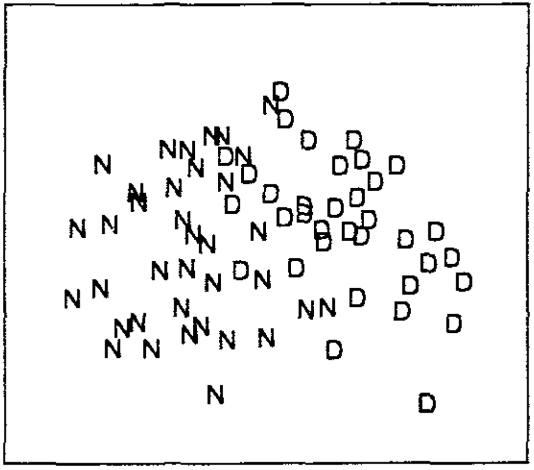
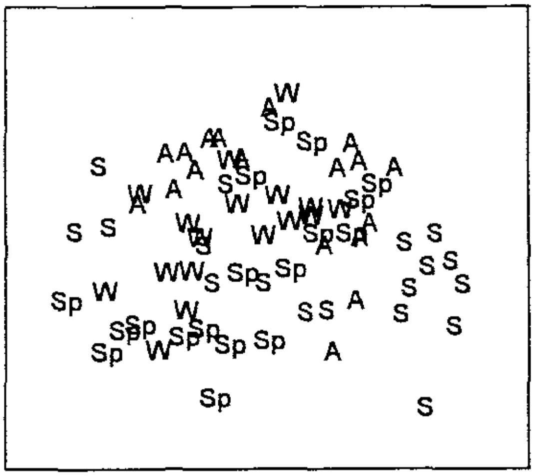


Figure 4. 4 Bray-Curtis cluster dendrogram of samples based on invertebrate plankton fauna collected at St. Lucia, revealing 8 community groups or assemblages. Codes represent samples e.g. SJ2D=summer, January, Site 2, Day (season, month, site and time).

Time of day, Stress = .27



Season, Stress = .27



Sites, Stress = .27

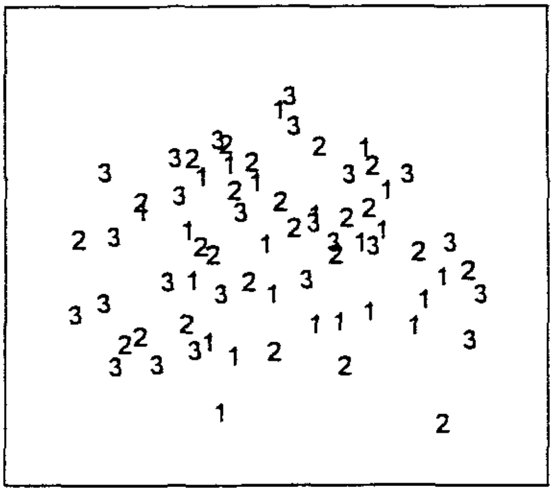


Figure 4. 5 MDS 2-dimensional ordination of samples showing 8 community groups at St. Lucia derived by cluster analysis. Symbols D, N, S, A, W and Sp represent day, night, summer, autumn, winter, and spring. Numbers are sampling Site 1, 2 & 3.

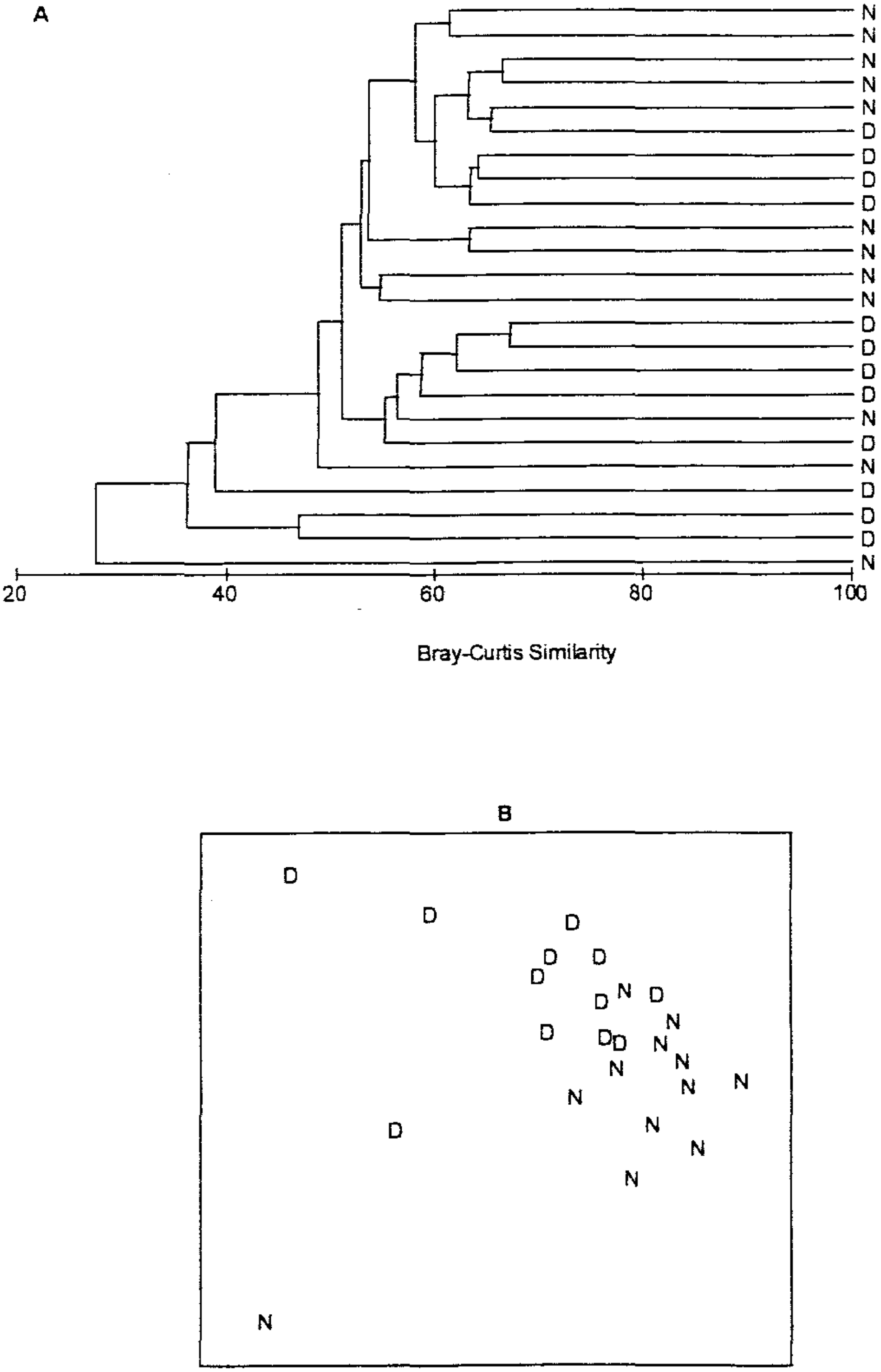


Figure 4. 6 Bray-Curtis dendrogram (A) and corresponding NMDS plot (B) of zooplankton sampled in the St. Lucia surf zone, illustrating diel (time of day) patterns in the community structure. Sampling times are represented as D=day and N=night.

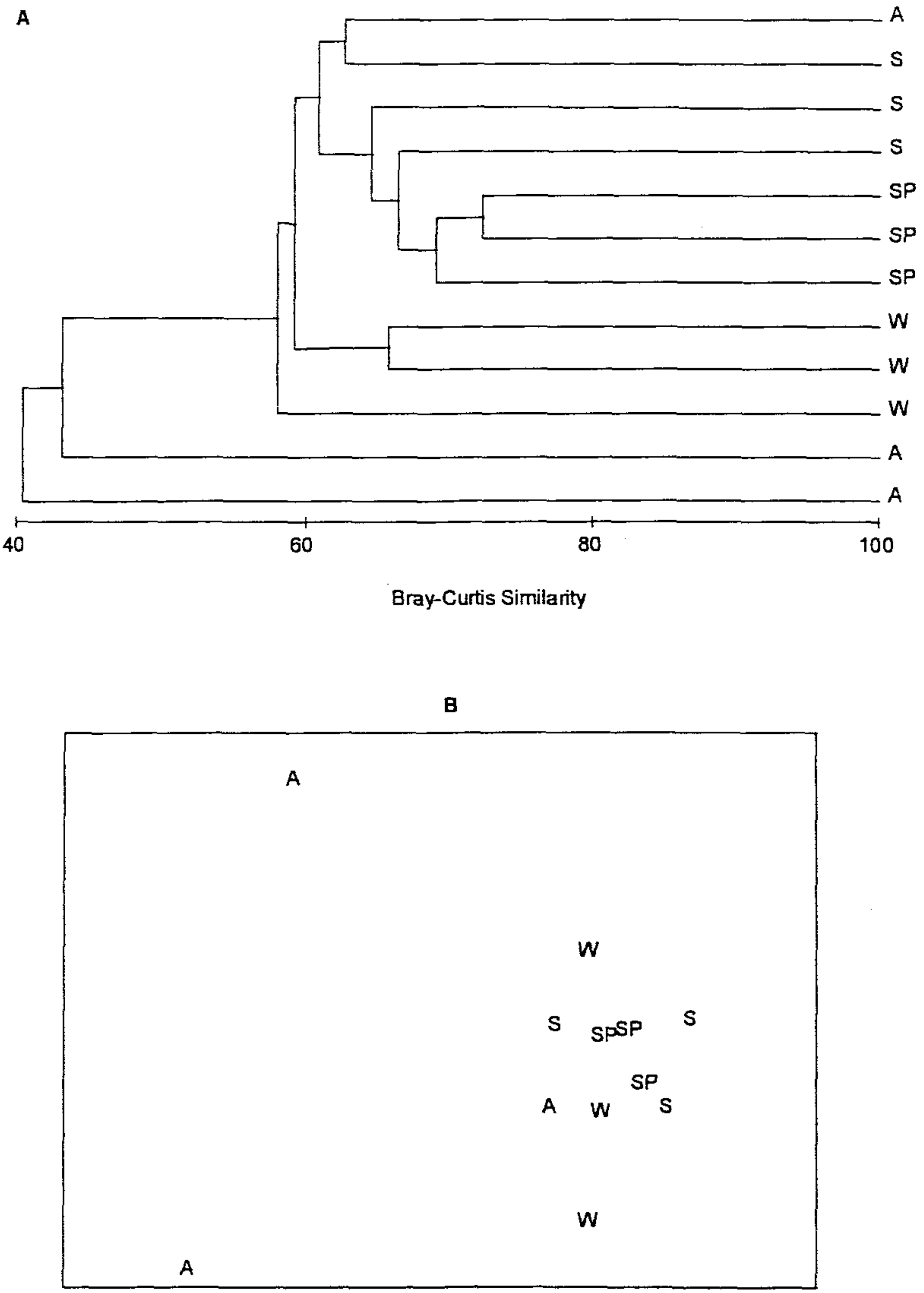


Figure 4. 7 Bray-Curtis dendrogram (A) and corresponding NMDS plot (B) of averaged densities of zooplankton collected in the St. Lucia surf zone, illustrating seasonal patterns in the community structure. S=summer, A=autumn, W=winter and Sp=spring.

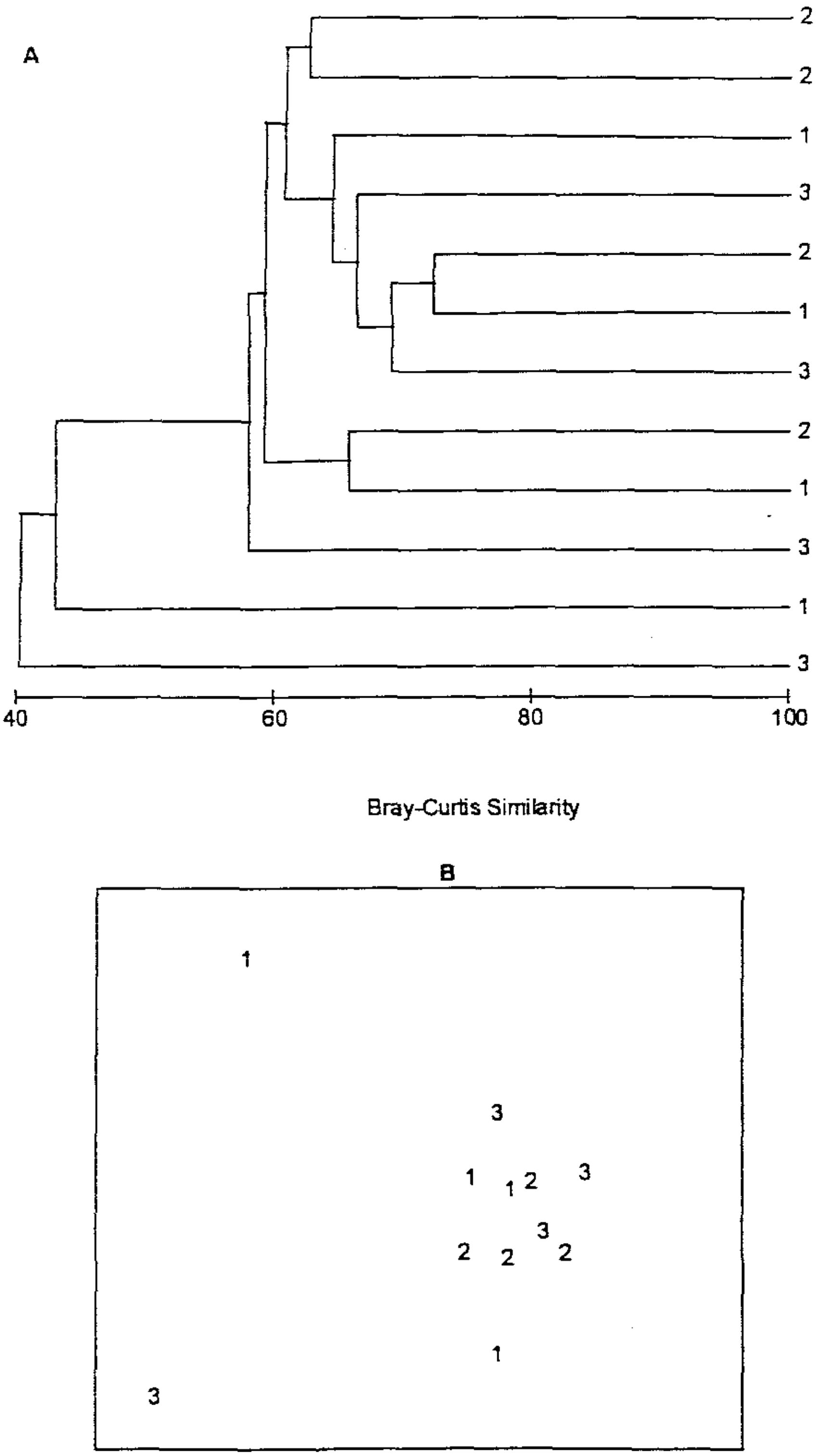


Figure 4. 8 Bray-Curtis dendrogram (A) and corresponding NMDS plot (B) of zooplankton sampled in the St. Lucia surf zone, illustrating spatial (site) patterns in the community structure.

The St. Lucia night summer assemblage was characterised by *Gastrosaccus* spp., *Cirolana* spp., brachyurans megalopa and zoeae, calanoid copepods and Cumacea sp.

Group 4 was divided into four sub-groups on the basis of seasonality at 32 % similarity level. Group 4a consisted mainly of invertebrate plankton sampled at Sites 1, 2 and 3 during autumn and at Site 2 in summer predominantly made up of night samples. This group also included planktonic invertebrates sampled at Sites 1 and 3 during the day in spring and winter. Group 4a was mainly dominated by the samples collected in autumn, and was designated as an autumn assemblage. This group was dominated by *Gastrosaccus* spp., calanoid copepods, *Cirolana* spp., brachyurans megalopa and *Sagitta* sp. Group 4b was consisted of zooplankton which were dominated by *Cirolana* spp., calanoid copepods, *Gastrosaccus* spp. and brachyuran megalopa. Group 4b consisted of zooplankton sampled in autumn and winter appeared mainly at Sites 1, 2 and 3. The same autumn/winter assemblage was also observed during spring at Sites 1 and 3 in day time samples and at Sites 1 and 2 during summer at night. Group 4c was dominated by *Gastrosaccus* spp., calanoid copepods and *Cirolana* spp. This assemblage appeared at Sites 1, 2 and 3 mainly during spring and was designated as a spring assemblage. The same spring assemblage also appeared at Site 3 during both summer and winter. During the period spring to autumn Group 4d appeared mainly at Site 3 during spring and summer and was characterised by the dominance of calanoid copepods, *Cirolana* spp. and brachyuran megalopa. This group also occurred at Site 1 during autumn at night.

It is evident from these results that Cluster analysis and NMDS ordination indicated a faunal grouping by time of day, followed by seasonal patterns with no obvious grouping of fauna according to site. However, the differences between day and night or the strong diel patterns (Figure 4.4-4.6) had masking effects on season and site factors. The same analysis was performed on the season and site data without the time of day. Cluster analysis revealed unclear seasonal patterns or seasonal relationship of samples in terms of species composition and/or abundance (Figure 4.7A). However, the corresponding NMDS analysis did show a uniform faunal grouping (Figure 4.7B). The stress value was 0.03, which indicated that the NMDS analysis gave a good representation of the sample relationship. With respect to site, clustering (Figure 4.8A) and NMDS (Figure 4.8B) showed no separation of sampling sites (i.e. samples from Site 1 grouped together). The above results indicate that the zooplankton of the St. Lucia surf zone were more influenced by temporal changes than by site. This was highlighted by the absence of site clusters in the classification and ordination.

Testing for the significance of differences between seasons, sites and sampling times.

Since the biological data set from the present study could not be normalised by any transformation, it was invalid to make the standard assumptions of normality. The use of parametric statistical methods was consequently discarded. A summary statistic was computed directly from the underlying (rank) similarity matrix containing the community level data through a simple non-parametric permutation procedure termed ANOSIM (analysis of variance). Since the current data were non-replicated, a specific type of ANOSIM test, termed ANOSIM2 (two-way ANOSIM without replication) was employed to determine if differences between groups are statistically significant at a significance level of 95%. After it was established whether there were any significant differences between monthly samples (Table 4.2), monthly samples were grouped per season to provide replicates. The significance of any differences ($p<0.05$) between day/night, season groups and sites within each system was tested using one-way analysis of similarity (ANOSIM).

The St. Lucia biotic data were analysed for the significance of any differences at 95% significance level using ANOSIM. This was done to investigate the "main effects" of factors such as time of day, season and site on communities. The analysis of similarity compares every sampling site, time of day and season over the sampling period to yield a test statistic and significance level (Clarke and Warwick 1994). Clarke and Warwick (1994) have given the basis of interpreting *R* (statistic value), where *R* is taken as the degree of similarity between sites and ranges between 1 and –1. The statistical value is approximately equal to zero if the null hypothesis is true. The statistical value $R=1$ only if all replicates within sites, seasons and times are more similar to each other than any replicates from different sites. A statistical value of R less than zero would correspond to similarities across different sites being higher than those within sites.

Table 4.2: St. Lucia and Mhlathuze surf zones. Similarity test statistics (R) and significance levels ($p<0.05$) of differences between samples (TWO-WAY ANOSIM: NO REPLICATION).

SYSTEM	Monthly samples	
	R	p
St. Lucia surf zone	-0.101	0.668
Mhlathuze surf sone	0.022	0.227

The results of analysis of similarity between sites, seasons and sampling times (day/night) at the St. Lucia surf zone are shown in Tables 4.3-4.5. Analysis of similarity (ANOSIM) showed that there was a significant difference between day and night in terms of zooplankton abundance. These results validate diel (day/night) pattern which was identified by clustering and NMDS ordination indicating the influence of changes in time of day (Table 4.3). One-way analysis of similarity (ANOSIM) also showed that sites are similar suggesting that there was no statistically significant relationship between the abundance and distance from the mouth (Table 4.4). These results indicate that there was no significant accumulation of zooplankton near the mouth over the sampling period at St. Lucia (Tables 4.3 and 4.4). One-way of similarity (ANOSIM) further indicated significant differences between seasons, which was observed between summer and winter (Table 4.5).

Table 4.3: St. Lucia and Mhlathuze surf zones. Analysis of similarities test statistic (R) and levels of significance (p) between time (averaged across seasons and sites), seasons (averaged *across sites and time of day) and sites (averaged across seasons and time of day).* Significance levels marked with asterisks indicate significant difference (* = $p < 0.05$).

SYSTEM	TIMES		SEASONS		SITES	
	R	p	R	p	R	p
St. Lucia surf zone	0.258	0.001*	0.249	0.01*	-0.053	0.71
Mhlathuze surf zone	0.269	0.002*	0.631	0.001*	-0.19	0.942

Table 4.4: Similarity test statistic (R) and significance levels (P) of differences between sites (Sites 1, 2 and 3) sampled during the day (D) and night (N) between February 1992 and January 1993 St. Lucia surf zone. Asterisks indicate significant difference (* = $P < 0.05$).

Sites	R	P
Site 1 vs Site 2	0	0.571
Site 1 vs Site 3	-0.052	0.543
Site 2 vs Site 3	-0.063	0.74

Table 4.5: Similarity test statistic (R) and significance levels (P) of differences between seasons (across sites) sampled during the day (D) and night (N) between February 1992 and *January 1993 St. Lucia surf zone. Asterisks indicate significant difference (* = $P < 0.05$).*

Season	R	P
summer vs autumn	0.05	0.26
summer vs winter	0.241	0.015*
summer vs spring	0.065	0.238
autumn vs winter	-0.045	0.716
autumn vs spring	0.165	0.054
winter vs spring	0.122	0.089

Taxa characterising sites, seasons and times (day/night) at St. Lucia

The SIMPER program in the Primer package was used to determine site relationships (in terms of species assemblages) separated a *priori* on the St. Lucia data. Groups were selected as sites, seasons and sampling times. This was also done to determine which species/taxa are principally responsible for the formation of groups (i.e. to determine characteristic species for each site, season and time of day) and to establish if any discriminating species were present among groups. This is based on the calculation of similarity percentages of the contribution of each taxon to the average similarity within a group and to the average dissimilarity between groups. According to Clarke and Warwick (1994) the more abundant a species within a site, the more it contributes to intra-site similarity and hence typifies that site. The data were transformed using double square root transformation and only dominant species (those species comprising >3% of the total abundance at any sampling site) were included in the analysis to obtain a manageable data set (Clarke and Warwick 1994).

Dissimilarity between sites

At St. Lucia forty-seven zooplankton taxa (Table 4.6) were identified as dominant taxa, and were examined as characteristic or indicator species. Table 4.7 shows the results of dissimilarity percentages between site groups. Site 1 was relatively dissimilar to Sites 2 and 3, due to a relatively high dissimilarity percentage (>50%). Sites 2 and 3 were less dissimilar to each other in terms of composition or abundance. The reasons for this was that Site 1 near the mouth was characterised by increased abundances of taxa such as calanoid copepods, *Cirolana* spp., brachyuran megalopa and zoeae larvae and *Sagitta* sp. However, Sites 2 and 3 had marked increased abundances of *Gastrosaccus* spp., *Cirolana* spp. and calanoid copepods.

Table 4. 6: List of dominant zooplankton taxa (>3% of total numerical abundance any one occasion) at the St. Lucia surf zone and their association of with marine (Mar.) estuarine (Est.), estuarine/marine (E/M) and freshwater (F.W.) environments.

Taxa	Environment
Muggiaea kochi	Mar.
Siphonophora	Mar.
Ctenophora	Mar.
Scyphozoa	Mar.
Dendronereis sp.	E/M
Polychaete larvae	Est.
Platynereis dumerillii	Mar.
Phyllodoce sp.	Mar.
Unid. Polychaete	Est.
Bivalvia	E/M
Cephalopoda	
Gastropoda	E/M
Unid. Gastropod 3	E/M
Ostracods	Est.
Rhincalanus spp.	E/M
Calanoids	E/M
Corycaeaus sp.	Mar.
Unid. amphipods	E/M
Podocerus spp	Est.
Grandidierella spp.	Est.

Table 4.6 continued...

Polycheria atolli	Est.
Caprellina cicur	Est.
Ampelisca palmata	Est.
Amphipod larvae	E/M
Cirolana spp.	E/M
Isopod larvae	E/M
Gnathia africana	Est.
Isopoda sp. 3	Est.
Isopoda sp. 5	Est.
Parisocladus perforatus	Est.
Jaeropsis spp	Est.
Unid. Isopods	Est.
Gastrosaccus spp.	E/M
Unid. mysids	E/M
Penaeids	Mar.
Lucifer sp	E/M
Brachyuran zoeae	E/M
Brachyuran megalopae	E/M
Pagurid larvae	E/M
Cumacea	E/M
Tanystylum brevipes	Est.
Nymphosis cuspidata	Mar.
Anomuran larvae	E/M
Sagitta sp.	Mar.
Unid. Chaetognaths.	Mar.
Appendicularis spp.	Mar.

Table 4.7: Percentage dissimilarity of species assemblages between three sampling sites in the St. Lucia surf zone.

	% dissimilarity between sampling sites		
Site	**1**	**2**	**3**
1		54.17	55.63
2			47.74

The contribution each species made to the average similarity within each site was also calculated using the same procedure and the results are shown in Table 4.8. Site 2 had a relatively high percentage of similarity between species (>50%), indicating that throughout the sampling period a relatively similar species assemblage was sampled at this site. However, fluctuation in species assemblages was reflected in a low intrasite percentage similarity mainly at Site 1.

Table 4.8: Percentage average similarity of species assemblages between three sampling sites in the St. Lucia surf zone.

Site	**% Similarity within a sampling site**
1	41.95
2	54.60
3	48.44

Taxa characterising sampling sites

The results of the SIMPER analysis showing the characteristic species/taxa of Sites 1 to 3 are shown in Appendix 5. At Site 1, a number of taxa formed 75% of the cumulative contribution with the most characteristic species of this group being calanoid copepods, *Sagitta* sp, brachyuran megalopa, *Cirolana* spp. and Penaeidae. At Site 2, over 75% cumulative percentage was achieved by 18 taxa but this site was mainly characterised by calanoids, *Cirolana* spp., *Gastrosaccus* spp. and *Sagitta* sp. The taxa such as calanoids, *Cirolana* spp., *Gastrosaccus* spp., brachyuran megalopae and *Sagitta* sp. characterised Site 3 assemblages. These taxa were also present in low abundance at Site 2.

Dissimilarity between seasons

Seasonally, assemblages in winter were relatively dissimilar to those sampled in autumn and summer (>55% dissimilarity percentage) (Table 4.9). The assemblages sampled in autumn, spring and summer were less dissimilar to each other than any winter comparisons (Table 4.9). The similarity breakdown within season group showed that winter had a relatively high fluctuation in what was sampled in the surf zone, whilst spring and summer had relatively stable species assemblages (Table 4.10).

Table 4.9: Percentage dissimilarity of species assemblages during each of the sampling seasons in the St. Lucia surf zone.

	% dissimilarity between sampling sites			
Season	**autumn**	**winter**	**spring**	**summer**
autumn		56.81	51.53	51.69
winter			53.18	56.99
spring				45.41

Table 4.10: Percentage average similarity of species assemblages during each of the sampling seasons in the St. Lucia surf zone.

season	% Similarity within a sampling site
autumn	44.07
winter	41.03
spring	57.07
summer	53.74

Taxa characterising seasonal groups

Appendix 6 shows the characteristic species of each seasonal group as identified by SIMPER analysis. During autumn over 75% cumulative percentage was formed by a wide array of species/taxa with the most characteristic species being the calanoid copepods, *Sagitta* sp and brachyuran megalopa. The winter assemblages in the surf zone were characterised by calanoids, *Sagitta* sp., *Cirolana* spp. and penaeids. The spring assemblages were characterised by calanoids, *Gastrosaccus* spp., *Cirolana* spp., penaeids and *Sagitta* sp. Finally, the summer assemblages were characterised by calanoids, *Cirolana* spp., *Gastrosaccus* spp., brachyuran megalopae and *Lucifer* sp.

Dissimilarity between sampling times

The day and night assemblages were dissimilar from each other either in terms of species composition or abundance at a 54.32% dissimilarity level. Differences between day and night were due to increased abundances of benthoplanktonic and meso-zooplankton crustaceans such as isopods, mysids and decapod megalopa and zoea larvae at night. The similarity breakdown within time of day showed a greater fluctuation in species assemblages sampled during the day compared with those sampled at night (Table 4.11).

Table 4.11: Percentage average similarity of species assemblages during each of the sampling times in the St. Lucia surf zone.

Time	% Similarity within a sampling site
Day	49.99
Night	50.00

Taxa characterising each sampling time

During the day the surf zone assemblages were characterised by a number of species with 22 taxa contributing 75% of the cumulative percentage. These included calanoid copepods, *Sagitta* sp., brachyuran megalopa, Penaeidae, zoea larvae and *Cirolana* spp. (Appendix 7). At night, a 75% cumulative percentage was achieved by 17 taxa which formed the characteristic taxa of the assemblages sampled in the surf zone (Appendix 7). Night assemblages were characterised by *Cirolana* spp, calanoid copepods, *Gastrosaccus* spp., Penaeidae, brachyuran megalopa and *Sagitta* sp. (Appendix 7).

Community diversity at St. Lucia.

Shannon-Wiener's index of diversity, Margalef's (1961) measure of species richness and Pielou's Evenness index (1986) were used to describe zooplankton species-abundance relationships as explained in Section 4.2.4. Figure 4.9 displays the results of this analysis. All diversity indices showed similar variation in community structure at St. Lucia.

These indices showed a slight decrease in community diversity, richness and abundance between summer and winter, followed by a marked increase in spring. Generally, spring and summer periods had the highest species richness with more diverse assemblages. The least diverse assemblages occurred in winter (Figure 4.9a).

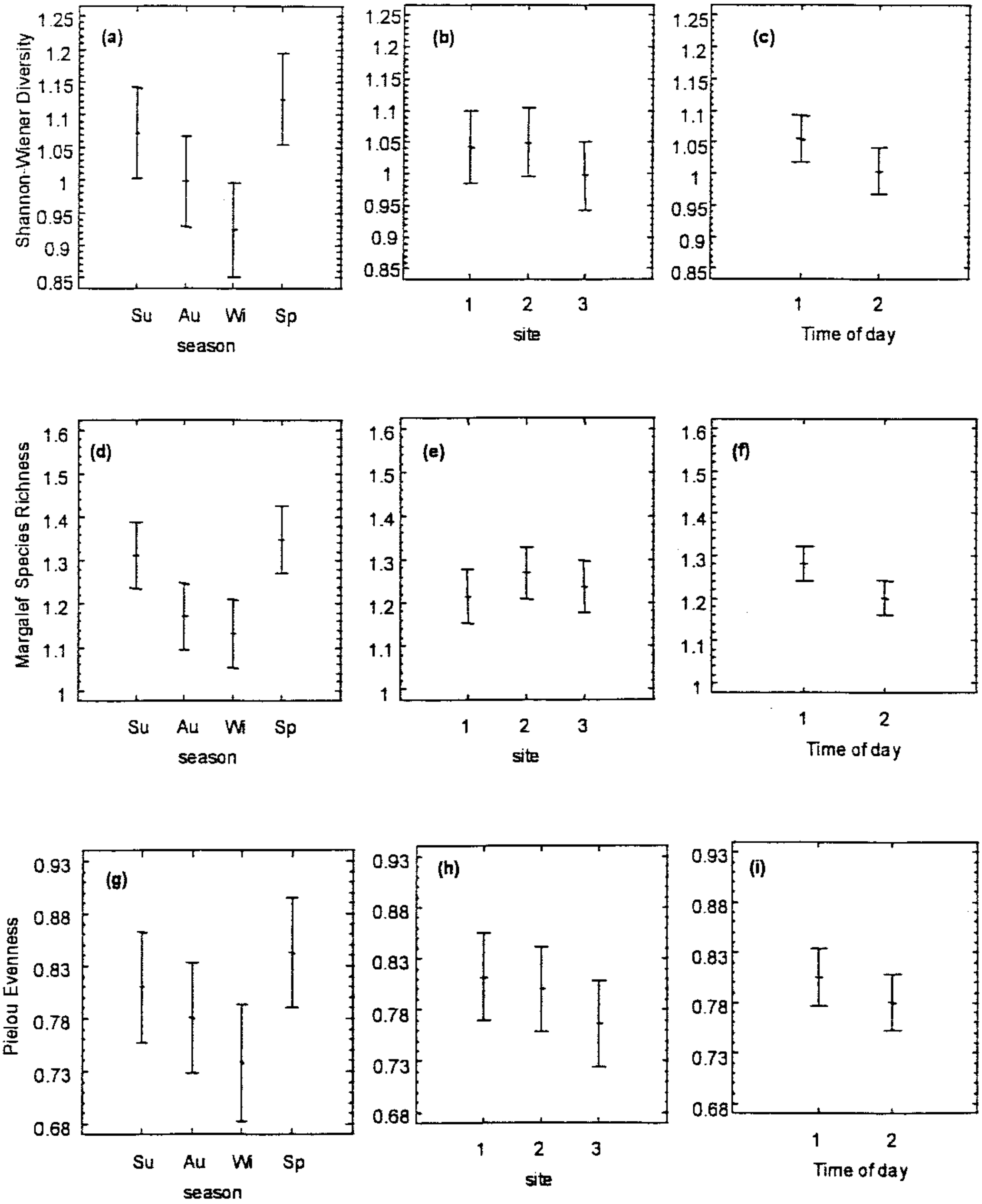


Figure 4. 9 Mean ± 95%CL of diversity indices averaged across all sites and time of day for each season (a, d, g), averaged across all sampling time of day and seasons for each site (b, e, h), and averaged across all seasons and sites for each time of day (d, f, i) at the St. Lucia surf zone between February 1992 and January 1993. Su=summer, Au=autumn, Wi=winter and Sp=spring. Time 1=day and 2=night.

Spatially, Site 3 had a lower diversity and evenness compared with Sites 1 and 2 (Figure 4.9) but had increased densities at night (Figures 4.3D and 4.3F). This was attributed to the marked increased densities of crustaceans including bentho-planktonic forms such as mysids and isopods. Site 2 had relatively higher species diversity mainly during the day compared with Sites 1 and 3 (Figure 4.9). These high diversities showed a high number of species in the surf zone, but with low numerical abundance in summer and spring at Sites 1 and 2, mainly during the day.

Differences between seasons, sites, times were tested for significance using species diversity, richness and evenness indices using analysis of variance (MANOVA) (Table 4.12). Here the model tested the validity of the null hypothesis that the observed variations in diversities were not due to any changes of the above factors. Multifactor analysis (three-way ANOVA) revealed that there was a highly significant relationship between univariate indices (Shannon-Wiener diversity, species richness and evenness) and season indicating the effect of changes in seasons on zooplankton at St. Lucia (Table 4.2).

Table 4.12: Multifactor analysis of variance (MANOVA) (*P<0.05) of double square root transformed univariate indices (Shannon-Wiener diversity, species richness and evenness) of zooplankton for site, season and time of day (tod) factors from the St. Lucia and Mhlathuze surf zones.

		Shannon-Wiener (H')		Richness (d)		Evenness (J)	
source of variation	DF	F	P	F	P	F	P
St. Lucia							
tod	1	2.250	0.140	0.906	0.346	0.580	0.450
season	3	6.827	<0.001*	5.907	0.002*	3.418	0.025*
site	2	1.363	0.266	0.923	0.404	1.549	0.223
tod x season	3	0.543	0.655	1.165	0.333	1.009	0.397
tod x site	2	0.338	0.715	0.550	0.580	0.563	0.573
season x site	6	1.074	0.391	1.120	0.365	1.413	0.229
tod x season x site	6	0.499	0.806	0.748	0.614	0.415	0.866
The Mhlathuze							
tod	1	0.826	0.368	0.904	0.347	0.00131	0.971
season	3	0.753	0.526	0.509	0.678	0.607	0.614
site	2	0.392	0.678	0.947	0.395	0.603	0.551
tod x season	3	1.630	0.195	1.500	0.226	1.494	0.228
tod x site	2	0.599	0.554	0.0317	0.969	1.406	0.255
season x site	6	0.442	0.847	0.885	0.513	0.602	0.727
tod x season x site	6	0.242	0.960	0.429	0.856	0.543	0.773

The Mhlathuze surf zone

Abundance, dominance and distribution of taxa

The total number of taxa collected in the Mhlathuze surf zone during the study period was 108 (Appendix 3) and the volumes of water trawled at each site during the study period are shown in Appendix 4. Like the St. Lucia surf zone, this community was also dominated by crustaceans.. The numerical abundance of the total zooplankton at the Mhlathuze varied from 0.17 to 106 ind.m^{-3} (mean ± SD: 12 ± 17). Figures 4.1B and 4.2B show the overall percentage contribution of major taxonomic groups and zooplankton taxa to the total composition of planktonic fauna sampled in the Mhlathuze surf zone. The most important major taxonomic group was the Brachyura, which formed approximately 35% of the total assemblage composition. The next important groups were the Copepoda (20%), Isopoda (20%), Mysidacea (8%), Ctenophora (7%) and Chaetognatha (3%). Other groups, with each contributing less than 3%, included the Insecta, Ostracoda, Cirripedia, Cumacea, Amphipoda, Penaeidae, Siphonophora, Bivalvia, Sergestidae (Figure 4.1B).

The most dominant taxa within the major groups listed above were brachyuran megalopa, which contributed 30% to the total zooplankton faunal composition (Figure 4.2B). Calanoids and *Cirolana* spp. were the next dominant taxa, with each contributing 20% to the total species composition. The Ctenophora (combjellies) contributed 7%, whilst the brachyuran zoeae and *Sagitta* sp. contributed 5% and 2%, respectively (Figure 4.2B).

Figure 4.10 shows variations in the percentage contribution to the overall invertebrate zooplankton community and mean densities of these taxa at the Mhlathuze. The zooplankton community at the Mhlathuze was dominated by six taxa, namely brachyuran megalopae, *Cirolana* spp., calanoids, *Gastrosaccus* spp., *Sagitta* spp., ctenophores and siphonophores. During summer, brachyuran megalopae dominated the zooplankton community, but a slightly lower contribution of *Gastrosaccus* spp. was evident.

During winter, the assemblage was characterised by the increased contribution of calanoids, ctenophores, *Cirolana* spp., and *Gastrosaccus* spp., with calanoids being the most dominant group. However, during spring, the zooplankton community was dominated by brachyuran megalopae, *Cirolana* spp. and *Gastrosaccus* spp. The dominance of brachyuran megalopae and zoeae, *Gastrosaccus* spp. and *Cirolana* spp. was observed mainly at Sites 1 and 2 at night, whilst calanoids, *Sagitta* spp. and ctenophores dominated the zooplankton community at Site 3 during the day. As at St. Lucia, the community was not constantly dominated by a single taxon over the study period.

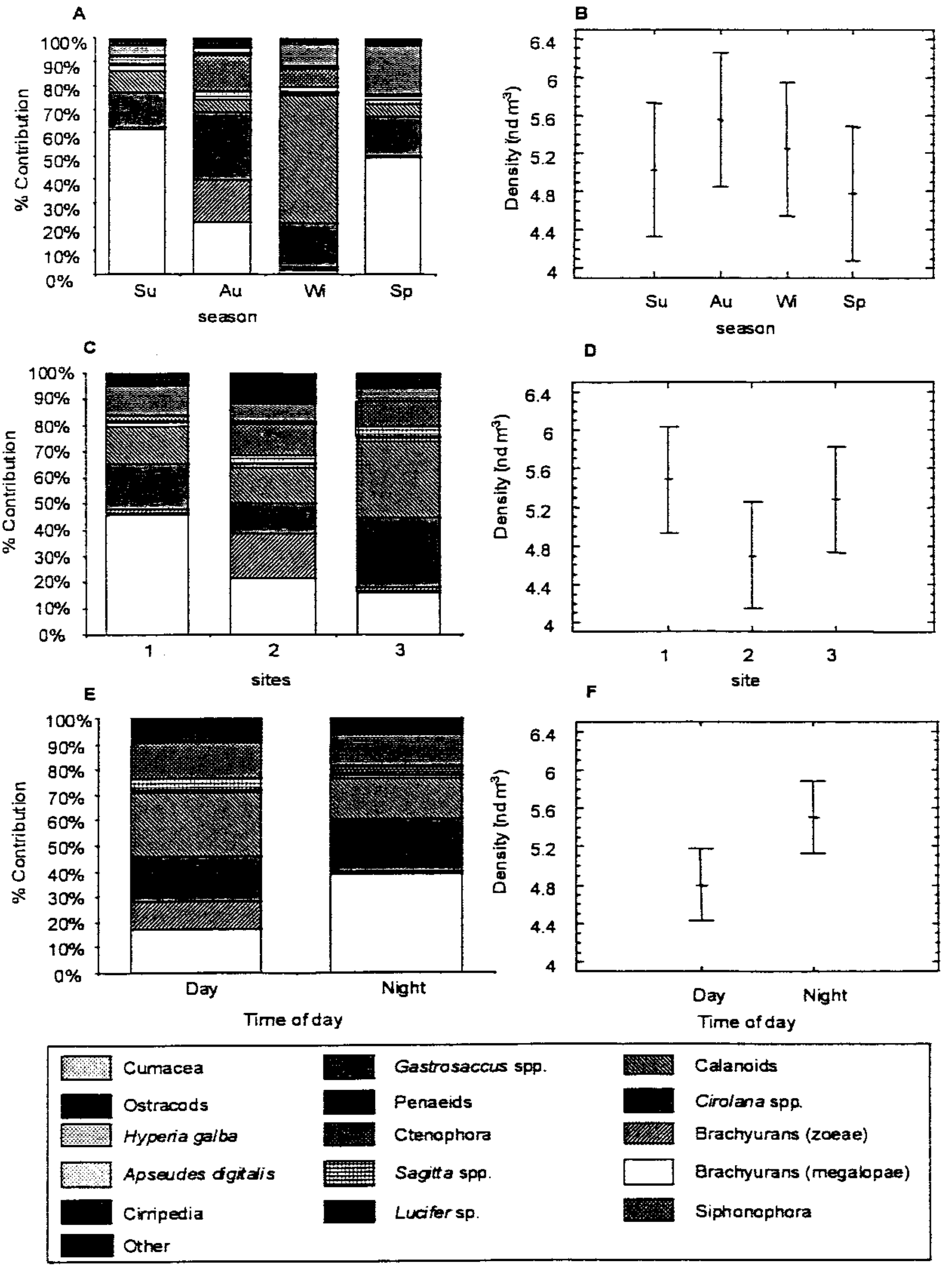


Figure 4. 10 Variation in dominance and mean ± 95%CL of zooplankton abundance sampled at the Mhlathuze surf zone. A and B=seasons, C and D=sites, E and F=time of day.

Figure 4.10B, 4.10D and 4.10F show changes in the numerical abundance of taxa at the Mhlathuze. The numerical abundance increased between summer and autumn, followed by a decline during winter and spring (Figure 4.10B). The abundance data could not be validated for assumptions of parametric methods as explained in Section 4.3.1. Significance of differences between groups could not be determined using parametric methods. The high numerical abundance observed in autumn occurred mainly at Sites 1 and 2 at night due to the presence of high numbers of brachyuran megalopae and zoeae, *Cirolana* spp., calanoids, and *Gastrosaccus* spp.

Due to the marked high contribution to the overall invertebrate zooplankton community of brachyuran megalopae, this group was investigated further to clarify its spatial and temporal distribution. The mean density of brachyuran megalopae was very high at Site 1, decreased at Site 2, and increased slightly at Site 3. These high densities were mainly recorded at night.

The total density of brachyuran megalopae sampled in the Mhlathuze surf zone varied seasonally over the study period. Higher densities were recorded during summer, autumn and spring, with a maximum density in summer (January 1999). Low densities were recorded during winter through to early spring. These results show that high numbers of brachyuran megalopae were present in the surf zone during summer and autumn periods. The highest peak in the brachyuran megalopae density was reached in January 1999 at night when a maximum of 106.16 ind.m^{-3} was recorded. A maximum density of 21.58 ind.m^{-3} was recorded during the day sampling, which was much lower than the maximum density recorded at night.

Patterns in community structure and abundance (Cluctering and ordination)

Bray-Curtis similarity matrices and dendrograms were created to show any seasonal, diel and spatial patterns in the zooplankton community. The matrices were then used as an input to NMDS ordination, to confirm the existence of any relationships. The dendrograms and NMDS plots in Figures 4.11 to 4.15 show relationships between samples in the Mhlathuze surf zone.

Clustering segregated Group 1 at 24 % similarity level which was made up predominantly of day samples (Figure 4.11). Group 2 was made up predominantly of night samples. Clustering further separated Group 1 and 2 by season at 34 % similarity level, resulting in four sub-groups during each time of day (day/night) (Figure 4.11). The NMDS 2-dimensional plot showed groups of the invertebrate plankton, validating the results of cluster analysis (Figure 4.11).

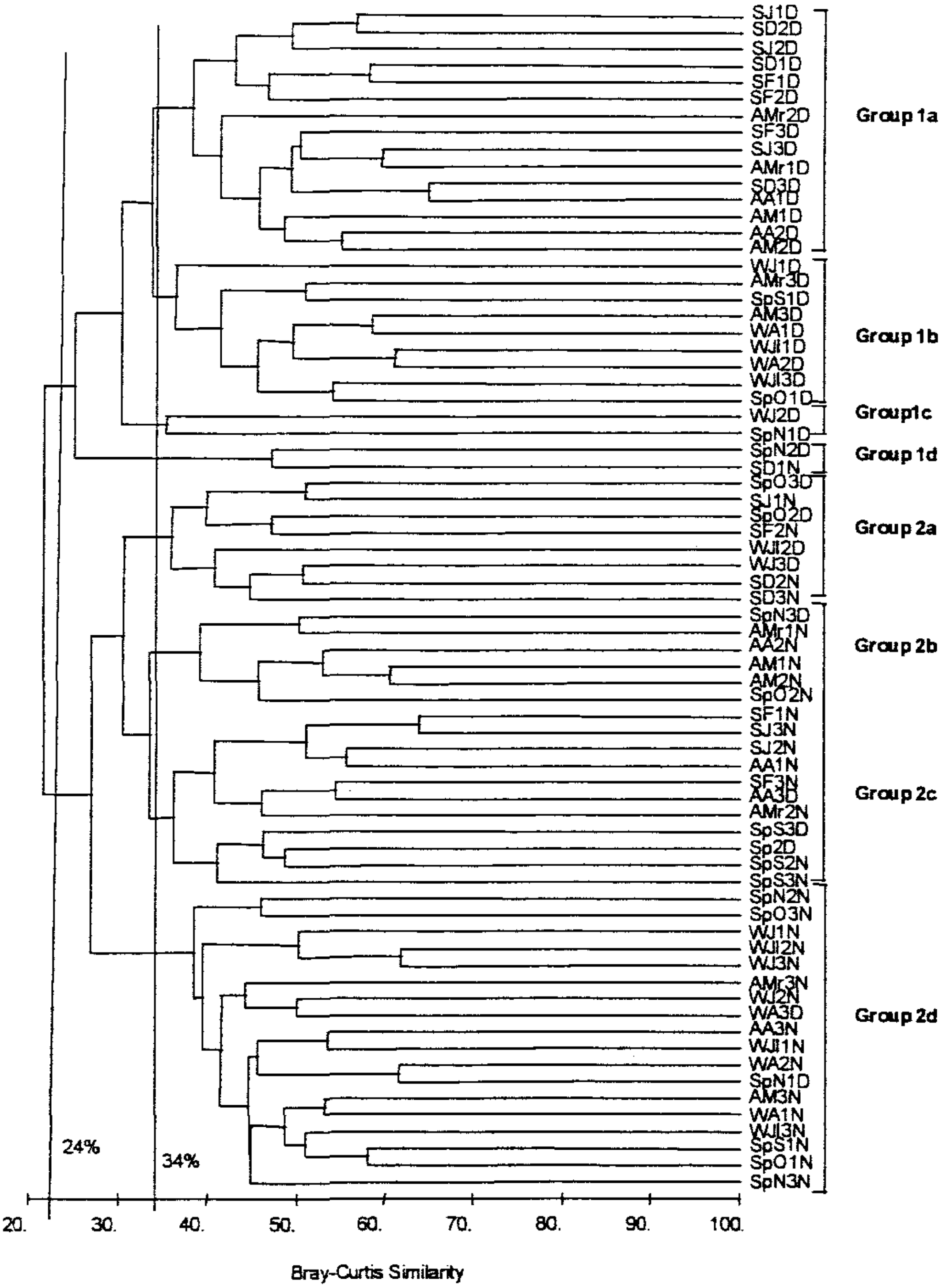


Figure 4. 11 Bray-Curtis cluster dendrogram of samples based on invertebrate plankton fauna collected at the Mhlathuze, revealing 8 community groups or assemblages. Codes represent samples e.g. SJ2D=summer, January, Site 2, Day (season, month, site and time).

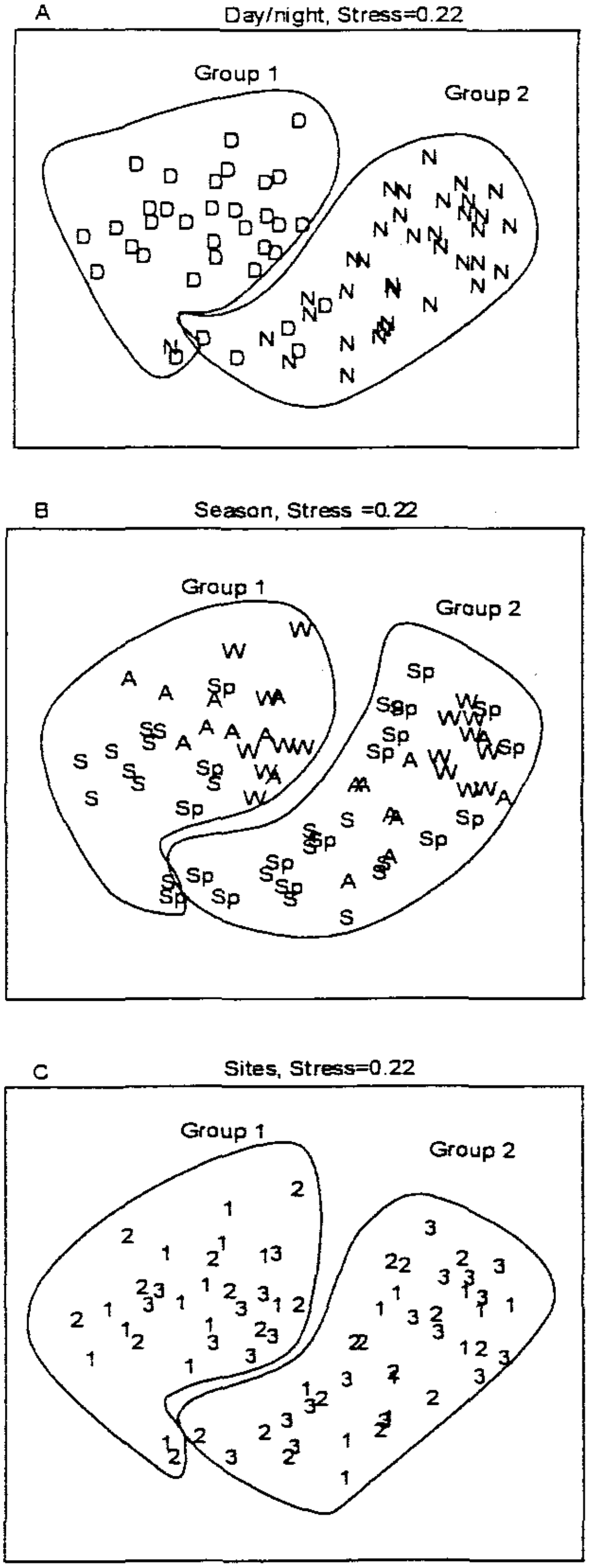


Figure 4. 12 MDS 2-dimensional ordination of samples showing 2 community groups derived at the Mhlathuze by cluster analysis. Symbols D, N, S, A, W and Sp represent day, night, summer, autumn, winter, and spring, respectively. Numbers are sampling Site 1, 2 & 3.

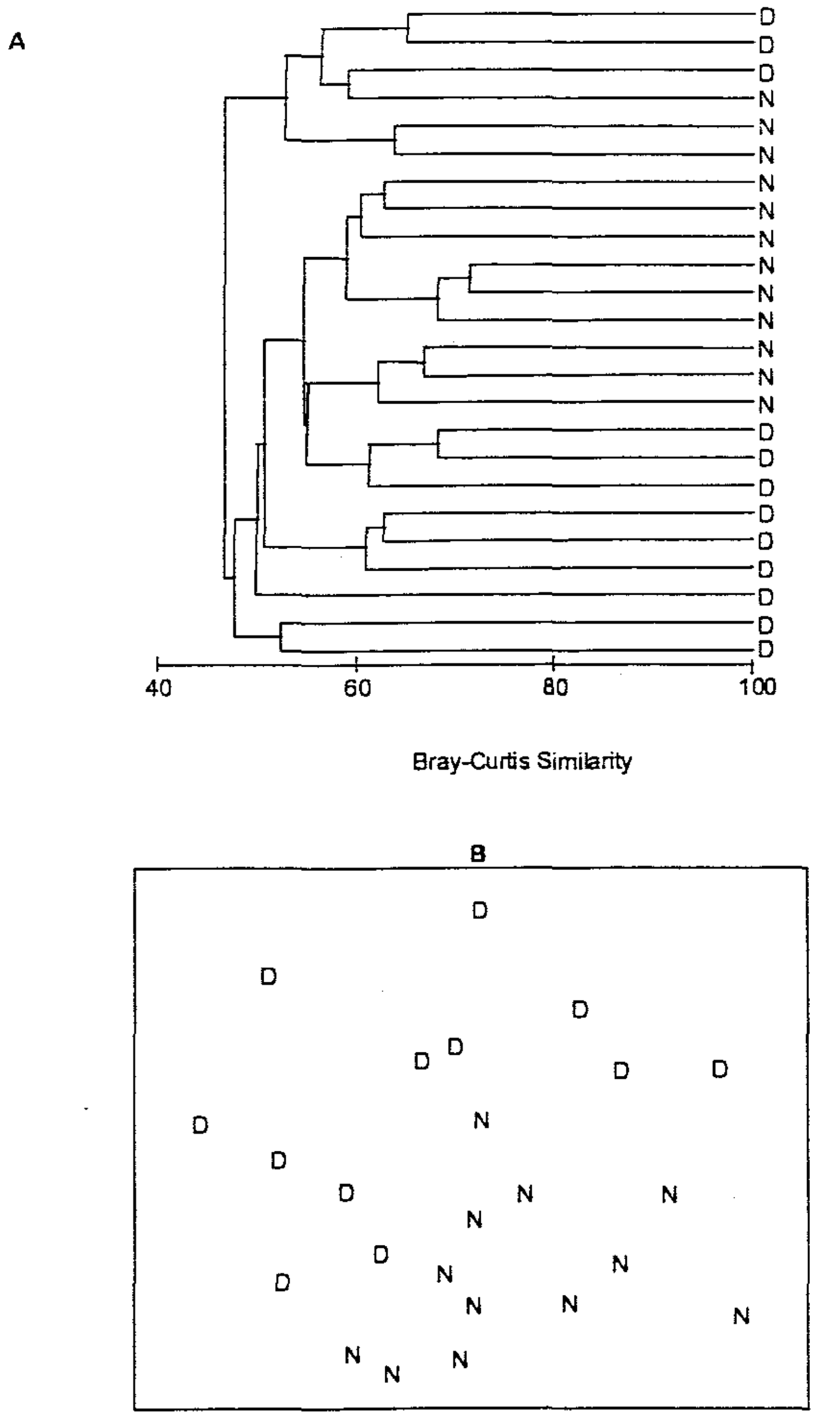


Figure 4. 13 Bray-Curtis dendrogram (A) and corresponding NMDS plot (B) of averaged density of zooplankton collected in the Mhlathuze surf zone, illustrating diel (day/night) patterns in the community structure. Sampling times are represented as D=day and N=night.

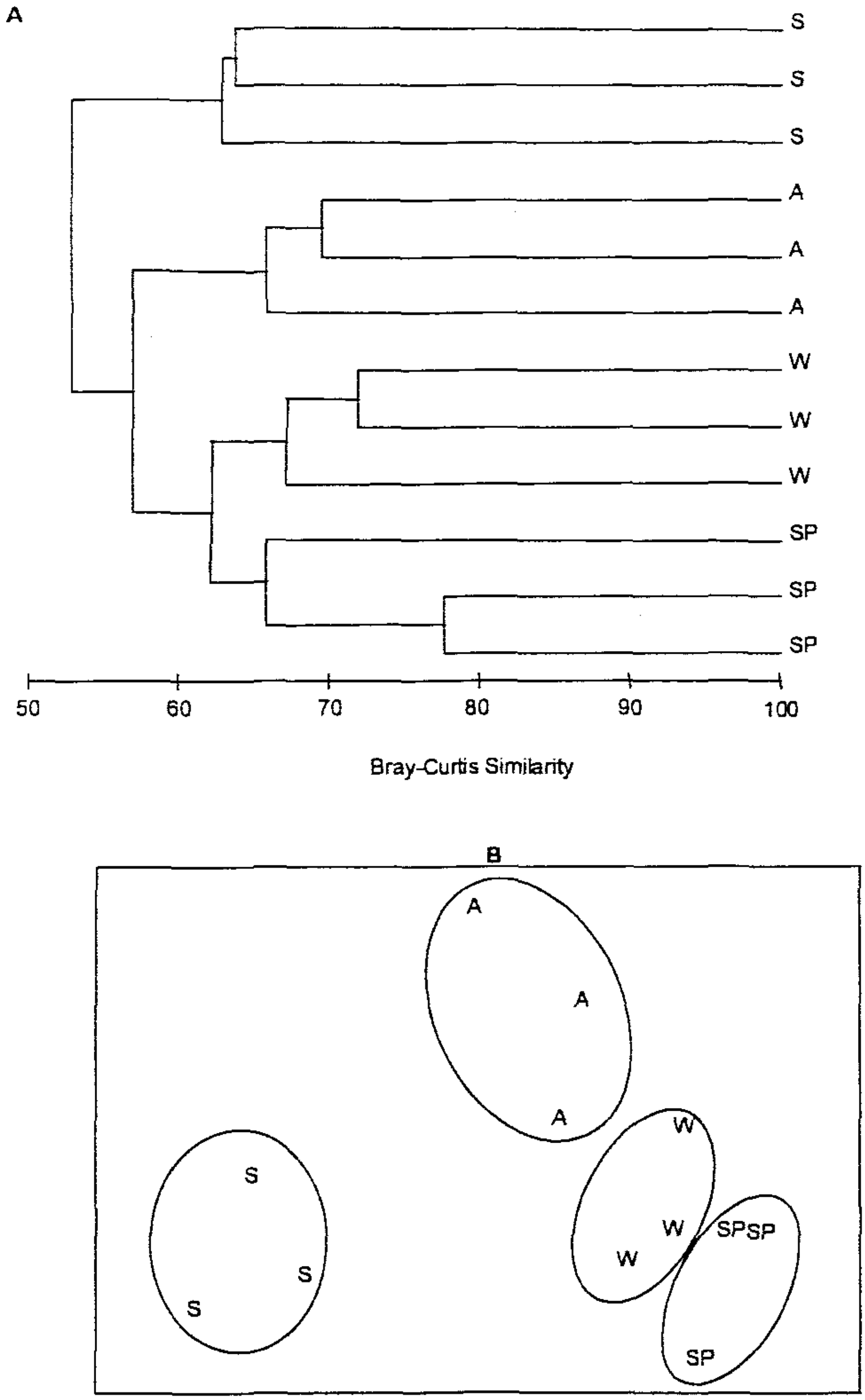


Figure 4. 14 Bray-Curtis dendrogram (A) and corresponding NMDS plot (B) of averaged density of zooplankton collected in the Mhlathuze surf zone, illustrating seasonal patterns in the community structure. S=summer, A=autumn, W=winter and Sp=spring.

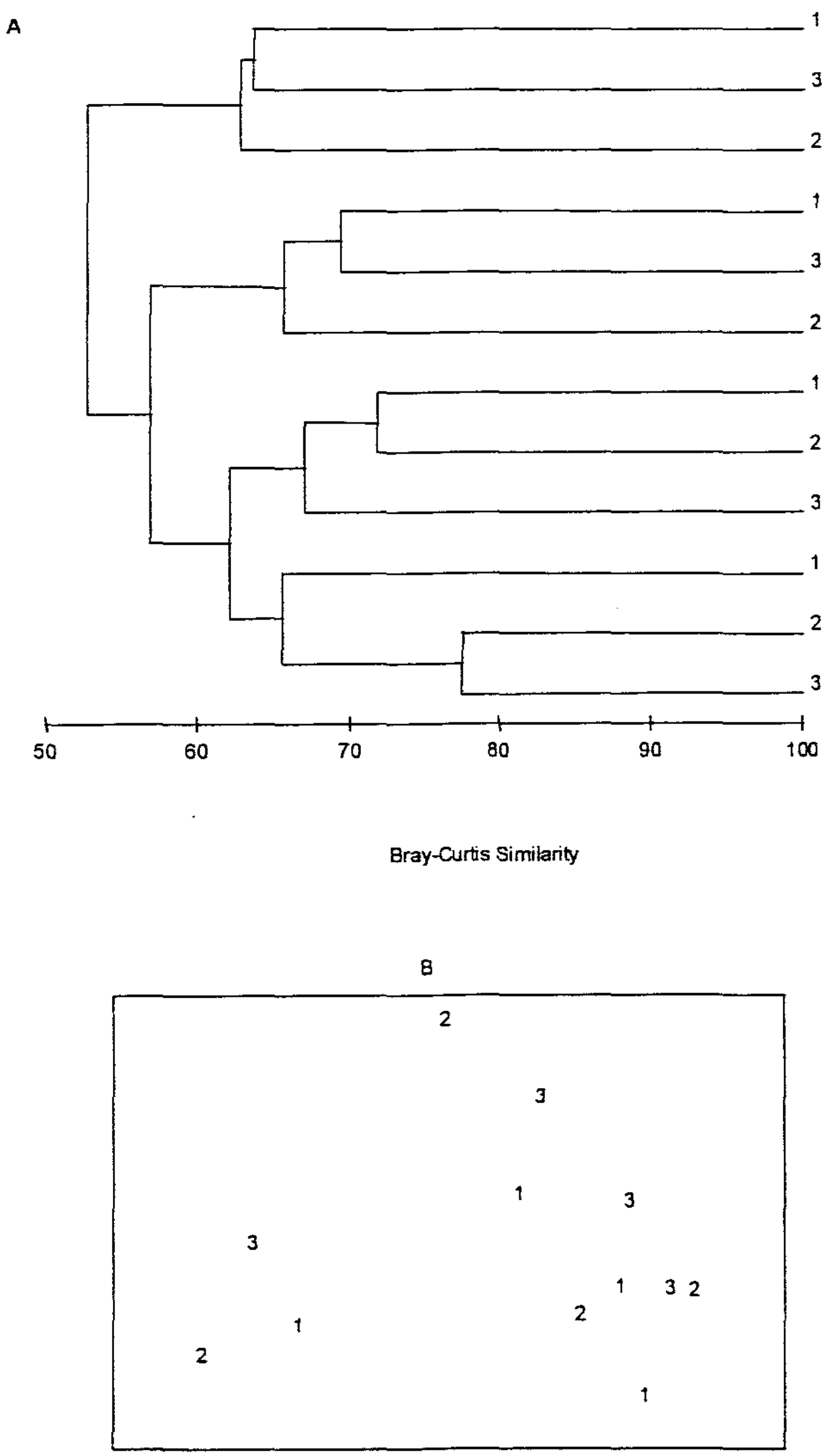


Figure 4. 15 Bray-Curtis dendrogram (A) and corresponding NMDS plot (B) of zooplankton sampled in the Mhlathuze surf zone, illustrating spatial (site) patterns in the community structure.

The stress value was 0.22 which does not give a very good 2-dimensional picture suggesting that the interpretation should be based on both cluster and NMDS analyses. Group 1a, which mainly consisted of invertebrate plankton sampled at Sites 1, 2 and 3, appeared exclusively during the day in summer and autumn (summer/autumn assemblage). Brachyuran megalopae and zoeae, ctenophores and calanoids dominated this assemblage. Group 1b included Site 1 spring samples, Site 3 autumn, and all winter sites. This group was, however, characterised by the dominance of winter samples and was designated as the winter assemblage. The winter assemblage was dominated by calanoids, *Cirolana* spp., Ctenophores and brachyuran megalopa. Group 1c was characterised by the dominance of calanoids, siphonophores and *Sagitta* sp. which occurred at Sites 2 and 1 during winter and spring respectively. Group 1d included Site 1 samples collected during summer at night and Site 2 spring day samples. The characteristic taxa of this group included brachyuran megalopa, *Cirolana* spp. and *Gastrosaccus* spp, and was designated the Mhlathuze spring/summer assemblage.

Group 2a included night samples from Sites 1, 2 and 3 collected during summer dominated by brachyuran megalopae, *Cirolana* spp. and calanoids. This group also appeared during the day at Sites 2 and 3 in winter and spring samples. Group 2b included Sites 1 and 2 during autumn and Site 3 during spring (spring/autumn assemblage). The spring/autumn assemblage was characterised by the dominance of *Cirolana* spp., brachyuran megalopae, *Gastrosaccus* spp. and ctenophores.

Group 2c occurred mainly at Sites 2 and 3 during spring and summer (spring/summer assemblage). This group was characterised by the dominance of brachyuran megalopae, *Cirolana* spp. and calanoids. The spring/summer assemblage, however, appeared again at Site 1 in autumn. Finally Group 2d designated, as the winter/spring assemblage, was observed at Sites 1, 2 and 3 during winter and spring. This assemblage was dominated by calanoids, brachyuran megalopae, *Cirolana* spp. And *Gastrosaccus* spp. This assemblage also appeared at Site 3 in autumn during this study.

Although seasonal patterns were observed in these data, the faunal assemblages were not distinctively clustered due a strong influence of time of day (Figure 4.13) which might have a masking effect on seasonal and spatial patterns. It was then considered worthwhile performing the same analysis on season (across all sites) and sites that excluded the time factor to elucidate seasonal and spatial patterns. The clustering and NMDS ordination exhibited a distinctness of the different seasonal groups (Figure 4.14). However, there were no obvious differences between sampling sites in terms of composition and/or abundance within the surf zone (Figure 4.15). It would appear that at Mhlathuze clustering and NMDS ordination revealed no spatial patterns, with faunal composition and/or abundance being grouped according to time of day and season (Figure 4.11-4.15), suggesting a strong influence of these factors on the invertebrate zooplankton.

Testing for the significance of differences between seasons, sites and sampling times.

Since the biological data from this study could not be reduced to approximate normality by any transformation, it was invalid to make the standard assumptions of normality as explained in Section 4.3.1. After it was established that there were no significant differences between monthly samples (Table 4.2), monthly samples were grouped per season to provide replicates. The significance of any differences ($p<0.05$) between day/night, season groups and sites within each system was tested using one-way analysis of similarity (ANOSIM).

Tables 4.3, 4.13 and 4.14 display the results of analysis of similarity showing the significance of any differences between sampling times, sites and seasons at the Mhlathuze surf zone, respectively. This was done to validate the patterns identified by the cluster and NMDS analyses. At the Mhlathuze surf zone, significant differences were recorded between day and night (Table 4.3). In addition, all seasonal groups were found to be significantly different from each other suggesting a strong seasonal influence (Table 4.14). The one-way analysis of similarity (ANOSIM) showed that there was no statistically significant difference between sites (Table 4.13). These results, therefore, validate the patterns and groups identified in Bray-Curtis classification and NMDS ordination.

Table 4.13: Similarity test statistics ® and significance levels (P) of differences between sites (Site1-3) sampled during the day (D) and night (N) between November 1998 and October 1999 in the Mhlathuze surf zone. Asterisks indicate a significant difference (* = $p < 0.05$).

Sites	R	P
Site 1 vs Site 2	-0.271	0.914
Site 1 vs Site 3	-0.115	0.714
Site 2 vs Site 3	-0.177	0.80

Table 4.14: Similarity test statistics ® and significance levels (P) of differences between seasons (across sites) sampled during the day (D) and night (N) between November 1998 and October 1999 Mhlathuze surf zone. Asterisks indicate a significant difference (* = $p < 0.05$).

Season	R	P
summer vs autumn	0.7	0.002*
summer vs winter	0.706	0.002*
summer vs spring	0.894	0.002*
autumn vs winter	0.537	0.002*

Table 4.14 continued...

autumn vs spring	0.759	0.002*
winter vs spring	0.259	0.015*

It would appear from the Cluster, NMDS and ANOSIM analyses that surf zone faunal communities at both the St. Lucia and Mhlathuze surf zones were structured on the basis of time of day and season. Changes in sites within each system, however, had no effect on faunal communities suggesting that there was no relationship between their abundance, distribution and distance from the mouth.

Taxa characterising sites, seasons and times (day/night) at Mhlathuze

The SIMPER program in the Primer package was used to determine site relationships (in terms of species assemblages) separated *a priori* on the Mhlathuze surf zone data. Groups were selected on the basis of site, season and sampling time. As at St. Lucia, this was also done to determine which taxa were principally responsible for the formation of groups (i.e. to determine characteristic taxa for each site, season and time of day) and to establish if any discriminating taxa were present between groups. The data were transformed using double square root transformation and only dominant species (those species comprising >3% of the total abundance at any sampling site) were included in the analysis.

Dissimilarity between sampling sites

At the Mhlathuze estuary, thirty-seven zooplankton taxa (Table 4.15) were identified as dominant taxa (those taxa that comprising >3 % of the total abundance at any sampling site), and were examined for characteristic taxa. The results of SIMPER analysis are shown in Tables 4.16 and 4.17, while Appendix 8 shows characteristic taxa of site groups. Site 1 was more dissimilar to Site 2 (Table 4.16). The similarity within each site (Table 4.17) showed a relatively higher fluctuation in species assemblages, reflected in the low similarity percentages (<40%).

Table 4. 15: List of dominant zooplankton taxa (>3% of total numerical abundance any one occasion) at the Mhlathuze surf zone and association of species with marine (Mar.) estuarine (Est.), estuarine/marine (E/M) and freshwater (F.W.) environments.

Taxa	Environment
Unid. Coelenterata	Mar.
Obelia spp	Mar.
Anthomedusa	Mar.
Siphonophora	Mar.
Tubularia	E/M
Ctenophora	Mar.

Table 4.15 continued...

Bassia bassensis	Mar.
Scyphozoa	Mar.
Polychaeta	Est.
Polychaete larvae	Est.
Bivalvia	Mar.
Ostracods	Est.
Calanoids	E/M
Corycaeaus sp.	Mar.
Podocerus spp.	Est.
Grandidierella spp.	Est.
Polycheria atolli	Est.
Ampelisca palmata	Est.
Corophium sp.	Est.
Hyperia galba	Est.
Urothoe spp.	Mar.
Paraphoxus oculutus	Est.
Cirolana spp.	E/M
Isopod larvae	E/M
Gastrosaccus spp.	E/M
Unid. mysids	Est.
Palinurus vulgaris	Mar.
Caridean zoea	Est.
Penaeids	Mar.
Penaeidae larvae	E/M
Lucifer sp.	Mar.
Brachyurans (zoeae)	E/M
Megalopal larvae	E/M
Cumacea	E/M
Apseudes digitalis	Est.
Longicomis sp. (zoeae)	E/M
Cirripedia	
Sagitta sp.	Mar.
Unknown taxa	

Table 4.16: Percentage dissimilarity of invertebrate zooplankton assemblages between three sampling sites in the Mhlathuze surf zone.

	% dissimilarity between sampling sites		
Site	**1**	**2**	**3**
1		61.81	63.13
2			63.66

Table 4.17: Percentage average similarity of invertebrate zooplankton assemblages between three sampling sites in the Mhlathuze surf zone.

Site	**% Similarity within a sampling site**
1	37.49
2	37.03
3	34.35

Taxa characterising sites

At Sites 1-3, over 75% cumulative percentage was formed by 7 and 6 taxa respectively (Appendix 8). Site 1 was mainly characterised by calanoids, *Cirolana* spp, brachyuran megalopae, *Sagitta* sp., *Gastrosaccus* spp., ctenophores and cumaceans. Sites 2 and 3 assemblages were also characterised by calanoids, brachyuran megalopae, *Cirolana* spp., *Gastrosaccus* spp., *Sagitta* sp. and ctenophores.

Dissimilarity between seasons

Tables 4.18, 4.19 and Apppendix 7 show the results of the SIMPER analysis giving characteristic species of seasonal groups. All seasonal groups were dissimilar in terms of composition and abundance (>60% dissimilarity level) (Table 4.18). The similarity breakdown within each season (Table 4.19) showed that winter and spring had relatively similar assemblages throughout the sampling period, reflected in the high similarity percentage (>40%). On the other hand, summer and autumn showed fluctuations in their assemblages.

Taxa characterising seasonal groups

Seasonally, over 75% cumulative percentage contribution was achieved by eight, eight, six and and five taxa during summer, autumn, winter and spring respectively (Appendix 9). The summer assemblages within the surf zone were mainly characterised by *Cirolana* spp., calanoids, brachyuran megalopae, ctenophores, *Sagitta* sp., bivalves, penaeid prawn larvae and Cirripedia.

Table 4.18: Percentage dissimilarity of invertebrate zooplankton assemblages between sampling seasons in the Mhlathuze surf zone.

	% dissimilarity between sampling sites			
Season	**summer**	**autumn**	**winter**	**spring**
summer		65.72	64.61	67.48
autumn			62.57	64.88
winter				60.62

Table 4.19: Percentage average similarity of invertebrate zooplankton assemblages between sampling seasons in the Mhlathuze surf zone.

Season	***% Similarity within a sampling site***
summer	39.50
autumn	38.64
winter	43.44
spring	40.75

During autumn the surf zone assemblages were mainly characterised by brachyuran megalopa and zoea larvae, calanoids, *Cirolana* spp., ctenophores, *Sagitta* sp., ostracods and *Gastrosaccus* spp. The winter assemblages within the surf zone waters were mainly characterised by calanoids, *Cirolana* spp., *Sagitta* sp., brachyuran megalopa, *Gastrosaccus* spp. and ostracods. Finally, the spring assemblages were characterised by brachyuran megalopa, calanoids, *Cirolana* spp., *Gastrosaccus* spp. and Penaeidae sp.

Dissimilarity between sampling times

The day and night assemblages were dissimilar to each other in terms of numerical abundance at a 65% dissimilarity percentage. The reason for such dissimilarity is that there was a marked increase in abundance of crustaceans including isopods, mysids and brachyura megalopae at night. The similarity breakdown within each time of day showed a higher degree of fluctuation in species assemblages sampled during the day than those sampled at night (Table 4.20).

Table 4.20: Percentage average similarity of invertebrate zooplankton assemblages between day and night in the Mhlathuze surf zone.

Time	% Similarity within a sampling site
Day	34.78
Night	42.90

Taxa characterising day and night samples

During the day the surf zone assemblages were characterised by a number of species with six taxa forming >75% of the cumulative percentage. These included calanoids, brachyuran megalopae, *Cirolana* spp., *Sagitta* sp., ctenophores and brachyuran zoeae (Appendix 10). Over 75% of the cumulative percentage was achieved by seven taxa that formed the characteristic taxa of the assemblages sampled at night in the surf zone (Appendix 10). The night assemblages were characterised by *Cirolana* spp., brachyuran megalopae, calanoids, *Gastrosaccus* spp., *Sagitta* sp., cumaceans and ctenophores. It is evident from the above results shown in Appendix 10 that the day assemblages were mainly characterised by holoplankton such as copepods, whilst the night assemblages were mainly characterised by bentho-planktonic taxa (isopods and surf zone mysids) and meroplankton (brachyuran megalopa).

Community diversity at the Mhlathuze

Shannon-Wiener's index of diversity, Margalef's (1961) measure of species richness and Pielou's (1986) Evenness index were also used to describe zooplankton species-abundance relations at the Mhlathuze in order to elucidate differences between the sampling season, sites and time of day using the zooplankton data as explained in Section 4.2.3.

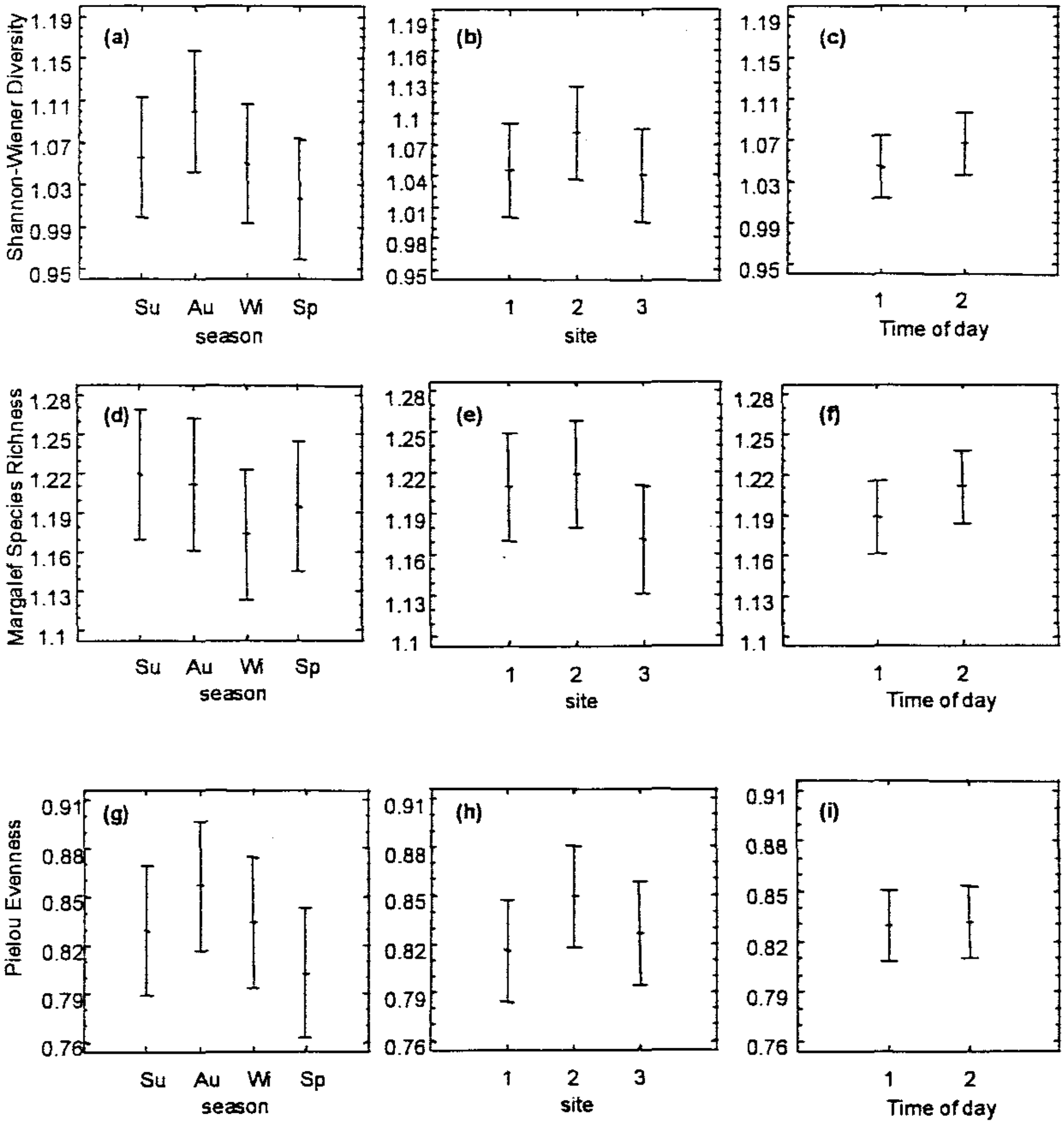


Figure 4. 16 Mean ± 95%CL diversity indices averaged across all sites and time of day for each season (a, d, g), averaged across all sampling time of day and seasons for each site (b, e, h), and averaged across all seasons and sites for each time of day (d, f, i) at the Mhlathuze surf zone between November 1998 and October 1999. Su=summer, Au=autumn, Wi=winter and Sp=spring. Time 1=day and 2=night.

Figure 4.16 shows differences between seasons, sites and time of day in terms of community diversity, richness and evenness. Diversity increased slightly between summer and autumn followed by a decline in winter and spring (Figure 4.16a) reflecting a higher species richness and more diverse assemblages during autumn. A similar pattern was noted in the Pielou Evenness index, which showed a more even distribution of individuals during autumn.

Higher species richness and more diverse assemblages, were recorded in autumn with increased densities (Figure 4.10B). This contrasted with spring lower diversities. With respect to spatial variations, Site 2 had relatively more diverse assemblages, an increased number of species and was characterised by evenly distributed individuals. However, low densities of invertebrate zooplankton were recorded at this site. During both day and night sampling times, the diversity remained relatively unchanged, reflecting a relatively stable community between day and night but with increased densities of taxa such as mysids, brachyuran megalopae and zoeae, and isopods at night.

Table 4.2 shows the results of multifactor analysis of variance (MANOVA) which was used to test for significance of differences among seasons, sites and times with respect to diversity, richness and evenness indices. There were no significant differences seasons, sites and day/night with respect to diversity indices (Table 4.2). The analysis of variance (MANOVA) also showed that factors had no statistically significant effect on community diversities at the Mhlathuze surf zone (Table 4.2).

4.3.3 Statistical comparison of the invertebrate zooplankton assemblages in St. Lucia and Mhlathuze surf zones.

Clustering and NMDS ordination of mean seasonal zooplankton (averaged across sites) in each system are shown in Figure 4.17. Clustering and NMDS ordination analyses revealed two groups of fauna delineated at 50% similarity level, with Group 1 predominantly formed by samples collected at St. Lucia and Group 2 dominated by samples collected at the Mhlathuze surf zone. Significant differences (R=0.973; P=0.001) were found between these systems, confirming that the differences revealed by Clustering and NMDS ordination analyses were significant. Differences between the St. Lucia and Mhlathuze communities in terms of abundance were also noted where a relatively higher mean density of 103 (ind.m^{-3}) was recorded at St. Lucia compared with a mean density of 12 (ind.m^{-3}) recorded at Mhlathuze. SIMPER analysis showed that 31 taxa formed 75% of the cumulative percentage contribution which were characteristic of the invertebrate zooplankton community at St. Lucia.

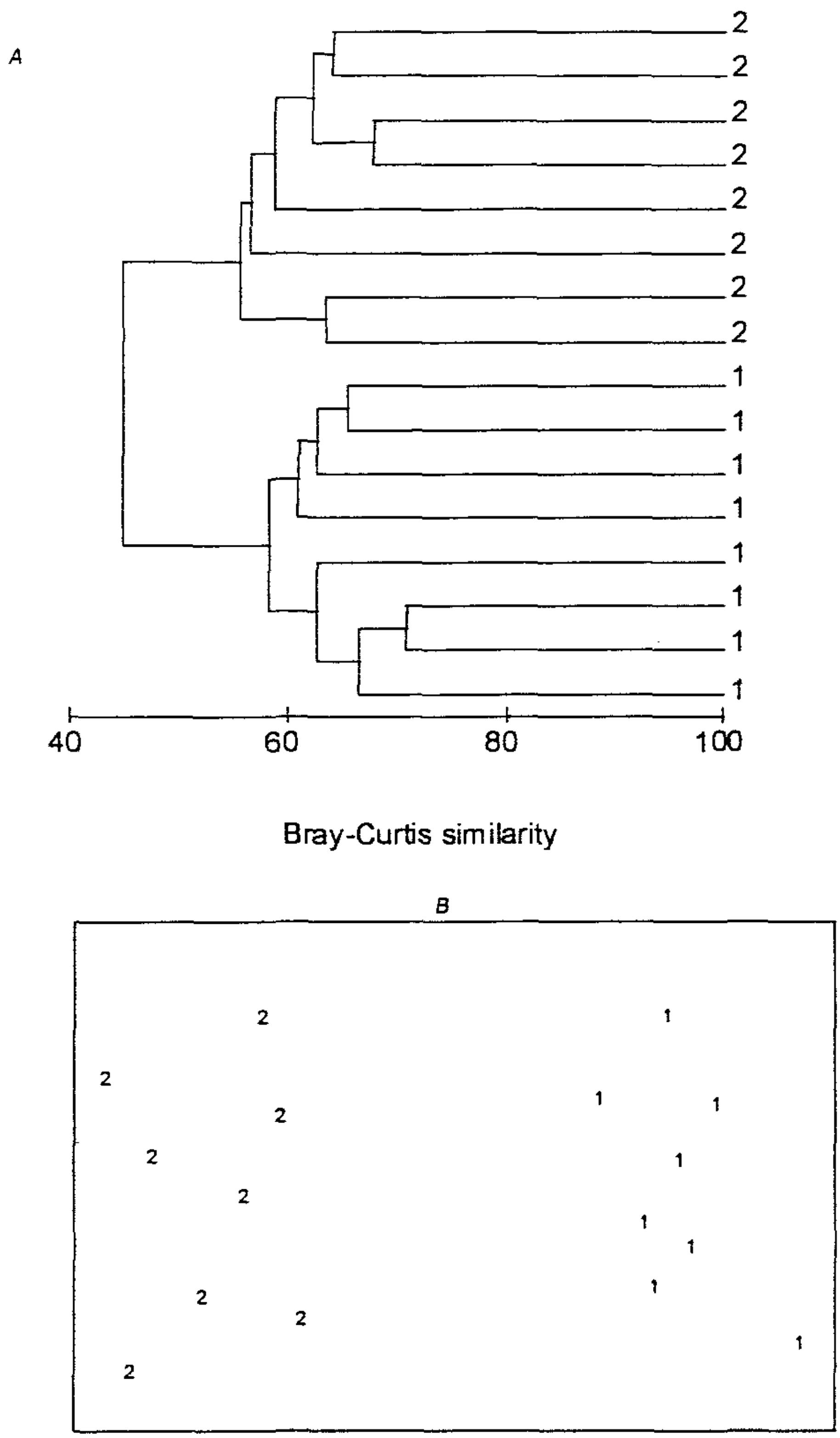


Figure 4. 17 Bray-Curtis dendrogram (A) and corresponding NMDS plot (B) of mean zooplankton sampled in the St. Lucia and the Mhlathuze surf zones, illustrating differences in the community structure between two systems. Numbers 1 and 2 represent the St. Lucia and Mhlathuze surf zones, respectively.

The characteristic taxa were, however, dominated by calanoids, *Gastrosaccus* spp., *Cirolana* spp., *Sagitta* sp. and brachyuran megalopae (Appendix 11). At Mhlathuze, 75% cumulative contribution was achieved by 19 taxa. Taxa that characterised the Mhlathuze surf zone community included *Cirolana* spp., brachyuran megalopae, calanoids, *Sagitta* sp., ctenophores and *Gastrosaccus* spp. (Appendix 11).

Diversity indices such as Shannon-Wiener diversity, Margalef's (1961) species richness and Pielou's (1986) evenness were also used to investigate differences between these systems in terms of species-abundance relationship. Figure 4.18 shows the plots of diversity indices, illustrating differences between the St. Lucia and Mhlathuze surf zone community diversities. At St. Lucia, the invertebrate zooplankton community had a higher species richness and slightly lower diversity than at Mhlathuze which had a lower species richness and diverse assemblages. The St. Lucia surf zone community had a less evenly distributed individuals and had a high dominance of few taxa (i.e. few taxa with high abundance) in contrast to the Mhlathuze community, which had more evenly distributed individuals within taxa and high number of taxa with low densities (Figure 4.18).

4.3.4 Relating planktonic invertebrate data to physico-chemical data.

The St.Lucia surf zone

The physico-chemical variables such as temperature, salinity and turbidity measured at St. Lucia were log transformed and examined for colinearity prior to the analysis. Turbidity was not recorded in October 1992 during night sampling. As a result three samples collected at night during this period (October) were excluded in the analysis. Table 4.21 shows the results of the BIOENV procedure of temperature, salinity and turbidity combinations, as measured by weighted Spearman rank correlation (ρ_w). These combinations did not give groups that "best matched" the faunal patterns. However, the single environmental variable which best accounted for the faunal patterns obtained in Section 4.3.2 (Figure 4.7 and 4.8), was salinity with a maximum Spearman's rank correlation value (ρ_w) of 0.127 (Table 4.21).

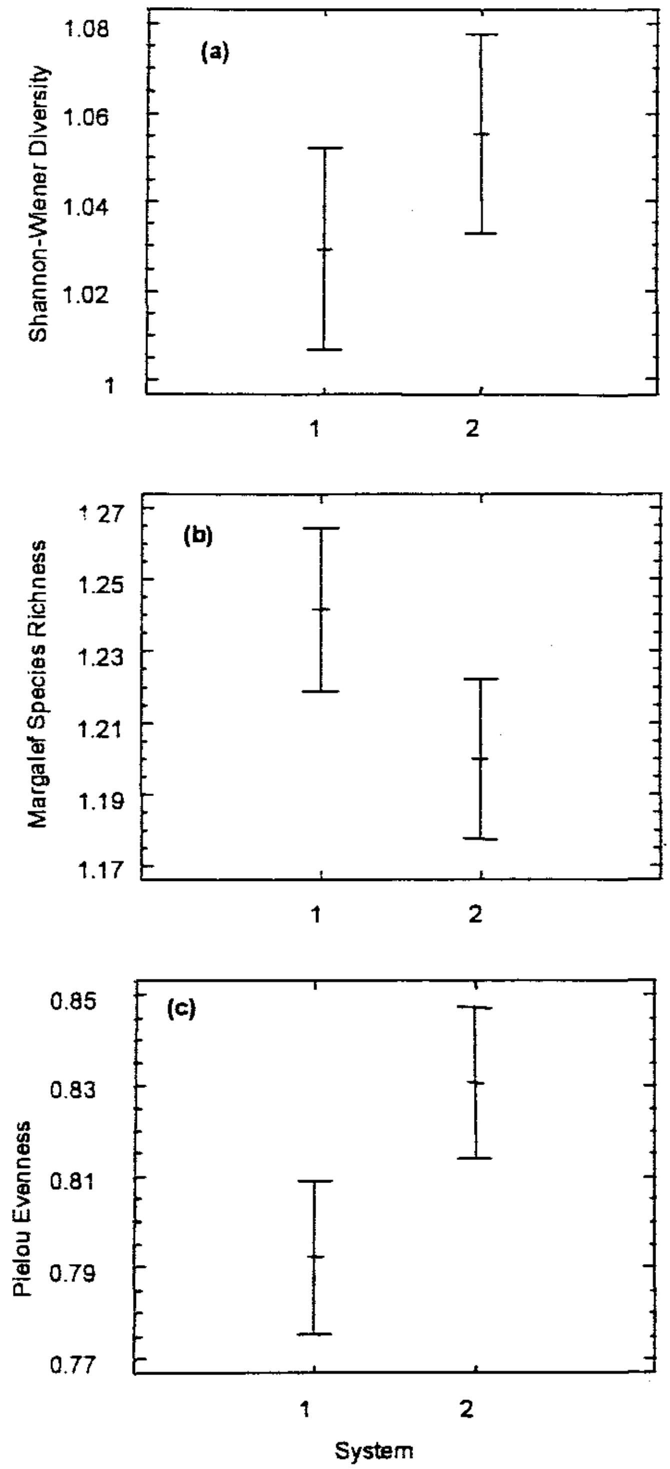


Figure 4. 18 Mean ± 95%CL of diversity indices averaged across all sampling time, season and sites for each system. Numbers 1 and 2 represent the St. Lucia surf zone and Mhlathuze surf zone, respectively.

Table 4.21: St. Lucia surf zone. Combinations of the 3 environmental variables, taken k (i.e. once, twice, etc.) at a time, yielding the best matches of biotic and abiotic matrices for each k, as measured by weighted Spearman's rank correlation (ρ_w). Bold type indicates overall maximum ρ_w. T = Temperature, Sal = Salinity and Turb. = Turbidity.

k	Best variable combination (ρ_w)		
1	T (-0.074)	**Sal** **(0.127)**	Turb. (-0.019)
2	T, Sal (-0.011)	T, Turb (-0.065)	Sal, Turb (0.007)
3	T, Sal, Turb (-0.038)		

The Mhlathuze surf zone

The results of the BIOENV analysis, which was used to determine the relationship between the biotic and physico-chemical patterns, are shown in Table 4.22. The physico-chemical variables were first log transformed and examined for colinearity. Due to the interrelationship/correlation of salinity and conductivity, only salinity was used as a representative as explained in section 4.2.4. Other environmental variables such as oxygen (saturation and dissolved), pH and conductivity were not measured in July 1999 and it was not possible to perform the analysis because the data contained missing values. As a result these variables were excluded in the analysis. The single environmental variable which best accounted for the faunal patterns obtained in Section 4.3.2 (Figures 4.12 and 4.13), was temperature with a maximum value for ρ_w of 0.227; the next best match was turbidity followed by salinity. The best 2-variable combination was temperature and turbidity with a correlation coefficient (ρ_w) of 0.072 (Table 4.22).

Table 4.22: Mhlathuze surf zone. Combinations of the environmental variables, taken k (i.e. once, twice, etc.) at a time, yielding the best matches of biotic and abiotic matrices for each k, as measured by weighted Spearman's rank correlation (ρ_w). Bold type indicates overall maximum ρ_w. T = Temperature, Sal = Salinity and Turb. = Turbidity.

k	Best variable combination (ρ_w)		
1	T **(0.227)**	Sal (0.069)	Turb (-0.007)
2	T, Turb. (0.209)	T, Sal (0.179)	Sal,Turb (0.022)
3	T, Sal,Turb. (0.170)		

However, a single variable alone could not be responsible for structuring communities at the St. Lucia and Mhlathuze systems due to interactions between variables. The analysis using the RELATE program in Primer to test the significance of any relationship between the abiotic and biotic patterns indicated no significant relationship at either estuary (Table 4.23). These results suggest that other variables not measured during the present study might also be responsible for structuring these communities.

Table 4. 23: Result of RELATE analysis, showing significance (P<0.05) of match between abiotic and biotic patterns.

System	R	P
St. Lucia surf zone	0.055	0.191
Mhlathuze surf zone	0.44	0.099

4.4 Discussion

4.4.1 Community structure, abundance and distribution.

The surf zone community can be divided according to their origin and motility (Brown and McLachlan 1990). These include obligate zooplankton (holoplankton and meroplankton), facultative sand-burrowing crustaceans and transient nearshore marine species (pelagic mysids and swimming penaeid prawns). Plankton and bentho-planktonic organisms belonging to different taxonomic types were sampled from the St. Lucia and Mhlathuze surf zones. The increased abundance of surf zone/beach mysids of the genus *Gastrosaccus* within the surf zone at St. Lucia may be explained by their swimming capabilities which make them relatively free from being transported by currents operative in the surf zone. Similar results were also reported by Wooldrigde (1983) who recorded mysids (more than 14 species) along transects out to depth of 20 m off sandy beaches in the Eastern Cape. He reported that *Gastrosaccus* dominated the swash and surf zones, while *Mesopodopsis* dominated the head zone and the area seaward of it. However, Clutter (1967) demonstrated an offshore zonation of four mysids, a large species dominating the surf zone, small *Metamysidopsis* dominating the rip head zone, and two other species further offshore. The body-size gradient was related to the gradient of turbulence. High abundances of mysids were also associated with their success in coping with surf zone conditions. For an example, Wooldridge (1983) suggests that continuous all-year cohort production by the *Gastrosacccus psammodytes* population, and retention and protection of a relatively large brood coupled with specific distribution and behavioural patterns contribute to the success of this species. He also suggests that by remaining close inshore, loss from the brood pouch as a result of abrasion, water turbulence and violent movements of the parent can be reduced. Wooldridge (1983) also reported intraspecific zonation in *Gastrosaccus* populations where brooding females are closest inshore, and immature females, males and juveniles are more abundant in the turbulent water of the surf zone.

High densities of mysids corresponded with recorded period of breeding activity during summer which was marked by the presence of breeding females and juvenile mysids (Wooldridge 1980). Wooldridge (1980) reported that young are released after 18-20 days in mid-winter and 8-10 days in mid-summer, which explains the presence of high numbers of mysids in summer months. In the present study the tidal influence was not investigated. However, Wooldridge (1983) reported that *Gastrosacccus psammodytes* is a tidal migrant and animals emerge periodically from the substrate and move up or down the beach as tides rise and fall. Longshore distribution patterns are associated with rythmic shoreline and surf zone patterns. McLachlan and Hesp (in Robertson and Lenanton 1984) showed that the surf zone benthoplanktonic amphipods and mysids of a reflective Australian beach concentrated at times off cusp horns, although the trend was less pronounced among the benthos. Wooldridge (In Brown and McLachlan 1990) has similarly demonstated a patchy distribution of the mysid *Gastrosaccus* alongshore, related to the spacing of rip currents and other shoreline features.

At the Mhlathuze estuary, the increased numerical abundance of brachyuran larvae may be explained by their mass recruitment into the estuary. High numbers of brachyuran megalopae found in the surf zone can be accounted for by the release of high numbers of crab larvae followed by megalopal return to the estuary (Pereyra-Lago 1993). This was also evident from the spatial distribution in brachyuran megalopae, which showed high densities near the mouth (at Site 1), indicating recruitment of megalopae into the estuary. The present study suggests that recruitment of megalopae into the Mhlathuze estuary occurred mainly at night during summer, autumn and spring. has demonstrated a pattern of tidal exchange for *Sesarma catenata* larvae, with highest abundance of zoeal larvae on the nocturnal ebb tide. He also found that the recruitment of megalopae into the estuary occurred mainly during flood tides from January to March.

Bentho-planktonic behaviour was also evident among several zooplankton species collected from the St. Lucia and Mhlathuze surf zones. Most prominent among those species were surf zone/beach sand-burrowing mysids *Gastrosacuss* spp. and the intertidal isopods *Cirolana* spp. These species are normally associated with high-energy marine beaches occurring in sand and the overlying water column. The occurrence of these infauna in the water column is well known (Warman *et al.* 1991; Brown and McLachlan 1990). Migrations between benthic and pelagic environments by infaunal species such as these are well established for a wide range of habitats (Ross *et al.* 1987). The animals emerge from the sand to feed in the water column (Brown and McLachlan 1990) displaying tidal, lunar and noctumal swimming rhythms (e.g. Wooldridge 1981, Romer 1986 and Warman *et al.* 1991). The bentho-planktonic component, unlike holoplankton, appeared to be less influenced by planktonic environment. The migration behaviour and swimming helped to maintain them in the beach/surf zone environment. The distribution of bentho-planktonic organisms such as mysids when swimming is largely limited to the zone of breaking wave and slightly beyond (Wooldridge 1981). However, holoplankton have no particular relation to the beach/surf zone and their presence within the surf zone is probably a result of passive rather than active habitat preference.

At both the St. Lucia and Mhlathuze surf zones there were significant differences between day and night communities in terms of densities. Noctumal zooplankton activity within the water column was evident during the present study. Statistical analyses revealed a pattem of change in surf zone zooplankton from day to night which was attributed to the increased numbers of benthoplanktonic crustaceans, in patricular, at night. Similar noctumal zooplankton increases were reported by Romer (1986) off the Sundays River Beach in the Eastem Cape. Previous work by authors such as Wooldridge (1983) and Moran (1972) showed that emergence from the beach substrate of bentho-planktonic crustaceans is primarily a noctumal phenomenon. Noctumal swimming activity of infaunal zooplankton has been associated with diumal fish predation pressure (Romer 1986). The reason for the observed distribution of resident zooplankton in the surf zones at St. Lucia and Mhlathuze can be attributed to increased activity at night. However, the distribution of infaunal zooplankton observed off Eastem Cape beaches was inferred by predator-avoidance behaviour (Romer 1986). Predation of infaunal crustaceans by fish is well known (Rossouw 1983, Romer 1986) and their diumal concentration with the intertidal swash zone benthos may prevent them from being reached by subtidal fish such as sandsharks (Wooldridge 1983). Migration into the water column only after dark to feed may thus be an effective predator avoidance behaviour (Romer 1986).

Zooplankton may be distributed horizontally and vertically due to patches in phytoplankton, currents and day/night influences. Vertical distribution pattems of zooplankton were not investigated during the present study. However, vertical stratification was not evident at the Sundays Estuary surf zone (Romer 1986). Horizontally, sites near the mouth of the estuaries had relatively higher zooplankton densities than further away. The similarity between sites revealed by clustering and an NMDS analysis suggests that a homogenous community is present. This was also confirmed by ANOSIM analysis, which showed that sites were not influential in the distribution of zooplankton. However, Cockroft (1979) reported differences in zooplankton densities between sites at Kings Beach in the Eastern Cape. The results from this study, however, suggest the physical processes were the dominant factors controlling the observed spatial variability in the communities of the St. Lucia and Mhlathuze surf zones. Zooplankton within the water column are probably constantly dispersed by wave-induced subsurface currents which are variable (e.g. longshore and rip currents). As a result wave-driven geographic displacement of water and associated plankton between surf zone and immediate nearshore is also responsible for the fluctuations observed in the surf zone. This is evident from the intrusion of inshore coastal and neritic/oceanic taxa, such as Siphonophora, Calanoida and Chaetognatha, into the shallow surf zone. Similar patterns were reported by Murdoch (1989) who found that the oceanic species in the Blueskin Bay in New Zealand were carried by the shoreward flow of neretic water associated with eddy circulation.

Seasonally, invertebrate plankton abundance in subtropical waters exhibits a pattern of relatively low winter densities to a peak in the late summer. This pattern reflects the integrated response of zooplankton to seasonality of the environmental factors, e.g. light intensity, water temperature and food availability (Nielsen and Munk 1998). During the present study, the St. Lucia and Mhlathuze surf zone invertebrate plankton communities generally varied seasonally, with relatively high densities recorded in summer and low densities recorded in winter. The increased abundances of zooplankton in summer and spring can be associated with high phytoplankton production (Turner, Woo and Jitts 1979) and possibly migration of species into the surf zone during these periods. A decline in winter may be due to unfavourable conditions prevailing in the surf zone such as low phytoplankton production and nutrients.

Day and night communities in this study were further divided into four assemblages which were associated with season suggesting that seasonal changes were structuring invertebrate zooplankton communities. The hierarchical clustering and NMDS techniques, however, consistently identified more similar types of species assemblages occurring in the surf zone throughout the study regardless of season which emphasized the importance of physical processes in determining the spatial (sites) structure of the surf zone community.

4.4.2 A comparison of zooplankton in the St. Lucia and Mhlathuze surf zones.

The numerical abundance and mean densities of zooplankton were different in the St. Lucia and Mhlathuze surf zones with generally increased densities of dominant taxa at St. Lucia.

Clustering and NMDS ordination analyses revealed faunal assemblages which were grouped on the basis of geographic location (i.e. St. Lucia samples grouped together), indicating differences in the two systems. Differences between the St. Lucia and Mhlathuze surf zone community composition were attributable to dry (1992/93) and wet (1998/99) periods respectively (Figure 3.7 in Chapter 3). The differences observed between the two systems can also be due to different physical conditions in the surf zones including wave action/currents (longshore and Agulhas current), temperature, salinity and turbidity. At the Mhlathuze estuary, the mouth is wide open and kept so by the tidal regime. As a result greater water outflow from the Mhlathuze creates more estuarine conditions in the surf zone compared with St. Lucia. This may have resulted in the surf zone zooplankton being characterised by/or resembling that of the estuarine environment due to extension of the estuarine conditions. In contrast, the St. Lucia estuarine influence in terms of salinity was less pronounced with salinities well above 30 ‰. In addition, the Agulhas Current influence was evident in St. Lucia bringing water masses (characterised by high water temperatures) and associated neritic fauna into the surf zone as reflected in the higher species richness. At both surf zones, community diversity indices highlighted changes in the community which occurred at Site 1 in the Mhlathuze and Site 3 in the St. Lucia surf zone mainly at night which might indicate some degree of change in the invertebrate zooplankton at these sites. At Mhlathuze, the notable change associated with Site 1 could be the exchange of fauna such as decapod larvae across the mouth that took place mainly in autumn. The least diverse assemblages recorded at Site 3 at St. Lucia was attributed to reduced number of species, but increased abundances of bentho-panktonic crustaceans such as mysids and isopods in the surf zone at night. This emphasised the existence of nocturnal activity exhibited by these groups which joined the plankton at night to feed or to avoid predators.

4.4.3 Environmental variables influencing the invertebrate plankton communities.

The changes in community structure in the surf zones adjacent to St. Lucia and Mhlathuze estuaries reflected changes in the physical conditions such as temperature, salinity, currents, wave action, etc. Physical processes might have masked/surpassed the biological interactions since the surf zone water column is in continual motion, turbulent (due to wave action) and dilution and dispersion occur most frequently. As a result such changes might significantly affect and change the surf zone zooplankton. Murdoch (1989) reported the pattern of distribution of the zooplankton assemblages, which showed a strong correlation with local hydrographical features such as eddy circulation. Consequently, it was difficult to detect *in situ* biological processes that might have contributed to the observed distribution patterns (Murdoch 1989). He also found seasonal differences in the species composition of the assemblages which were attributed to biological processes such as the timing of spawning by fish and benthic crustaceans. In the surf zone environment, seasonal changes in temperature tend to be strongly pronounced and may be linked to changes in salinity which is also associated with seasonal patterns in rainfall and river runoff. Nutrients may be found in high concentrations owing to freshwater inputs. The turbidity of coastal waters tends to be high. From Chapter 3 it is evident that temperature, salinity and turbidity varied seasonally, without any obvious spatial and day/night patterns in the measured variables and thus could not be considered important driving variables of invertebrate zooplankton community structure in this study at spatial and diel level.

Many studies have been undertaken that attempt to relate zooplankton communities to environmental variability using multivariate analyses (Mazzocchi and Ribera d'Alcala 1995; Siokou-Frangou *et al.* 1998). Siokou-Frangou *et al.* (1998) demonstrated the importance of some environmental factors such as temperature, eutrophication-pollution, water mass circulation and topography on zooplankton community composition in a Mediterranean coastal area (Saronikos Gulf).

Water circulation seems also to be an important factor in zooplankton distribution. Although it was not measured, direct influence was evident in the analyses where there was a lack of distinct differences between sampling sites. The prevailing currents (e.g. longshore currents) allowed connection between sites and transportation of zooplankton from one site to another along the surf zone. At St. Lucia, salinity was found to be the main environmental variable influencing the zooplankton community of the St. Lucia surf zone. Temperature could not be regarded as the influencing factor for invertebrate zooplankton composition at St. Lucia. However, at the Mhlathuze it was found to be the most influential factor on the distribution of zooplankton structure. The influence of water temperature was expected since the seasonal succession is mainly dependent on temperature (Villate 1994). Similar results were found by Beyst *et al.* (2001). Beyst *et al.* (2001) found that the main abiotic factors that determine the occurrence of hyperbentic assemblages in the surf zone were temperature, wave height and turbidity. Siokou-Frangou *et al.* (1998) also demonstrated that temperature was the main factor in structuring the coastal zooplankton community.

The distinct assemblages observed during the present study reflect seasonal patterns, which can be explained by the influence of temperature. However, a single physico-chemical variable alone could not be the sole variable that regulates distribution and triggers biological responses in zooplankton (Siokou-Frangou *et al* 1998). This is due to the interaction between the physico-chemical variables. The combination of temperature, salinity and turbidity and other variables such as the availability of chlorophyll-a and wind-driven wave action/currents which might be responsible for structuring the surf zone communities. For example, combined physical variables such as wind, water temperature, wave height, surf-zone width and salinity proved to be most influential in affecting the zooplankton in the Sundays estuary surf zone (Romer 1986).

Comparisons between the present study and other data are, however, difficult to make since few studies have attempted to sample the entire surf zone zooplankton assemblage off the open beach environment either locally or elsewhere. The surf zone at the Sundays River estuary, unlike at St. Lucia and the Mhlathuze, had surf algal blooms (Romer 1986). Generally, similar taxa were present in the Sundays surf zone and diel patterns were similar to those observed during the present study. However, diel patterns in the Sundays River surf zone were dominated by bentho-planktonic species such as *Gastrosaccus psammodytes* and *Eurydice longicornis.*

4.4.4 Conclusions

The following conclusions can be drawn with respect to the zooplankton of the St. Lucia and Mhlathuze surf zones:

- zooplankton abundance tends to occur irregularly over time and space but is generally very high at night;
- zooplankton may be characterised by a few important taxa which include mysids, copepods, brachyuran megalopal larvae, zoea larvae, chaetognaths, combjellies and jellyfishes;
- *densities of individual taxa are not uniform throughout the surf zone;*
- zooplankton abundances are similar with respect to distance from the mouth;
- pronounced variations in abundance over the diel period are evident, with mysids, isopods and brchyuran larvae being most abundant within the surf zone at night;
- the two surf zones were different in terms of community diversity which highlighted the fact that even though these surf zones are located in the same geographical region their community compositions are dissimilar probably due to different physical processes operative in these systems, size and the nature of their estuary mouths;
- Differences between the two surf zones in terms of community composition can be due to a 6 years sampling difference highlighting the long term environmental cycles (dry and wet);

- changes in communities in terms of abundance, particularly of holoplankton and meroplankton, are predominantly controlled by physical factors with wind-driven currents/waves appearing to play a role in transporting these species; seasonal patterns were also evident which might be related to seasonal changes in temperature;
- although physical processes probably determined the zooplankton patterns, the possibility of biological interactions such as predator-prey relationships may be responsible for the diel motility observed in crustacean macrozooplankton such as mysids and isopods.

CHAPTER 5

GENERAL DISCUSSIONS AND RECOMMENDATIONS

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5.1 General Discussion

The main objective of this study was to describe the planktonic community structures of the surf zones adjacent to St. Lucia and Mhlathuze estuaries. This was done to identify and describe faunal groups in the surf zone and the relationship between these environments and the adjacent estuaries in terms of planktonic groups so that anthropogenic and natural driven changes in future might be identified and better understood. At both the St Lucia and Mhlathuze surf zones, taxa associated with estuarine and marine environments and taxa common to both were present throughout the study. Marine plankton species included copepods, chaetognaths, larvaceans, cladocerans and ostracods. The meroplankton was formed by crab megalopae and zoeae, and polychaete larvae probably from the nearby estuary. Bentho-planktonic taxa found in these surf zones consisted of mysids, isopods, tanaids and amphipods associated with both marine and estuarine environments. Of interest were the nocturnal increases in abundance, in particular of bentho-planktonic crustaceans, over the study period. Similar patterns that were attributed to predator avoidance by these groups were observed in the Eastern Cape surf zone by Wooldridge (1983) and Romer (1986). This highlights the point that even though physico-chemical processes were apparently responsible for structuring the invertebrate zooplankton communities, biological interactions (predator-prey) would have been inevitable. This stresses the necessity for more detailed studies at population level to clarify this aspect in these systems. It is well established, however, that zooplankton are food items for fish and form an important link between producers and secondary consumers (McLachlan *et al.* 1981). Several studies were undertaken in the Eastern Cape which led to the realisation of the quantitative importance of fauna within the surf zone. These studies also demonstrated the important role of phytoplankton as primary producers within beach/surf zone ecosystems and the subsequent flow of energy through the surf zone and the nearshore faunal communities (McLachlan *et al* 1981, Webb 1987 and Romer 1986). Such a holistic study is, however, lacking in the KwaZulu-Natal surf zones with the work by Harris (1996) and this study describing the fish and zooplankton assemblages respectively.

5.1.1 A comparison of faunal assemblages of surf zones and their adjacent estuaries

The surf zone forms a transition between the marine (offshore) and estuarine environments (Beyst *et al.* 2001) such that it might be influenced by many physical and chemical processes occurring within these systems. This includes transport of silt, nutrients and chemicals from the nearby estuary through tidal action, and from offshore by currents.

Faunal exchange through the tidal inlet between the marine and estuarine environment has been reported in the literature by many authors (e.g. Odum 1971; Ketchum 1983; Wallace *et al* 1984; Day 1981b). The interaction between the surf zone and estuaries has been reported for ichthyoplankton species by Whitfield (1989). During migrations in or out of the estuary, fish and invertebrate groups have to pass through the surf zone. Turner *et al.* (1979) reported relationships or couplings between the estuary and continental shelf on the southeastern U. S. continental shelf (South Carolina and Georgia continental shelf).

Since the plankton of the nearshore zone are strongly influenced by what occurs in the adjacent estuaries (Turner *et al.* 1979), a faunal link between the surf zone and the estuary might be excepted in these estuaries. For the purpose of this study, the following available information on the invertebrate plankton and benthos of the St. Lucia and Mhlathuze estuaries was used to compare groups recorded in the surf zone with those found in these estuaries:
In the St. Lucia Estuary, the zooplankton were reported by Grindley (1981: In Day 1981) whilst the benthos of the Narrows were reported by Owen and Forbes (1997). The latest quantitative biological surveys conducted in the Mhlathuze Estuary include zooplankton (Jerling 1998/9) and benthos (Mackay and Cyrus 1998/9). This study has demonstrated that there was a faunal relationship between the surf zones and estuaries at St. Lucia and the Mhlathuze. Groups common to both environments included calanoids, cumaceans, tanaids, amphipods, mysids, isopods, brachyuran megalopae and zoeae, polychaetes and chaetognaths. The faunal relationship between estuaries and surf zones, however, would depend on the state of the estuary mouth, tidal rhythms and physico-chemical variables that regulate the distribution of many organisms such as temperature, salinity and turbidity. These factors also act as cues that trigger migration of organisms in and/or out of the estuary. During this study the St. Lucia and Mhlathuze estuary mouths were permanently opened allowing for the faunal exchange between the estuarine and marine environments.

Examination of the density distribution patterns extending away from the estuary mouths, however, failed to reveal any relationship between densities and the distance along the surf zone from the estuary mouth. Analysis of similarity between sites confirmed these results, indicated that no significant relationship existed between invertebrate zooplankton densities and distance from the mouth. As a result, there was no apparent accumulation of zooplankton near the mouth. This was attributed to inshore currents, which transport zooplankton along the surf zone. Other characteristics in common included the presence of decapod larvae and juveniles in both estuarine and surf zone areas sampled. However, it remains unknown or difficult to demonstrate from the present study whether these areas are extensively utilised as nursery grounds or not.

Differences in numbers and taxa were also found between the surf zones and estuaries. A high proportion of zooplankton species was found in the surf zone, suggesting the importance of the systems for different species including mysids, isopods, decapod larvae, prawns, chaetognaths, ctenophores, polychaetes and copepods. However, estuarine taxa such as brachyuran megalopae occurred in high densities in both surf zones. The different sampling gear used in the surf zone for this study and the estuary coupled with difficulties of sampling surf zone area might have caused the differences observed. During this study a sampling design did not allow proper comparison of the surf zone invertebrate assemblages with that of the adjacent estuaries since a 500 µm mesh was used to sample the two surf zones. In contrast to the surf zone invertebrate zooplankton sampling for this study, the benthos (Mackay and Cyrus 1998/99; Owen and Forbes 1997) and zooplankton (Jerling 1998/99) of these estuaries were collected using 500 µm and 60 µm mesh respectively. As a result, comparisons are rather superficial and further studies are needed before firm conclusions can be made. However, this study does provide general information on the invertebrate groups common to the St. Lucia and Mhlathuze surf zones and the nearby estuaries.

A number of species including *Upogebia africana* (Wooldridge 1994) and *Palaemon pacificus* (Emmerson 1986) have also been reported from estuaries and the nearshore coastal environment. These species spawn in nearshore marine habitats and return to estuaries to utilise food sources provided by the estuary (Emmerson 1986). This faunal relationship however depends on the state of the estuary mouth. If the mouth is closed for a prolonged period migration into and out of the estuary might be affected, resulting in the local extinction of these species (Day 1981b). The flow of freshwater to the sea plays an important role by preventing the build-up of hypersaline conditions within the estuary and also acts as a cue for certain marine organisms to enter the estuary (Pearce and Schumann 1997). On the other hand, certain estuarine organisms require a marine phase to complete their full development cycle (Wooldridge 1994). Temporary and partial closure of the mouth would inhibit such cues, resulting in a reduction in biotic diversity and a decline in marine species with an estuary phase (Whitfield and Bruton 1989).

5.1.2 Estuarine management in relation to the surf zone

In South Africa, estuaries and coastal zones including surf zones are recognised as natural resources (Mann *et al.* 1996). Government authorities such as the Department of Environmental Affairs and Tourism (DEAT) ensure the protection and conservation of these natural resources through Marine and Coastal Management (MCM). Legislation that is relevant to these systems include the Sea-shore Act (Act 21 of 1935) and the Marine Living Resources Act (Act 18 Of 1998). In terms of the National Water Act (Act 36 of 1998), which centers on the concept of sustainable utilisation of resources, water resources must be classified. Methodologies for determination of resource quantity for riverine (Instream Flow Requirement) and estuarine (Estuarine Freshwater Requirement) have been developed (Cyrus 1998/9). An Ecological Reserve for estuaries was developed to establish the present class of the estuary. This is necessary to determine the amount of water that can be abstracted from rivers without causing unacceptable deleterious effects to the river and their estuaries. Impacts such as physical destruction, water quality deterioration, modification of flow regime and subsequent effects on biota have been separately evaluated by a panel of experts. However, this methodology does not incorporate possible impacts on surf zones which is probably relevant since these environments depend on nutrient inputs from the nearby estuaries. In addition, constructions such as dams and weirs become barriers to migration and these restrict biotic exchange between estuarine and marine environments.

5.1.3 Conclusions

It may be concluded that surf zone ecosystems at St. Lucia and Mhlathuze are important habitats to a number of zooplankton groups. This was evident from the large proportion of invertebrate plankton which was restricted to the surf zone indicating the importance of this environment as a habitat for these invertebrate groups, rather than being used as a transient area between the open ocean and estuaries.

Similarities or the lack of any clear relationship between the abundance values and distance from the estuary mouth was related to longshore currents that transported taxa between sites. Consequently, there was no apparent accumulation of invertebrate zooplankton near the mouth.

It would appear from this study that a faunal relationship between the surf zone and estuaries at St. Lucia and Mhlathuze exists. However, a small percentage of surf zone invertebrate taxa were found in the estuarine communities. In terms of numbers, a high percentage of invertebrate zooplankton such as brachyuran megalopae that would be recruited from the surf zone into the estuary via the estuary mouth was noted. This, probably, indicates that the link between the surf zone and the adjacent estuary is strong. Finally, the patterns that have emerged need to be investigated further.

5.2 Recommendations

The following recommendations based on the information from this study are made:

- Future research should include measurement of a wider range of variables such as chlorophyll-a, wind, water circulation and nutrients because of the role they play in structuring zooplankton communities.
- A major gap in the knowledge of invertebrate plankton in the St. Lucia estuary system was noted in this study. Therefore, it is recommended that more intensive research in this regard is needed to establish a significant relationship between the surf zone and the estuary.
- The use of different mesh nets in the surf zone and the adjacent estuary did not allow for proper comparison of the surf zone invertebrate assemblages with that of the adjacent estuary. A study which will incorporate the use of the same mesh net in the surf zone and the estuary is needed. It was also noted that the use of 500 μm mesh net would have resulted in the holoplankton component being under-represented in the samples. Therefore, future research should include the use of small mesh (60 μm) to allow for proper determination of the importance of the St. Lucia and Mhlathuze surf zones to invertebrate larvae.
- This study formed a seasonal baseline study and replicate samples were not taken at each site due to the limited time period for sorting and analysis. Future studies should include replicate samples in order to have a clearer picture of temporal (short-time scale) and spatial patterns in zooplankton of these systems.
- In view of the importance of surf zones and estuaries, consideration of the faunal relationship between these habitats should be made in future when formulating management strategies for estuarine mouth and in determining the importance of estuaries as reserves.
- Taxa such as *Gastrosaccus* mysids need to be investigated and identified to species level to provide more information on the dynamics at a species level in the surf zone with respect to seasonal and spatial variation.
- Biological interactions highlighted during this study need to be investigated to further clarify the predator-prey relationship as the factor responsible for the observed noctumal behaviour of bentho-planktonic crustaceans in particular.

CHAPTER 6

REFERENCES

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CHAPTER 7

APPENDICES

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Appendix 1: Monthly physico-chemical variables measured at Site 1, 2 & 3 during the day and night between February 1992 and January 1993 at St. Lucia surf zone.

Time of day	*Month*	*Season*	*Site*	*Temperature (°C)*	*Salinity (‰)*	*Turbidity (NTU)*
Day	December	summer	1	23.6	35	7.8
			2	23.4	35	11.6
			3	23.3	35	14.2
	January		1	22.6	35	5.4
			2	22.6	35	4
			3	26.6	35	3.9
	February		1	28.8	36	7.9
			2	27.1	36	9.7
			3	25.9	36	5.5
	March	autumn	1	25.7	36	16.8
			2	24.9	36	6.2
			3	24.2	36	5.4
	April		1	22.8	36	7.7
			2	22.5	36	23.4
			3	22.2	36	5.4
	May		1	22.8	34	17.6
			2	22.7	34	11.5
			3	23.1	33	5.3
	June	winter	1	22.3	34	9.3
			2	22.6	34	4
			3	21.8	34	7.6
	July		1	20.5	35	7
			2	20.2	35	5.4
			3	20.6	36	4.4
	August		1	19.4	36	4.4
			2	18.8	34	3.6
			3	19.7	34	1.9
	September	spring	1	21.8	35	4.2
			2	22.6	35	2.6
			3	23.3	35	3.3
	October		1	23.1	35	4.2
			2	21.8	35	8.1
			3	20.5	35	16.8
	November		1	23.3	35	22.2
			2	23.3	35	19.7
			3	23.3	35	27.3
Night	December	summer	1	24.9	35	8
			2	24.7	35	9.7
			3	26.6	35	3.1
	January		1	24.8	35	48.9
			2	25.2	35	6.5
			3	25.9	36	7
	February		1	26.2	36	25.5
			2	26.2	36	25.5
			3	23.3	35	10.7
	March	autumn	1	24.2	36	14.7
			2	24.4	36	2
			3	24.2	36	6.23

Appendix 1: Physico-chemical data continued...

April		1	22	35	16
		2	22	35	15.4
		3	22.2	35	4.5
May		1	22.9	35	11.8
		2	22.9	35	5.8
		3	23.1	35	3.2
June	winter	1	21.3	34	8.2
		2	21.4	34	2.8
		3	21.8	34	4.3
July		1	19.8	35	5.6
		2	19.8	36	6.9
		3	20.6	35	3
August		1	20.6	35	4.4
		2	20.4	34	8.8
		3	19.7	34	3.2
September	spring	1	22.1	35	5.6
		2	21.8	35	4.6
		3	23.3	35	4
October		1	21.2	35	4
		2	20.9	35	4
		3	20.5	35	7
November		1	22.6	35	7.6
		2	22.4	35	8.7
		3	23.3	35	13.1

Appendix 2: Monthly physico-chemical variables measured at Site 1, 2 & 3 during the day and night between November 1998 and October 1999 at Mhlathuze surf zone.

Time of day	*Month*	*Season*	*Site*	*Temperature* (°C)	*Salinity* (‰)	*Conductivity* (mS/cm)	*TURBIDITY* (NTU)	*DO* (%)	*DO* (mg/L)	*pH*
Day	December	summer	1	24.55	31.9	48.8	10.5	75	5.95	8.12
			2	24.13	34.8	52.7	10.5	76.2	5.54	8.13
			3	23.74	35.2	53.1	10.2	70.5	5.22	8.11
	January		1	25.67	14.7	24.3	13			8.25
			2	25.45	32.9	50.1	15			8.03
			3	25	11.1	18.8	14			8.31
	February		1	24.71	34.6	54	17	101.7	6.84	7.96
			2	24.15	34.7	54.2	17	101.7	6.85	8.06
			3	24.69	34.5	53.9	18	98.7	6.67	8.07
	March	autumn	1	23.4	15.9	26	17	100.5	7.95	8.15
			2	22.88	20.5	32.3	17	101.1	7.73	8.16
			3	24.1	32.7	50.2	15.5	100.7	6.96	8.19
	April		1	18.93	36.9	55.6	16.5	71.7	5.52	8.13
			2	18.81	36.4	54.8	19	81.3	7.87	8.26
			3	19.12	36.7	55.2	18	79.3	6.36	8.26
	May		1	22.48	34	53.1	25	73.4	5.39	7.495
			2	22.34	11.3	17.6	25	70.4	5.75	8.04
			3	22.29	34.3	53.5	25	70.7	7.22	8.02
	June	winter	1	21.29	10.5	17.2	19	94.3	7.49	8.12
			2	21.31	10.7	17.8	25	114.2	8.803	8.24
			3	21.27	10.6	17.98	20	91.2	9.9	8.22
	July		1	20	35		18			
			2	20	35		16			
			3	21	35		15			
	August		1	21.4	35.3	53.3	16	78	6.89	8.53
			2	21.9	31.7	53.9	15	80.9	6.8	8.61
			3	21.8	35.7	53.3	17	82.9	6.65	8.61
	September	spring	1	20.64	35.1	54.7	13	105.3	7.58	7.79
			2	20.31	16.9	25.6	12	104.1	8.5	7.85
			3	19.48	35.4	55.5	10	107.5	8.08	7.92
	October		1	20.25	35.5	53.6	26	73.3	6.44	8.06
			2	20.4	35.3	53.4	22.5	83.5	5.8	8.15
			3	20.61	35.4	53.4	26	83	6.29	8.16
	November		1	21.43	35.4		15.9	96.7	6.85	8.69
			2	21.08	35.4		11.5	98.6	7.04	8.69
			3	21.02	35.3		12.5	98.2	7.12	8.72
Night	December	summer	1	25.03	34.6	52.4	10.5	96.6	6.48	8.14
			2	23.71	33.6	51.3	10.5	95.3	6.49	8.13
			3	23.37	34.8	52.6	10.2	98.8	6.83	8.11
	January		1	24.83	34.5	52.3	14	94.9	6.43	8.36
			2	24.85	10.1	17.4	13	100.1	7.57	8.36
			3	24.97	33.2	50.2	12	99.6	6.67	8.37
	February		1	21.67	36.8	55.4	18	98.6	7.21	8.14
			2	21.35	31.2	46.3	18	99.5	7.22	8.13
			3	21.05	10.6	18	18	101.1	8.25	8.12
	March	autumn	1	24.15	16.4	26.8	15	8.21	102.6	8.27
			2	23.54	10.6	18	17.5	101.8	7.57	8.27
			3	22.7	10.7	18.1	18	75.7	8.05	8.24
	April		1	18.68	10.8	18.2	16	78.1	6.43	8.33
			2	18.16	11	18.7	17	80	7.25	8.27

Appendix 2: Physico-chemical data continued...

			3	17.86	26.4	29.7	16	76	6.46	8.18
	May		1	21.85	34.2	53.4	22	71.2	5.52	7.97
			2	21.92	34.2	53.3	20	80.5	6.3	7.98
			3	21.76	34	53.1	25	69.4	5.84	7.98
	June	winter	1	20.84	10.6	18.1	18	95.6	8.04	8.23
			2	20.85	11	18.6	19	102	6.7	8.18
			3	20.2	10.6	17.9	20	143.4	8.16	8.12
	July		1	19.5	35		13			
			2	19.5	35		15			
			3	19.5	35		12			
	August		1	20.96	35.7	53.8	16	79.8	6.56	8.51
			2	20.75	35.6	53.8	18	73.2	5.9	8.53
			3	20.75	35.5	53.8	15	90.5	6.22	8.55
	September	spring	1	17.84	30.3	47	11	77.4	7.05	7.92
			2	17.69	12.8	20.6	13	84.15	8.15	7.15
			3	17.61	12	18.3	13	115.1	7.01	7.91
	October		1	20.17	17.9	30	24	67.4	5.97	8.23
			2	20.18	35.3	53.3	19	79.7	7.02	8.23
			3	19.91	35.5	53.6	16	78.7	7.11	8.23
	November		1	21.75	35.4	53.5	18	98.61	6.78	8.8
			2	21.66	35.4	53	16	99.2	6.95	8.82
			3	21.81	35.2	53.91	16	99	7.09	8.82

Appendix 3: Mean and maximum density (individuals/100m^3) of zooplankton collected at Sites 1, 2 and 3 at the St. Lucia and Mhlathuze surf zones and their association with marine (Mar.), estuarine (Est.), marine/estuarine (Est./Mar.) and freshwater (F) environments (Day 1969, Mackay and Cyrus 1998/99 and Jerling 1998/99). S1-S3=St. Lucia surf zone sites and M1-M3=Mhlathuze surf zone sites.

	Environment	S1	S1	S2	S2	S3	S3	M1	M1	M2	M2	M3	M3
		(aver.)	(max.)	(aver.)	(max.)	(aver.)	(max.)	(aver.)	(max.)	(aver.)	(max.)	(aver.)	(max.)
PROTOZOA:													
Tintinnida	Mar.											0.04	0.94
COELENTERATA:													
Unid. Crideria	Mar.							1.28	30.63			0.64	14.80
HYDROZOA													
Muggiaea anthrica	Mar.									0.11	2.64		
Muggiaea kochi	Mar.	10.77	216.67	2.68	64.39	5.47	40.68	0.22	5.36	0.36	8.34	1.98	34.58
Obelia spp.	Mar.			0.07	1.67	0.08	1.97	0.31	2.56	0.27	2.78	0.13	3.02
Eucheilota sp.	Mar.	1.53	13.68	0.06	1.56	0.10	2.30			1.90	41.70	2.19	25.89
Leptomedusa sp. 2	Mar.	1.53	32.94	1.35	32.34	0.07	1.61	0.05	1.32				
Anthomedusa sp	Mar.	6.65	146.08	0.19	2.43	0.24	2.11	2.06	33.77	1.34	27.80	0.70	13.45
Eutima gracilis	Mar.			0.30	7.15								
Eudoxides sparalis	Mar.	0.86	19.76	3.82	64.39	0.59	14.08	0.12	2.92	0.12	2.78	0.12	2.86
Siphonophora	Mar.	21.25	250.33	2.79	43.65	4.03	32.25	6.54	74.75	10.53	175.09	11.82	197.40
Dimophyes artica	Mar.	0.07	1.71										
Tubularia sp.	Mar.					0.21	3.88			15.80	363.43		
Bassia bassensis	Mar.											0.13	3.02
SCYPHOZOA													
Scyphozoa	Mar.	8.49	138.43	3.25	43.86	6.50	59.84	8.71	203.18	1.02	11.12	2.15	37.22
CTENOPHORA													
Beroe sp.	Mar.					0.19	4.64						
Ctenophora	Mar.	21.72	342.06	19.31	446.21	0.97	15.75	40.09	317.11	88.91	1656.98	137.31	1735.69
NEMATODA													
Nematoda sp.	Est./Mar.	0.20	2.32	0.07	1.76					0.18	2.74	0.15	2.19
Nematoda 1	Est./Mar.									0.14	3.16		
Nematoda sp. 2	Est./Mar.	0.28	4.96										
Planocera	Est./Mar.	0.07	1.65	0.10	2.38							0.31	0.31
ANNELIDA:													
POLYCHAETA													
Callizona sp.	Mar.	0.47	8.55	0.25	2.38	0.37	3.42						
Cirriformia spp.	Mar.	0.10	2.20										
Dendronereis sp.	Mar.	0.51	10.00			1.32	25.97						
Fabelligera sp.						0.07	1.76						
Glycera sp.	Mar.	0.10	2.30	0.07	1.76			0.13	1.68				
Iospilus sp.												0.18	4.07
Lagisca sp.						0.05	1.11	0.05	1.21				1.21
Pionisella sp.	Est./Mar.									0.06	1.37		
Phyllodoce	Mar.			83.22	1995.15								
Platynereis dumerillii	Mar.	4.08	63.72	43.61	880.87	13.62	177.18	0.07	1.68			0.05	1.15
Polydora spp.	Mar.					0.13	3.09	0.44	8.76	0.51	8.34	0.08	1.89
Proceraea		0.37	3.16	0.08	1.91	0.08	1.93	0.33	2.56	0.18	2.66		
Scolelepis squamata	Mar.	0.48	8.78	0.29	1.91	0.28	3.35					0.04	0.97
Tomopteris sp.	Mar.	0.13	2.94	0.21	2.03	0.13	1.61						
Heterospionidae						0.06	1.55						
Trochochaetae		0.19	4.45					0.08	1.88				
Terebellidae						0.05	1.11						
Unid. polychaete	Est./Mar.	1.81	13.84	0.53	2.38	2.21	16.87	0.05	1.32	0.37	2.78	0.55	4.34

Appendix 3: Biotic data continued...

Polychaete larvae	Est	2.97	37.03	3.98	36.10	10.89	141.78	1.05	20.21	0.75	9.72	3.37	60.41
MOLLUSCA:													
Bivalvia	Est/Mar.	36.68	731.71	15.07	202.14	19.44	361.13	4.66	35.62	4.13	34.04	4.52	84.32
Cephalopoda				0.95	22.71	99.49	2387.77	0.13	3.04				
Sepia				0.07	1.67	1.76	38.70						
Fissurellidea		0.14	1.71	0.60	6.19	1.16	14.76						
Unid. Gastropod 1		1.86	28.57	2.94	22.71	6.28	84.37						2.19
Unid. Gastropod 2				1.15	21.06	5.91	128.66						
Unid. Gastropod 3				1.97	42.12	0.89	21.28						
Unid. Gastropod 4						1.64	27.38						
Gastropod larvae		0.10	2.20	0.76	9.34	1.37	21.36			0.31	5.56		
ARTHROPODA:													
ARACHNIDA													
Amauroboides sp.		0.17	2.20			0.65	13.59						
Araneae								0.06	1.53	0.05	1.08	0.12	1.89
PYCNOGONIDA													
Achelia quadridentata	Mar.					0.07	1.73						
Endeis clipeatus	Mar.	0.17	2.20			0.69	14.76						
Nymphon setimanus	Mar.			0.13	3.11	0.39	9.28					0.06	1.36
Nymphosis cuspidata	Mar.	8.45	73.92	10.83	76.38	9.65	79.74	0.16	1.58	0.08	1.94		
Pycnogonum cataphractum	Mar.			0.06	1.56	0.06	1.55						
Queutus jamesanus	Mar.					0.06	1.55			0.06	1.49	0.06	1.36
Tanystylum brevipes	Mar.	0.46	6.59	0.94	9.73	0.87	6.33						
Pycnogonida sp.	Mar.	0.07	1.68			0.08	1.94			0.06	1.49		
Pycnogonida larvae	Mar.			0.17	2.19	0.35	8.44			0.07	1.58		
CRUSTACEA													
Copepoda													
Anomalocera partesomi		0.41	4.39	0.15	3.67	0.66	4.22	0.56	10.63	0.12	2.76	0.17	2.16
Rhincalanus spp.		5.36	123.29										
Calanoids	Est/Mar.	2063.82	24706.96	1202.38	11842.51	3172.56	18694.81	220.34	3544.27	102.32	605.72	409.10	5144.18
Corycaeaus sp.	Mar.	56.23	1149.16	24.53	174.26	225.98	5087.08	1.03	6.37	1.09	12.62	2.71	34.58
Caligus rapax	Est							0.05	1.13	0.06	1.32	0.10	1.35
Eurytemora sp.								0.10	2.30				
Lepeopthirius nordmanni	Est	1.22	26.35	1.19	12.40	0.48	6.33	0.06	1.40	0.07	1.55		
Calanoida (nauplii)	Est/Mar.	0.04	0.98	0.15	3.67					0.08	1.94		
Copepoda larvae	Est/Mar.							0.08	1.88				
Unid. copepod 1	Est/Mar.	1.78	34.35	0.31	7.33	0.56	6.33	0.35	7.59	0.07	1.58		
Unid. copepod 2	Est/Mar.	2.30	51.53	0.77	16.69	1.61	30.92			0.85	19.46		
Unid. copepod 3	Est/Mar.	0.07	1.61										
Cladocera													
Cladocerans	F/Mar.					0.08	1.93				1.45	0.06	1.35
Ostracoda													
Conchoecia elegans	Est			0.17	2.38	0.32	7.73					0.12	2.72
Ostracods	Est	0.17	2.30	0.47	5.29	2.39	52.22	6.08	105.92	3.81	49.27	5.51	72.09
Unid. Ostracoda 1	Est	0.15	1.76	0.49	10.02								
Philomedes globosa	Est	0.35	6.59	0.74	17.78	0.95	13.40					0.18	4.07

Appendix 3: Biotic data continued...

Mysidacea													
Gastrosaccus spp.	Est./Mar.	235.69	1894.09	3645.19	63651.93	7057.31	98194.33	169.74	1228.31	48.48	330.98	60.88	876.87
Rhopalophthalamus sp.	Est./Mar.	0.15	3.42	0.13	3.11	2.64	60.21	1.83	15.83	0.97	11.12	0.62	8.63
Mesopodopsis sp.	Est./Mar.							0.10	2.30				
Thysanoessa sp.	Est./Mar.							0.21	3.83				1.21
Unid. mysids		10.42	239.62					4.14	70.61	3.25	74.66	9.72	143.10
Mysid larvae		24.95	501.03	4.88	112.09	1.14	27.42						
Euphausidae										0.06	1.39		
Euphausidae larvae												1.72	39.53
Cumacea		6.69	90.74	12.33	168.47	3.23	32.22	3.29	19.74	2.50	22.44	1.35	9.52
Tanaidacea													
Apseudes digitalis	Est./Mar.	1.70	37.35	0.06	1.55	0.07	1.71	5.30	125.64	0.22	5.17		
Amphipoda													
Amaryllis sp												0.12	2.72
Ampelisca palmata	Est./Mar.	2.28	39.38	13.02	258.94	8.06	50.62	1.21	15.19	0.83	11.05	0.96	7.03
Caprellina cicur	Mar.	6.44	59.29	7.01	57.13	10.38	101.24						
Caprellina equilibra	Mar.	0.79	5.00	2.38	41.95	1.85	30.92						
Caprellina longicollis	Mar.	3.47	15.38	11.96	50.34	6.60	36.90			0.04	0.86	0.12	2.66
Corophium sp.	Est.	0.85	16.80	0.24	4.13	0.17	3.99	0.98	6.30	0.39	6.03	1.16	13.86
Cyproidea ornata		0.07	1.71										
Grandidierella spp.	Est.	4.12	48.34	7.87	86.42	24.90	149.52	4.87	111.03	0.32	4.31	0.12	1.80
Hyperia galba	Mar.	2.15	24.15	4.87	34.57	4.86	37.42	1.97	9.45	1.60	18.06	3.03	30.55
Laetmatophilus spp		0.26	5.93	0.52	6.22	0.21	3.09	0.24	5.84				
Palinnotus natalensis				0.09	2.06	0.09	2.11						
Paramoera capensis								0.06	1.52			0.14	1.95
Parathemisto sp.	Mar.									0.07	1.51		
Paraphoxus oculutus		0.45	10.42	1.17	12.82	1.19	14.76	0.88	5.84	1.06	5.56	1.73	15.10
Podocerus spp		7.32	87.22	21.41	169.93	5.68	35.86	0.06	1.40	0.07	1.52		
Polycheria atolli		9.79	153.81	2.60	60.68	1.53	21.09	0.29	2.92	0.04	0.86	0.25	8.74
Talorchestia spp.		0.08	1.73			0.71	13.40	0.03	0.77				
Urothoe spp.	Mar.	0.86	6.85	1.35	10.67	3.70	38.87	3.21	26.27	2.15	20.57	2.73	29.92
Amphipod larvae		11.25	228.79	5.06	73.13	13.99	265.88	0.27	3.63	0.19	2.76	0.06	3.63
Unid. amphipod 1		7.02	109.98	171.88	3397.65	30.57	295.25						
Unid. amphipod 2								0.35	7.30	0.04	0.86		1.21
Unid. amphipod 3				0.13	3.23			0.12	2.92	0.04	2.90		
Unid. amphipod 4						0.16	3.87						
Unid. amphipod 5		1.22	28.11	0.07	1.60	0.24	5.83			0.06	1.49		
Unid. amphipod 6				0.20	4.81								
Unid. amphipod 7				0.21	3.23								
Isopoda													
Acalathura indica	Est.			0.06	1.56	0.06	1.55						
Alloniscus marinus		0.04	0.98										
Cirolina spp.	Est./Mar.	431.48	4190.29	1960.17	32604.03	956.71	6777.40	261.41	2180.71	65.87	473.92	374.83	3162.09
Cythura *estuaria*	Est.					0.21	2.11						
Gnathia africana	Est.	0.68	14.08	0.40	4.67	11.60	229.91			15.25	334.41		
Jaeropsis spp.	Est.			0.32	3.76	0.94	10.55						
Stenetrium sp.				0.07	1.68								
Parisocladus perforatus	Est.	0.32	5.14	7.57	125.84	11.33	172.96	0.16	3.74				
Isopod larvae		30.45	540.98	8.75	205.10	8.95	213.24	0.13	1.59	0.13	1.64		
Unid. isopoda 1.		86.97	2000.35					0.07	1.75	0.11	2.64		
Unid. isopoda 2		10.36	127.44	12.07	128.02	7.94	120.23			0.06	1.49	0.06	1.36

Appendix 3: Biotic data continued…

Unid. isopod 3				0.07	1.67	0.15	1.94			0.07	1.50		
Unid. isopod 4		0.29	3.52	7.83	176.23	0.29	1.91						
Unid. isopod 5		0.07	1.71			0.32	7.77						
Unid. isopod 6						0.15	2.11						
Unid. isopod 7						0.28	6.70					0.06	1.48
Decapoda:													
Caridea													
Caridean larvae				0.20	4.77			0.07	1.75			0.13	3.02
Penaeidea													
Lucifer sp.	Mar.	101.62	1020.86	44.41	346.97	14.51	132.88	2.73	40.52	1.05	5.28	5.77	77.26
Penaeids	Est.	62.30	1011.58	73.86	882.69	66.73	712.88	6.79	86.64	8.53	108.08	7.81	79.12
Penaeid prawn larvae	Est./Mar.	1.33	21.96	1.95	24.89	1.22	13.69	1.50	23.78	4.49	37.97	1.41	21.52
Palinura													
Palinurus vulgaris	Mar.	0.29	6.59			0.25	5.98	0.03	0.63	0.25	1.64	0.16	2.16
Anomura													
Callianassa spp.	Est./Mar.			0.07	1.67			2.38	39.49	0.44	8.28	0.74	8.63
Emerita austroafricana	Mar.	3.24	67.72			0.08	1.97	0.52	4.76	0.21	1.74	1.71	14.94
Longicornis sp. (zoea)		6.07	82.74	1.10	9.17	0.28	4.22	1.18	14.18	0.37	2.82	5.71	82.66
Munica *bamffica*								0.07	1.59				
Porcellana sp. (larvae)								0.12	2.92	0.21	2.78	0.09	2.16
Upogebia spp.	Est.	0.13	1.56	0.15	1.95	0.15	2.38	0.25	4.20	0.62	4.51	1.71	37.93
Upogebia sp. (larvae)	Est./Mar.							0.49	11.66	0.30	5.49	0.17	3.96
Anomuran larvae	Est./Mar.	54.43	764.85			0.49	3.88	0.48	7.29	0.13	1.50		
Brachyura													
Dehaanius sp.		0.17	2.20	0.45	3.34	1.27	10.55						
Ovalipes punctutus						0.09	2.11						
Philyra punctata				1.25	27.08	0.13	1.94						
Pilumnus hirsutus				0.10	2.38								
Unid. brachyuran 1		5.81	79.87	1.81	19.74	1.14	27.42			0.12	2.74		
Unid. brachyuran 2		0.45	10.42										
Unid. brchyuran 3										0.07	1.50		
Brachyurans (zoeae)	Est./Mar.	16.38	150.50	14.97	133.82	1696.36	39618.23	33.22	370.74	126.24	2471.56	31.06	333.58
Brachyurans (megalopae)	Est./Mar.	223.30	2183.41	59.34	407.89	3646.41	70673.59	706.10	9491.78	164.23	963.71	221.96	1190.30
Stomatopoda													
Harposquilla harpax	Mar.							0.11	1.32	0.23	1.49	0.19	4.32
Paguridae													
Anapagurus sp. (zoea)	Mar.											0.04	0.94
Pagurid larvae	Mar.	12.04	276.93										
Cirripedia													
Cirripedia sp.		0.64	13.18	0.61	4.77	0.42	2.11	2.71	29.10	3.40	42.13	11.08	223.04
CHAETOGNATHA													
Sagitta sp.	Mar.	336.36	1964.31	139.00	1800.62	1465.20	33160.56	13.52	99.86	23.66	129.50	52.38	462.07
Unid. chaetognaths	Mar.	6.34	145.86					0.25	6.05	0.73	16.68		6.05
ECHINODERMATA													
Echinodiscus biserforis	Mar.	0.08	1.74	0.07	1.68			0.07	1.70			0.14	1.80
Ophiurodea sp.		0.15	1.76	0.44	3.36	1.20	15.54			0.25	5.83		
Echinodermata (larvae)	Mar.			0.32	7.78								
UROCHORDATA:													
LARVACEA													
Appendicularis spp	Mar.	12.23	276.68	5.38	129.14	1.86	23.46			0.07	1.58	0.18	4.07
THALIACEA													

Appendix 3: Biotic data continued...

Salpida													
Salpa spp	Mar.	3.94	83.44	0.32	7.78	0.14	3.35	0.10	2.42				2.42
Salpa democratica	Mar.	*1.22*	*11.76*	*0.31*	*5.04*	*1.08*	*15.54*	*0.08*	*1.88*	*0.12*	2.78		
Doliolida													
Doliolum nationalis	Mar.					0.13	3.09						
Diliolum sp	Mar.	0.30	6.86	0.06	1.56	0.34	6.18						
UNKNOWN taxa		3.46	54.90	1.87	14.60	2.27	25.25	0.63	7.30	12.88	278.02	6.34	134.25

Appendix 4: Monthly volumes (m^3) of water trawled at each site during the day and night at the St. Lucia and Mhlathuze surf zone. Months J-D=January to December.

Month	St. Lucia						Mhlathuze					
	Site 1		**Site 2**		**Site 3**		**Site 1**		**Site 2**		**Site 3**	
	Day	**Night**	**Day**	**Night**	**Day**	**Night**	**Day**	**Night**	**Day**	**Night**	**Day**	**Night**
J	60	58	41	60	51	58	76	66	67	36	63	35
F	102	67	103	33	84	90	131	21	73	69	74	74
M	32	44	59	28	52	30	53	34	36	58	25	46
A	61	64	55	65	57	79	57	39	51	66	33	38
M	63	58	65	60	62	51	59	59	93	61	87	69
J	65	48	49	52	43	51	59	49	66	57	68	57
Jl	N.S.	58	60	62	65	52	89	54	72	71	72	67
A	58	53	62	59	62	61	44	63	75	76	73	56
S	60	57	42	48	73	50	63	69	63	36	106	51
O	46	43	57	61	47	47	158	64	137	75	113	80
N	58	46	64	46	58	61	83	68	66	116	46	103
D	62	58	58	53	57	58	60	71	65	63	67	60

Appendix 5: Taxa characterising Site 1, 2and 3 assemblages, in the St. Lucia surf zone as identified by SIMPER analysis, presented as a percentage of the total contribution within each group. Only those species responsible for up to 75% of cumulative contribution are presented. Av.Abund=average abundance (no.m^{-3}), Av.Sim=average similarity, Sim/SD=similarity/standard deviation, Contrib%=percent contribution and Cum.%=cumulative percent.

Site/Taxa	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Site 1					
Calanoids	1978.02	5.24	2.00	12.50	12.50
Sagitta sp.	360.20	4.44	1.98	10.59	23.09
Brachyurans (megalopae)	214.17	2.75	1.43	6.56	29.65
Cirolina spp.	417.83	2.39	1.19	5.71	35.35
Penaeids	59.59	2.33	5.95	5.55	40.90
Siphonophora	20.65	1.76	1.36	4.20	45.10
Lucifer sp	97.38	1.41	0.96	3.36	48.45
Nymphosis cuspidata	8.10	1.19	1.50	2.83	51.28
Gastrosaccus spp.	225.87	1.17	0.67	2.79	54.08
Caprellina cicur	6.53	1.16	1.38	2.78	56.85
Isopod larvae	29.29	1.10	0.94	2.62	59.48
Brachyurans (zoeae)	15.70	1.10	0.92	2.62	62.10
Scyphozoa	11.02	1.01	0.97	2.41	64.50
Corycaeaus sp.	53.89	0.92	0.95	2.19	66.70
Muggiaea kochi	10.47	0.90	0.95	2.15	68.84
Anomuran larvae	52.56	0.77	0.62	1.83	70.67
Unknown taxa	3.43	0.75	0.95	1.79	74.28
Caprellina longicollis	3.32	0.58	0.73	1.39	75.67
Site 2					
Calanoids	1202.38	5.68	4.65	10.41	10.41
Cirolina spp.	1960.17	4.03	1.96	7.38	17.79
Gastrosaccus spp.	3645.19	3.80	2.28	6.95	24.75
Sagitta sp.	139.00	2.58	2.43	4.73	29.48
Penaeids	73.63	2.56	4.97	4.69	34.17
Brachyurans (megalopae)	59.34	2.23	2.06	4.09	38.26
Caprellina longicollis	11.96	2.23	5.29	4.08	42.33
Lucifer sp	44.41	2.16	2.74	3.96	46.30
Amphipoda sp.	171.88	2.15	1.59	3.94	50.23
Corycaeaus sp.	24.53	2.04	3.71	3.74	53.97
Unid. Isopoda 3	12.07	1.87	4.44	3.42	57.40
Platynereis dumerillii	43.61	1.74	2.66	3.19	60.59
Nymphosis cuspidata	10.83	1.60	1.63	2.94	63.52
Hyperia galba	4.87	1.49	4.48	2.72	66.25
Polychaete Larvae	3.98	1.41	4.97	2.58	68.83
Bivalvia	15.07	1.30	1.58	2.38	71.21
Podocerus spp	21.41	1.26	0.96	2.32	73.53
Brachyuran zoeae	14.97	1.06	0.99	1.94	75.47
Site 3					
Calanoids	3172.56	6.69	3.43	13.80	13.80
Cirolina spp.	956.71	4.08	1.75	8.43	22.23
Gastrosaccus spp.	7057.31	3.29	1.28	6.80	29.03
Brachyurans (megalopae)	3646.41	2.47	1.62	5.09	34.12
Sagitta sp.	1465.20	2.44	3.05	5.03	39.15
Penaeids	66.73	2.28	2.58	4.70	43.85
Brachyurans (zoea)	1696.36	1.92	1.42	3.97	47.81
Nymphosis cuspidata	9.65	1.68	6.57	3.46	51.28
Lucifer sp	14.51	1.47	1.61	3.03	54.31
Corycaeaus sp.	225.98	1.41	1.63	2.92	57.23
Bivalvia	19.44	1.40	5.47	2.90	60.13
Grandidierella spp.	24.90	1.24	1.48	2.57	62.69
Caprellina longicollis	6.60	1.14	1.55	2.35	65.04
Hyperia galba	4.86	1.09	1.51	2.25	67.30
Platynereis dumerillii	13.62	1.06	1.41	2.20	69.49
Ampelisca palmata	8.06	1.00	0.98	2.06	71.55
Unid. isopod 3	7.94	0.98	1.59	2.02	73.58
Podocerus spp	5.68	0.87	1.04	1.80	75.38

Appendix 6: Taxa characterising autumn, winter, spring and summer assemblages, in the St. Lucia surf zone as identified by SIMPER analysis, presented as a percentage of the total contribution within each group. Only those species responsible for up to 75% of cumulative contribution are presented. Av.Abund=average abundance (no.m^{-3}), Av.Sim=average similarity, Sim/SD=similarity/standard deviation, Contrib%=percent contribution and Cum.%=cumulative percent.

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Autumn					
Calanoids	3464.31	7.59	3.61	17.22	17.22
Sagitta sp.	226.79	3.65	3.16	8.29	25.51
Brachyurans (megalopa)	4107.46	3.55	2.28	8.06	33.57
Penaeids	33.09	2.77	5.94	6.29	39.86
Cirolina spp.	2108.17	2.40	1.00	5.44	45.30
Corycaeaus sp.	71.15	2.23	5.61	5.05	50.35
Nymphosis cuspidata	6.97	2.07	7.45	4.69	55.04
Gastrosaccus spp.	3597.67	2.01	1.12	4.56	59.60
Siphonophora	11.95	1.73	2.52	3.92	63.52
Lucifer sp	98.80	1.71	1.31	3.88	67.40
Bivalvia	1.58	1.11	1.35	2.53	69.93
Unid. isopoda 3	10.22	1.03	1.29	2.33	72.26
Hyperia galba	2.25	0.98	1.35	2.23	74.49
Platynereis dumerillii	55.46	0.92	0.75	2.09	76.58
Winter					
Calanoids	3012.08	6.65	1.80	16.22	16.22
Sagitta sp.	2105.12	4.28	2.40	10.44	26.66
Cirolina spp.	723.26	4.19	2.26	10.22	36.87
Penaeids	55.44	2.32	4.32	5.66	42.53
Unid. amphipods	43.55	2.10	1.32	5.11	47.64
Caprellina cicur	12.27	1.66	1.29	4.04	51.68
Siphonophora	9.30	1.56	1.15	3.81	55.49
Brachyurans (megalopae)	12.77	1.34	1.18	3.26	58.75
Gastrosaccus spp.	896.51	1.23	0.74	2.99	61.74
Unknown taxa	1.51	1.10	1.28	2.68	64.42
Podocerus spp	20.30	0.99	0.76	2.41	66.83
Brachyurans (zoeae)	25.49	0.98	0.76	2.40	69.23
Unid. polychaete	2.32	0.97	1.21	2.37	71.60
Bivalvia	1.47	0.93	1.33	2.27	73.87
Hyperia galba	7.31	0.87	0.77	2.13	76.00
Spring					
Calanoids.	905.83	4.70	6.69	8.24	8.24
Gastrosaccus spp.	4235.70	3.54	2.64	6.20	14.44
Cirolina spp.	582.30	3.29	2.51	5.76	20.19
Penaeids	144.39	2.62	3.51	4.59	24.79
Sagitta sp.	180.22	2.27	3.07	3.98	28.77
Brachyurans (megalopae)	61.13	2.09	2.62	3.67	32.43
Caprellina cicur	17.99	1.79	5.98	3.13	35.57
Lucifer sp	57.48	1.69	2.81	2.96	38.53
Corycaeaus sp.	29.64	1.67	3.62	2.92	41.45
Caprellina longicollis	7.78	1.66	9.05	2.92	44.37
Nymphosis cuspidata	21.31	1.63	2.50	2.86	47.23
Grandidierella spp.	34.18	1.63	2.70	2.86	50.09
Platynereis dumerillii	20.10	1.60	2.53	2.81	52.89
Unid. isopoda 3	21.48	1.60	3.08	2.80	55.69
Brachyurans (zoeae)	41.46	1.31	1.25	2.30	57.99
Unid. polychaete spp.	3.30	1.23	4.59	2.16	60.14
Podocerus spp	13.59	1.19	1.35	2.09	62.23
Unknown taxa	5.47	1.15	6.41	2.01	64.24
Gastropoda sp	10.55	1.10	1.30	1.93	66.17
Bivalvia	52.29	1.09	1.31	1.91	68.08
Unid. amphipods	25.43	0.90	0.76	1.58	69.66
Ampelisca palmata	5.78	0.90	1.25	1.58	72.81
Scyphozoa	6.04	0.90	1.24	1.57	74.38
Amphipod larvae	19.52	0.88	1.18	1.54	75.93
summer					
Calanoids	1088.38	5.07	6.93	9.43	9.43

Appendix 6 continued...

Season/Taxa	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Cirolina spp.	1032.55	3.85	1.44	7.17	16.60
Gastrosaccus spp.	5841.28	3.38	2.25	6.30	22.90
Brachyurans (megalopae)	1045.21	3.36	2.87	6.26	29.16
Lucifer sp	34.92	2.38	4.24	4.44	33.60
Brachyurans (zoeae)	2229.29	2.36	2.96	4.39	37.99
Sagitta sp.	107.06	2.10	2.61	3.91	45.85
Penaeids	33.68	2.09	3.50	3.89	49.73
Corycaeaus sp.	20.27	1.93	3.46	3.60	53.33
Nymphosis cuspidata	7.12	1.84	6.18	3.43	56.76
Caprellina longicollis	6.80	1.66	4.81	3.08	59.84
Polychaete larvae	18.00	1.59	5.01	2.97	62.81
Bivalvia	37.66	1.51	1.26	2.81	65.63
Cumacea	26.33	1.49	1.87	2.76	68.39
Platynereis dumerillii	2.61	1.32	4.86	2.46	70.85
Unid. Isopod 3	5.56	1.14	1.24	2.12	72.96
Ampelisca palmata	19.81	1.03	1.09	1.91	74.88
Parisocladus perforatus	3.96	1.02	1.35	1.89	76.77

Appendix 7: Taxa characterising the day and night assemblages, in the St. Lucia surf zone as identified by SIMPER analysis, presented as a percentage of the total contribution within this group. Only those species responsible for up to 75% of cumulative contribution are presented. Av.Abund=average abundance (no.m^{-3}), Av.Sim=average similarity, Sim/SD=similarity/standard deviation, Contrib%=percent contribution and Cum.%=cumulative percent.

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Day					
Calanoids	1802.54	5.89	2.73	11.78	11.78
Sagitta sp.	1264.05	4.48	2.78	8.97	20.75
Brachyuran (megalopae)	57.31	2.19	2.44	4.37	25.12
Penaeids	15.20	2.10	3.97	4.21	29.33
Brachyuran (zoeae)	42.43	2.07	1.93	4.14	33.47
Cirolina spp.	175.06	1.96	1.66	3.91	37.38
Lucifer sp	89.37	1.79	1.25	3.58	40.96
Gastrosaccus spp.	137.12	1.75	1.27	3.51	44.47
Corycaeaus sp.	160.74	1.67	1.75	3.34	47.81
Podocerus spp	13.23	1.56	1.88	3.12	50.93
Nymphosis cuspidata	5.14	1.36	1.92	2.72	53.65
Siphonophora	15.46	1.28	1.16	2.56	56.21
Caprellina cicur	13.14	1.25	1.26	2.49	58.70
Unid. Amphipods	23.99	1.17	1.02	2.34	61.05
Bivalvia	4.95	1.06	1.37	2.13	63.17
Unknown taxa	4.29	1.04	1.30	2.08	67.36
Hyperia galba	4.69	1.03	1.39	2.05	69.41
Caprellina longicollis	7.15	0.99	1.05	1.98	71.39
Unid. polychaete	2.16	0.89	1.26	1.79	73.18
Platynereis dumerillii	5.76	0.82	0.98	1.64	74.82
Unid. isopod 3	3.30	0.77	1.02	1.54	76.36
Night					
Cirolina spp.	2048.08	6.34	3.30	12.68	12.68
Calanoids	2432.76	5.95	2.80	11.90	24.59
Gastrosaccus spp.	7148.45	4.22	1.23	8.44	33.02
Penaeids	118.10	2.97	3.28	5.94	38.97
Brachyurans (megalopae)	2555.97	2.90	1.55	5.80	44.77
Sagitta sp.	45.55	2.23	3.01	4.46	49.23
Nymphosis cuspidata	13.92	1.65	1.95	3.30	52.53
Lucifer sp	14.83	1.63	1.88	3.27	55.80
Caprellina longicollis	7.44	1.48	1.93	2.95	58.76
Unid. isopod 3	16.65	1.47	1.77	2.93	61.69
Platynereis dumerillii	35.01	1.28	1.64	2.55	64.24
Corycaeaus sp.	42.19	1.24	1.37	2.49	66.73
Bivalvia	41.55	1.14	1.24	2.27	69.00
Polychaete larvae	3.19	0.99	1.40	1.99	70.99
Ampelisca palmata	12.37	0.92	1.01	1.84	72.83
Unid. amphipods	115.72	0.77	0.53	1.55	74.38
Brachyurans (zoeae)	1108.92	0.77	0.77	1.55	75.92

Appendix 8: Taxa characterising Site 1 assemblages, in the Mhlathuze surf zone as identified by SIMPER analysis, presented as a percentage of the total contribution within this group. Only those species responsible for up to 75% of cumulative contribution are presented Av.Abund=average abundance (no.m^{-3}), Av.Sim=average similarity, Sim/SD=similarity/standard deviation, Contrib%=percent contribution and Cum.%=cumulative percent.

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Site 1					
Calanoids	2.22	7.19	2.93	19.19	19.19
Cirolina spp.	2.61	6.88	1.56	18.34	37.53
Brachyurans (megalopae)	7.07	6.00	1.31	16.00	53.53
Sagitta sp.	0.14	3.39	1.17	9.03	62.56
Gastrosaccus spp.	1.71	2.34	0.67	6.25	68.81
Ctenophora	0.40	1.78	0.64	4.74	73.55
Cumacea	0.03	0.91	0.53	2.44	75.99
Site 2					
Calanoida spp.	0.99	7.70	3.42	20.81	20.81
Brachyurans (megalopae)	1.59	7.08	1.57	19.11	39.92
Cirolina spp.	0.83	5.87	1.42	15.86	55.78
Gastrosaccus spp.	0.46	2.82	0.76	7.61	63.39
Sagitta sp.	0.23	2.55	0.81	6.88	70.27
Ctenophora	0.85	2.04	0.71	5.52	75.78
Site 3					
Cirolina spp.	3.59	7.08	1.54	20.61	20.61
Calanoids	3.94	6.37	1.50	18.53	39.15
Brachyurans (megalopae)	2.13	4.91	0.96	14.29	53.43
Sagitta sp.	0.53	4.07	1.29	11.85	65.29
Gastrosaccus spp.	0.58	2.12	0.67	6.18	71.47
Ctenophora	1.32	1.62	0.48	4.71	76.18

Appendix 9: Taxa characterising summer, autumn, winter and spring assemblages, in the Mhlathuze surf zone as identified b SIMPER analysis, presented as a percentage of the total contribution within this group. Only those species responsibl for up to 75% of cumulative contribution are presented. Av.Abund=average abundance, Av.Sim=average similarit Sim/SD=similarity/standard deviation, Contrib%=percent contribution and Cum.%=cumulative percent.

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Summer					
Cirolina spp.	1.73	8.08	1.51	20.46	20.46
Calanoids	1.07	6.46	2.08	16.35	36.81
Brachyurans (megalopae)	7.17	3.91	0.92	9.89	46.70
Ctenophora	0.39	3.58	0.96	9.07	55.77
Sagitta sp.	0.32	3.12	1.02	7.91	63.68
Bivalvia	0.14	2.26	0.81	5.73	69.40
Penaeid prawn larvae	0.08	2.19	0.78	5.55	74.96
Cirripedia	0.17	2.12	0.78	5.37	80.33
Autumn					
Brachyurans (megalopae)	2.96	7.07	1.29	18.31	18.31
Calanoids	0.77	5.43	1.69	14.04	32.35
Cirolina spp.	3.78	5.35	1.45	13.83	46.18
Ctenophora	2.01	4.21	1.04	10.90	57.08
Sagitta sp.	0.45	2.72	0.95	7.03	64.11
Brachyurans (zoeae)	2.27	2.46	0.58	6.36	70.47
Ostracoda sp	0.12	1.66	0.62	4.29	74.76
Gastrosaccus spp.	0.27	1.32	0.60	3.42	78.18
Winter					
Calanoids	7.27	10.06	2.46	23.15	23.15
Cirolina spp.	2.59	7.60	1.46	17.50	40.66
Sagitta sp.	0.30	5.81	2.19	13.38	54.04
Brachyurans (megalopae)	0.29	5.15	1.60	11.85	65.89
Gastrosaccus spp.	1.27	2.72	0.78	6.27	72.15
Ostracoda	0.07	1.58	0.69	3.65	75.80
Penaeids	0.12	1.31	0.51	3.02	78.82
Spring					
Brachyurans (megalopae)	3.97	9.58	1.54	23.52	23.52
Calanoida spp.	0.42	7.40	3.61	18.16	41.68
Cirolina spp.	1.27	5.87	2.07	14.41	56.08
Gastrosaccus spp.	1.65	5.61	1.25	13.77	69.86
Penaeids	0.04	2.15	0.81	5.27	75.13

Appendix 10: Taxa characterising day and night assemblages, in the Mhlathuze surf zone as identified by SIMPER analysis, presented as a percentage of the total contribution within each group. Only those species responsible for up to 75% of cumulative contribution are presented. Av.Abund=average abundance, Av.Sim=average similarity, Sim/SD=similarity/standard deviation, Contrib%=percent contribution and Cum.%=cumulative percent.

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Day					
Calanoids	2.42	8.24	2.11	23.69	23.69
Brachyurans (megalopae)	1.63	5.29	1.14	15.22	38.91
Cirolina spp.	1.73	4.75	1.10	13.67	52.58
Sagitta sp.	0.44	4.57	1.33	13.14	65.72
Ctenophora	1.38	2.32	0.62	6.66	72.39
Brachyurans (zoeae)	1.08	1.63	0.49	4.68	77.06
Night					
Cirolina spp.	2.97	9.01	2.66	21.00	21.00
Brachyurans (megalopae)	5.57	6.91	1.40	16.11	37.11
Calanoids	2.35	6.11	2.62	14.24	51.35
Gastrosaccus spp.	1.81	5.34	1.19	12.46	63.81
Sagitta sp.	0.16	2.29	0.89	5.35	69.16
Cumacea	0.04	1.85	0.85	4.30	73.46
Ctenophora	0.33	1.44	0.61	3.35	76.81

Appendix 11: St Lucia and Mhlathuze surf zones. A list of taxa, in order of their importance, characterising St Lucia and the Mhlathuze surf zones at 60.53 and 58.13 percent similarity respectively identified by SIMPER analysis. The average dissimilarity between St Lucia and the Mhlathuze = 55.23%. Av.Abund=average abundance (no.m^{-3}), Av.Sim=average similarity, Sim/SD=similarity/standard deviation, Contrib%=percent contribution and Cum.%=cumulative percent.

System/Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
The St Lucia surfone					
Calanoida spp.	2165.62	4.98	4.55	8.23	8.23
Gastrosaccus spp.	3643.91	3.80	1.94	6.28	14.51
Cirolina spp.	1111.64	3.22	2.19	5.31	19.82
Sagitta sp.	705.33	2.44	2.93	4.03	23.85
Brachyura spp. (megalopa)	1306.75	2.27	2.39	3.76	27.61
Lucifer sp	52.51	1.86	6.28	3.07	30.68
Penaeidae sp	66.68	1.85	3.94	3.05	33.73
Corycaeaus sp.	110.31	1.69	4.23	2.79	36.52
Amphipoda sp.	70.60	1.67	3.59	2.76	39.29
Brachyura spp. (zoea)	576.19	1.50	2.33	2.48	41.76
Caprellina longicollis	7.41	1.43	11.58	2.36	44.13
Podocerus spp	11.70	1.35	4.56	2.24	46.36
Nymphosis cuspidata	9.57	1.31	11.06	2.17	48.53
Isopoda sp. 3	10.01	1.20	6.36	1.98	50.51
Platynereis dumerillii	20.48	1.15	3.47	1.91	52.42
Bivalvia spp.	23.27	1.14	3.62	1.89	54.31
Grandidierella spp.	12.25	1.13	3.27	1.87	56.18
Amphipoda larvae	10.42	1.03	3.32	1.70	57.88
Hyperia galba	4.05	1.02	4.00	1.68	59.56
Insecta sp	19.81	0.99	4.12	1.63	61.19
Polychaete spp. (Larvae)	5.94	0.93	4.10	1.54	62.73
Caprellina cicur	8.16	0.93	3.01	1.53	64.26
Siphonophora sp.	9.28	0.91	1.49	1.50	65.77
Gastropoda sp	3.70	0.87	4.17	1.44	67.21
Ampelisca palmata	7.75	0.86	1.58	1.42	68.63
Scyphozoa sp.1	6.22	0.86	1.51	1.42	70.05
Unknown spp	2.51	0.81	4.99	1.34	71.39
Muggiaea kochi	6.22	0.80	1.42	1.32	72.71
Isopoda larvae	15.64	0.68	0.93	1.12	73.83
Tanystylum brevipes	0.75	0.66	7.25	1.09	74.92
Caprellina equilibra	1.72	0.60	1.58	0.99	75.91
The Mhlathuze surf zone					
Cirolina spp.	234.53	5.64	10.05	9.70	9.70
Brachyura spp. (megalopa)	359.27	5.19	3.89	8.93	18.63
Calanoida spp.	237.71	4.89	4.26	8.41	27.04
Sagitta sp.	29.71	3.29	5.25	5.67	32.70
Ctenophora sp.1	85.63	2.84	1.98	4.89	37.59
Gastrosaccus spp.	91.51	2.46	1.78	4.24	41.83
Lucifer sp	3.09	1.87	6.29	3.22	45.05
Brachyura spp. (zoea)	61.78	1.87	1.56	3.21	48.26
Siphonophora sp.	9.32	1.86	2.83	3.19	51.46
Insecta sp	2.71	1.78	3.72	3.07	54.52
Hyperia galba	2.14	1.74	6.48	2.99	57.51
Penaeidae sp	7.66	1.66	1.63	2.86	60.37
Cirripedia sp.	5.61	1.65	3.93	2.84	63.21
Corycaeaus sp.	1.56	1.46	3.44	2.52	65.72
Cumacea sp.	2.40	1.36	3.31	2.33	68.06
Paraphoxus oculutus	1.21	1.27	5.07	2.18	70.24
Ostracoda sp.	5.01	1.25	1.41	2.16	72.39
Corophium sp.	0.82	1.01	1.58	1.74	74.13
Polychaete spp. (larvae)	1.73	0.81	1.03	1.39	75.52