THE INFLUENCE OF ANTHROPOGENIC IMPACTS FROM DEVELOPMENT AND HUMAN ACTIVITY IN AND AROUND FOREDUNE PLANT COMMUNITIES ALONG A PORTION OF THE KWA ZULU – NATAL COASTLINE"

by

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Abstract

The impact of development on coastal ecological processes within the coastal zone is often noted as being of ecological concern, due to the suggested destabilization of dune systems as a result of construction activities and post construction impacts such as stormwater disposal, trampling and other artificial influences on, in particular, the plant ecology of the frontal dune systems.

Given that the stability of frontal dune systems along the Kwa Zulu Natal north coast is often attributed to the maintenance of vegetation and seral progression on such systems, the identification of changes in dune plant communities that may arise from the influence of proximal or adjacent activities was sought to be identified. Utilising data collected from a number of sites in the Kwa Dukuza Municipal area, the classification and ordination of environmental and botanical species information collated over approximately 6 months was undertaken. The results of this investigation indicate that :

1 Species composition differs in terms of richness and abundance in the three frontal dune vegetation zones sampled.

2 Some species occur in all three zones and others are confined to one zone only.

3 Bearing and the associated influence of wind, the slope and length of the beach, and the steepness of the dune face all influence the species composition at any particular site

4 The influence of anthropogenic activities on dune synusia is such that human influence on one species may disrupt associations between species and may result in attenuation or reversal of seral movement.

5 Anthropogenic impacts influence species composition at different sites by causing some species to decline abundance or disappear from a site and others to invade or oust established species. In Zone I the species that appears to be most affected by human activity is *Gazania rigens*, which appears to dominate in sites of high human activity, at the expense of *Sporobolus virginicus*. In Zone II under high human activity species such as *Cynanchum obtusifolium*, *Rhoicissus digitata* and *Sporobolus virginicus* dominate, while the woody species *Mimusops caffra* and *Eugenia capensis*, as well as the liane *Gloriosa superba* appear to decline or be ousted from this Zone. In Zone III, *Asystasia gangetica*, is a dominant species where low to moderate human impacts are encountered,

while where human impacts are high, species common to Zone I, such as *G rigens* may become prevalent, ousting *A gangetica* and grasses such as *S virginicus* may be ousted by more competitive species such as *Stenotaphrum secundatum*.

It is thus concluded that human activities in and around the frontal dune system may be influential in re-inforcing aeolian impacts on sites with bearings affected by strong prevailing winds.

Preface

The experimental work described in this dissertation was carried out in the School of Life and Environmental Sciences, University of Kwa Zulu Natal, Durban from January 2003 to May 2004 under the supervision of Mr. B Page.

These studies represent original work by the author and have not otherwise been submitted in any form for any degree or diploma to any tertiary institution. Where use has been made of the work of others, it is duly acknowledged in the text.

The collection of primary data was undertaken through the establishment of a number of sites across a series of dunes in the Kwa Zulu Natal north coast extending over approximately 15 kilometres . The data was ordered and analysed using TWINSPAN and CANOCO with the compilation of biological spectra and the further visual assessment of particular sites to verify output from the statistical analyses.

The results were analysed and consideration of such results has led to the conclusions and discussion provided within this paper.

S.C. BUNDY
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I INTRODUCTION

1.1 Background

The establishment of permanent and temporary structures upon or adjacent to primary dune systems affects the structural integrity of such systems. Changes in sand movement or dune profiles, created by such developments, may affect the ability of the dune system to abate the natural physical impacts common to coastlines, including high winds and surging storm surf. Alternatively, changes in such factors as aerial salt spray and direction and amount of wind blown sands (Donnelly and Pammenter 1982) brought on by various developments both during and after construction may also serve to alter vegetation diversity and coverage on frontal dune systems. Such effects may only be apparent after some time and it is apparent that failure of dune systems and their related ecological systems is often the result of such changes (Brown and MacLachlan 1990).

Musila and others suggest that coastal dune vegetation is an important indicator of the general physical conditions of the dune environment and that vegetation also provides a basis for the management of the sand dunes (Musila et al 2001)

Within the coastal or dune systems, it is noted that any attempt to relate plant distribution to just one climatic (and possibly physical) variable is bound to produce a simplification with many exceptions and points of contention (Crawford 1987). Ward has noted that amongst other factors, wind, proximity to rivers, vegetation cover and marine activity, as well as the actions of Man is an influence on dune topography and in turn dune plant communities and their distribution (Ward 1980). Thus a review of a number of significant physical and climatic factors prevalent within the area is provided

The floral communities of frontal dune systems are important components in the growth and stabilization of dunes, primarily due to highly adapted species providing a barrier to reduce surface wind speed, reducing erosion and facilitating accretion of dunes (Bird 2000, Ranwell 1972). Such species exhibit important physiological adaptations to survival on dune systems, including surface root systems, tolerance of coverage by sand and aerial salt spray and the ability to withstand extreme temperatures and high insolation impacts. Particular species, associes and consocies within dune systems are seral indicators associated with climatic and edaphic factors within a dune system, leading to the formation of clines (Doing 1985). Dominance within an association is based on internal and external factors. Such factors have been highlighted by Boorman (1990) in undertaking experiments in Holkham in the United Kingdom, which has indicated that the raising of nutrient levels within dune systems leads to a decrease in species diversity and dominance of certain species, which has considerable implications for dune management.. Donnelly and Pammenter (1982) also suggested that the patterns of both aerial salt spray and short term wind blown sand, correlated well with species distribution in frontal dunes in the Beachwood area of Durban.. It is suggested that impacts from construction on dunes could lead to similar results.

Structural (geomorphologic and topographical) changes to the frontal dune system may often serve to alter factors such as exposure to wind that affect dune systems and thus lead to changes in species composition. Such changes are the result of the imposition of stresses and can result in (at low stress levels) adaptational changes by individual plants or at greater stress levels, the replacement of botanical families (Pearson and Rosenberg 1978).

1.2 Factors Influencing Coastal Dune Ecology

Insolation is considered to be a factor in the establishment of microclimatic regimes, particularly as a variance from the summer to winter seasons. (Ward 1980). Ward states that the two sides of a wind blown dune, have markedly different microclimates. While this may be considered to have an ecological role on some species, Ranwell (1972) noted that some frontal dune species were particularly tolerant of shade. It could thus be surmised that shade is not a great influencing factor on individual plants, but may impact upon the competitive displacement of vicarious species within plant communities.

Ranwell (1972) has noted that extremely wide and rapid temperature fluctuations can be expected on dunes in Newborough Warren in the United Kingdom. Furthermore, it can be expected that such extreme variations are common within this study area and possibly very high temperatures are experienced on dunes in the region. Ward has indicated that topography can, as with insolation factors, play a role in creating variations in temperature within the same dune systems leading to microclimatic variations (Ward 1980).

Low temperatures may also be considered to have a significant effect upon dune plant species but with the mean minimum temperature recorded in Durban of 9.8°c the likelihood of fatally low temperatures leading to frost or extended periods of low temperature are considered extremely unlikely. It is also to be noted that Lubke (1983) identified that surface temperatures varied extensively from those found at only 20cm below the surface.

Wind has a very strong influence upon frontal dune vegetation and is directly associated with the movement of sand, combined with the influence of established vegetation,. It is noted that wind is able to remove sand from areas of vegetative disturbance, while depositing sand in other areas. A minimum wind speed of about 4m/s is required to induce moderate grain size movement, which is achieved mostly by saltation, the process of "jumping" of grains across a beach and the subsequent mobilization of other grains of sand upon impact (Brown and MacLachlan 1990).

The tendency for dunes to stabilize is dependent on reduced wind strengths found on sheltered coasts and reduced frequency of higher wind strengths in any one particular direction." (Bird 2000 ; Ranwell 1972). The distribution of airborne salt and sand deposition, both influenced by wind direction and strength, are considered to be important factors in the distribution of common species. (Donnelly and Pammenter 1982).

Rainfall and dew are considered to be important factors in the maintenance of dune vegetation, particularly on the primary dunes where access to sub-surface aquifers and the permanent water table is often restricted (MacLachlan and Brown). However, the influence of soils moisture on the distribution of species is noted by Donnelly and Pammenter as having limited correlation with the distribution of species on coastal sand dune systems.

A significant factor that may account for much of the water relations in the frontal dune systems is the high humidity of the region, coupled with the rapid change between day and night time temperatures. Olsson and Sefer (1909) suggest "such fluctuations in soil temperature...are sufficient to cause periodical condensation of water vapour in the soil". Willis et al (1959) pointed out that the temperature gradient in the soil is favourable for an upward movement of water vapour from the warm and wetter layers of the sand below and this is so, even when the upper layers do not fall below the dew point of the external air. Ranwell has suggested that the water content at any one time in young dune soils is only enough for plants growing in it to survive for 2 to 5 days, thus suggesting that humidity and condensation play a significant role in dune plant – water relations (Ranwell 1972)

The age of dunes and organic matter within dunes, plays a significant role in plant - water relations. In general the water content of old dune soils are about twice that of young dune soils when the soils are at field capacity. (Ranwell pg 160).

Sand dunes effectively reflect the nature of the geology from which they are derived (Bird 2000). The sands of the Kwa Zulu Natal north coast are generally siliceous, being derived from off shore sources, as well as sandstone cliffs and shorelines around the coastline. Often other sediments, washed down from rivers are common, with some heavy minerals such as ilmenite and rutile becoming common in certain areas. As such, there are limited nutrients available within beach sediment that can be utilized by plants and the importation of nutrients and nutrient sources is a pre-requisite for plant establishment. Lubke (1983) has pointed out that soil factors are probably of secondary importance to wind and sand in the ability of plants to become established in the dune systems. Organic material, deposited on the shoreline, forms one of the primary organic sources for Zone I species and may be significant in assisting with species recruitment and establishment within this zone (Ranwell 1972). Once established within a stable portion of dune or beach, with the available nutrient and water resources, plant propagules are able to utilize nutrient resources at their disposal.

Anderson and Taylor (1987) noted that the longer that an individual genet lives within a particular portion of dune, the greater is its opportunity to pre-empt nutrient resources and to hold them against the demands of other individuals and the larger is the area from which it depletes such resources. Such competitive advantages may be an important factor in determining which species predominates on a dune system, while changes in this factor may lead to changes in vegetation dominance, ousting of particular species and recruitment of others, which in turn may lead to changes in topography, as vegetative influence on dune structure becomes manifest.

The first major biological influence on soil formation and possibly one of the primary sources of nutrients in a dune system are microbial, both fungal and bacterial. Webley (1952) showed that micro flora of the rhizosphere of sand dunes contain abundant bacteria, which are present only in very low numbers in intervening sand areas. (after Ranwell) Ranwell noted that "we are still very ignorant of nutrient pathways in sand dune habitats, but it does seem evident that there is a distinct switch from the bacterial based economy of the younger or more base rich dune soils to a fungal based economy on the older dunes." (Ranwell 1972).

Micro-floral influence is also related to the presence of mycorrhizal and nitrogen fixing species associated with some dune species (such as the legume *Canavalia rosea*). Nitrogen is limiting for the sand dune plants in open foredunes, thus making nitrogen fixation an important biological process.

Higher nitrogen levels, in the accompaniment of other nutrients, allows for invasion of dunes by other species, leading to the zonal distribution of 'synusia' or 'plant communities of similar habitats'. Ranwell (1972) noted that on European dunes higher nitrogen levels often lead to the spread of weedy species such as *Urtica* and *Cirsium* at the expense of many of the other less vigorous species. In the study area, it is suggested that improved nutrient status on dunes leads to invasion by species such as *Mimusops caffra*, *Chrysanthemoides monilifera* and *Euclea racemosa* often found associated with Zone II and III. (Ward 1980)

It has been suggested by Salisbury (1929) that organic matter augments slowly at first, but appreciably faster after about 200 years, especially in a higher rainfall climate. (Ranwell 1972). Such nutrient levels can be utilized to assess the age of dunes and may also reflect the age of the dune through vegetative composition.

The littoral active zone along the Kwa Zulu Natal coastline (incorporating both beach and 'white' or 'primary' dune) can be easily discerned from the other littoral and coastal habitats described above. The white dunes comprise of wind blown sands that have recently been deposited through both wave and aeolian action. As indicated, the prevailing north easterly wind in the region is primarily responsible for the deposition of sand, primarily through saltation (Brown and MacLachlan 1990) leading to sand dune establishment.

Saltation, the transfer of energy from falling sand grains to immobile grains, is the primary aeolian dune-building mechanism. MacLachlan and Brown estimate that 75% of the sand on dunes moves by saltation. The attenuation of the saltation process is achieved through either the loss of wind speed, dampening of the sand or the presence of an obstruction, more particularly vegetation. (Brown and MacLachlan 1990)

The variation in the marine and terrestrial factors between the high water mark and the hummock and stable primary dunes is *rapid* and *abrupt*. Kellman (1980) noted that 'in areas of low species diversity and sharp environmental discontinuities, relatively distinct and repetitive species assemblages may be found with little intergradations between these". In contrast, "in areas of great diversity and gradual environmental change, repetitiveness in composition is very difficult to discern and continual intergradation prevails" (Kellman 1980). Such discontinuities are prevalent within the frontal dune system of the study area and along coastlines in general. This has led to the identification of various habitat zones within dune systems, where, as indicated by Kellman, species diversity increases, the discontinuities between synusia or communities within similar habitats becomes less apparent and repetitiveness in species composition becomes less discernable.

1.3 Zonation Within Frontal Dune Plant Communities

As many as six foredune vegetation zones have been identified around the world and in general, four major zones can be identified in South Africa (MacLachlan and Brown 1990). Musila et al 2001 have suggested that in Kenya only three dune vegetative communities are present, these being those of the stable geomorphologic units and those of the mobile geomorphologic units and a mixed community of semi-stable vegetative communities found between the two. In general, the four zones suggested appear from a visual perspective to be relevant to the study area, being easily identified from a visual perspective and hence the zones identified as zones 1 to IV were utilized in undertaking the analysis of vegetation. These zones are described below (after MacLachlan and Brown 1990):

Zone I This is the so-called "pioneer zone", with creeping grasses and succulent herbs with stoloniferous growth, predominating. Species are commonly annuals (which die back after a year) or 'hemicryptophytes' or 'therophytes'. This is a physically controlled zone, by primarily wind and the mechanical effect of sand. Marine action may also play a role on an irregular basis. Plants in this zone typically show rapid growth, water storage and cuticular protection. Dispersal is normally by floating seeds or by vegetative growth. Within the study area it is often encountered that the rocky headlands common between Thompsons Bay and Christmas Bay provide shelter from both extreme onshore winds and wave attack, which may allow for species less tolerant of conditions in zone 1 to invade. *Helichrysum cymosum*, common to zones II and III, may be encountered in such sheltered areas, where marine activity is also limited.

Zone II Consists of shrub community – dune heath. There is a mixture of zone 1 plants and other psammophytes. The zone exhibits moderate sand movement. The flora includes annuals, forbs, creepers, succulents and shrubs. Phanerophtyes including woody specimens may, under favourable conditions appear in this zone. Common species in this zone include *Passerina rigida* and *Mimusops caffra*. The heliophyte, *Chrysanthmoides monilifera* is also prominent within this zone. Where climatic conditions allow, *C. monilifera* may be ousted by *M. caffra* or *B. discolor* (Ward 1980). Seed dispersal is ostensibly by wind with dispersal by birds (*C. monilifera*) becoming more common than in zone I.

It is worthy of note that narrow dune fields may only show zones 1 and II, often identified by direct on-shore winds, steep scarps and dunes, as well as limited off-shore sediment sources.

Zone III The shrub-thicket zone. Typical of this zone is a flat canopy due to wind pruning. Little or no sand movement is common to the zone particularly in comparison to zones I and II. Doing 1995 in Brown and MacLachlan 1990 indicated that zone III only develops where rainfall exceeds 250mm per year . The effect of wind as a master factor is apparent, with the 'dwarfing' of trees and shrubs. The low canopy within this zone is typically compact but height does increase with rainfall. Furthermore, there is little understorey such as a herb layer, but a distinct litter layer is typically encountered. The diversity of species is noted to increase in zone III, where seed dispersal is both wind-borne and avian. The height of the canopy in this zone increases in the lee of the dune leading to mergence with zone IV. Phanerophytes become more dominant in zone III. Within the study area, the dominant community within Zone III, appears to be a *Brachylaena – Chrysanthemoides* association. *Brachylaena discolor* , is common to those areas disturbed by natural climatic impacts, such as "blow outs" on dunes. Other species common to this area appear to be *Mimusops caffra* in a scrub form as well as *Eugenia. capensis*, invading this zone, where wind may be moderated by topography and soil – water relations improve.

Zone IV. Thicket or forest. This zone is typical in areas with high rainfall (in excess of 700mm), where the shelter of larger dunes allows for an increase in height and emergence of dune forest. There is typically a mixture of thicket species and forest species. Generally zone IV only occurs where soils are mature. Ward has stated that the common *Strelitzia nicolaii – Brachylaena discolor* association of this zone is a typical result of improved soil-water relations. (Ward 1980). Within this zone and where a closed upper canopy exists, a layer of smaller trees and shrubs, field layer and ground layer may be encountered. Seed dispersal is generally avian. This vegetative zone, is within the study area, most generally indicated by the presence of larger, more mature *M. caffra*, together with extensive stands of *S nicolaii*. Other common species within this zone include *Clerodendrum glabrum*, *Strychnos madagascarensis* and *Allophylus natalensis*. This zone is absent in most urban environments within the study area as it marks the most stable areas in close proximity to the beach and thus is favourable from a development perspective.

Given the zonation proposed by MacLachlan and Brown, Doing, Musila and others, it is worth comparing these dune communities against the zonations identified by Ward for the Isipingo psammosere (Ward 1980), as reference to both zonation classifications are made. Table 1 provides a comparison of these zones with typical vegetative indicators.

Table I Comparison of dune vegetation zones as defined by Maclachlan and Brown (1990) and Ward (1980)

Zone *(After MacLachlan and Brown)*	**Zone** *(After Ward)*	**Species Indicators and Form** *(After Ward)*
Zone 1	**Pioneer Strand Community**	*Arctotheca populifolia, Hydrophylax carnosa, Scaevola plumereii, Canavalia rosea, Carpobrotus dimidiatus, Sporobolus virginicus, Ipomoea pes caprae , Cyperus natalensis, Gazania rigens.* Low growing succulent plants, requiring high insolation, not generally tolerant of shade. Tolerance of salt spray and cover by sand
Zone 2	**Open Dune Scrub**	*Passerina rigida, Chrysanthemoides monilifera, Eugenia capensis, Maytenus procumbens, Mimusops caffra, Aloe thraskii ; Barleria obtusa* Tolerant of light salt spray. Height and cover increase, particularly in the lee of dunes. Individual plants become more umbraculiferous.
Zone 3	**Closed Dune Scrub**	*Cynanchum obtusifolium, Carissa macrocarpa, Asystasia gangetica, Mimusops caffra,Psychotria capensis, Canthium obovatum, C. inerme,* Mixed scrub with closed (contiguous) canopies. Increase in woody species. "Clipping" or shaping of canopy by wind. Field layer often present.
Zone 4	**Dune Forest** Ward recognizes a *Mimusops caffra* woodland as an intermediary zone between closed dune scrub and dune forest.	*Mimusops caffra, Brachylaena discolor, Allophylus natalensis , Strelitzia nicolaii, Apodytes dimidiata, Clerodendrum glabrum , Sideroxylon inerme ;Issoglossa woodii; Strychnos decussata.* Dominance by woody species with field layer (*I. woodii*) prevalent. Taller canopy merges with shorter canopy of closed scrub. Some clipping.

The dune slack is often a notable feature on dune systems. While not always present, the dune slack is a more definitive habitat than the frontal seaward dunes, as a result of the shelter afforded by the seaward dune crest. Such shelter allows for a decrease in the abrasive impact of the seaward winds. The dune slack is also representative of that portion of the frontal dune cordon that is closest to the water table. Ranwell (1972) has noted that on the dune to slack gradient, most of the environmental changes are dependent solely on the change in water relations and the gradient contains a mixture of species from each habitat. . Leeuwen (1965) in Ranwell (1972) indicates that the dune slack and the *dune to slack continuum* gives rise to a "specialized habitat" In urban environments, the dune slack is often removed through infilling during construction activities.

The idealized zonation proposed by Mac Lachlan and Brown (1990) and others is often broken by excessive climatic forces leading to the slumping of dunes or blow-outs, as well as the presence of headlands which may shelter certain areas of the coastline from excessive winds. In addition, proximity to blind rivers, wet slacks and estuaries can lead to changes in this zonation. Changes in the habitat of each zone is according to erosion, accretion and the disturbance or remobilization of sand and can lead to the recurring arrangement of zones and habitats over extended periods of time. Doing noted that most complex dune systems occur where there is both strong wind disturbance and strong plant re-growth.(Brown and MacLachlan 1990)

1.4 The Inter-relationship between Bio-physical Factors, Topography and Vegetation

The coastline forms a distinct junction between the marine and terrestrial environments. As such, there are a number of physical factors that change rapidly over a relatively short distance from the marine influenced environment to a terrestrially influenced environment. This area of rapid change is in many areas within the study site, a dune system, dominated by vegetation making up the psammosere. These dunes are colonized by a number of vascular plants, such species having been identified in Table 1, above.

The sandy beaches of the north coast are ostensibly 'eroding' or 'retrograding beaches' (Begg Tinley 1985), with reflective beaches being common in the north, although in some of the sheltered bays common between rocky headlands, dissipative beaches may also be present. Reflective beaches are steep (Bird 2000), where incoming wave energy is "reflected" back to the marine environment, while dissipative beaches are of a low grade. As a result of the common occurrence of reflective beaches, most frontal or white dune formations can be designated as "foredunes" (MacLachlan and Brown 1979). Such dune systems comprise of (1) incipient foredunes (dunes in the process of formation with pioneer plants), (2) established foredunes (where the four vegetative zones are common) and (3) relict foredunes, which are the remnants of earlier foredunes (Brown and MacLachlan 1990).

The feedback response between dune vegetation and topography can be ascribed to primarily the following factors

1 Bearing or aspect
2 Wind
3 Plant – water relations
4 Plant - nutrient relations (indicated or influenced by pH, microflora and related variables)
5 Insolation
6 Species invasion or access
7 Species dominance
8 Geno-typic adaptation

A number of other influences may be prevalent within any given dune system. The classification and identification of the level of influence by these factors and whether human activities have an influence on species diversity and composition requires consideration of many of the above factors and is particularly relevant to coastal management in urbanizing environments.

Ranwell (1972), utilizing the work of Martin (1959) showed that "*topography and vegetation are interrelated and interacting. Most community types could occur or do occur on more than one topographic facet and topographic facets can support more than one community type*". (Ranwell 1972). This indicates that there appears to be a feedback system employed within dunes between topography and plant associations. If such a "feedback system" as suggested by Ranwell, is accepted, the influence of developments along the coastline on coastal vegetation may possibly be predicted, furthermore influences within the various habitats or zone identified, may differ.

On the north coast of Kwa Zulu Natal, residential and tourist orientated coastal developments frequently include or abut the frontal dune system, often lying to within metres or even as far as the datum high water mark. While such built structures may be placed some distance from the primary vegetated dunes, landscaping and maintenance of the artificial landscape often extends to the vegetation / beach interface. (Fig 1). This study was undertaken to assess the influence such developments and associated anthropogenic influences may have on dune vegetation communities.

Fig 1. Example of the location of built structures with respect to the frontal dune system, (Ballito 2003)

1.5 Objectives

The broad objective of the investigation is to assess variations in patterns of plant communities representative of the coastline within the study area, in relation to a selection of readily measured environmental factors and anthropogenic impacts arising from the presence, nature and proximity of developments of different types, such as residential complexes, parking areas and other man- made infrastructure.

The specific aims of the investigation are thus:

1. To describe the composition of plant communities in different topographic positions on frontal dune systems in the lower north coast region.

2. To determine the influence of selected abiotic variables on the species composition of dune communities.

3. To determine whether anthropogenic impacts override or reinforce the influence of bio-physical factors, and under what conditions this may occur.

II DESCRIPTION OF THE STUDY AREA

The study area comprises the frontal coastal dunes (white and yellow sand systems) of the Kwa Zulu Natal north coast between 29°34' 22'S / 31°15' 13"E (Tongaat River) and 29°29' 12'S / 31°15' 24"E, (north of "Christmas Bay"), incorporating the residential and commercial urban beachfront centres of Ballito and Salt Rock.

The study area was restricted to the area of coastline between the Tongaat River in the south and the Umhlali River in the north [Fig 2]. The study area was selected as it is a single local authority or political unit with 'traceable' development history, as well as being purported to be one of the fastest developing coastal areas within South Africa (KwaDukuza Integrated Development Plan 2002). Comparisons can be made between the dune cordon at Zimbali (which is covered by relatively mature primary and secondary dune vegetation), Ballito - Salt Rock, (where several older developments have encroached well beyond the primary dune system and impact on the frontal dune area) and the Sheffield Beach area, north of Salt Rock (where relatively new developments have encroached well within the primary dune system).

At certain sites, sugar cane cultivation was the most proximal anthropogenic disturbance, which should have different ecological impacts on dune vegetation to those arising from the built environment. A general description of the nature of the study site is provided.

2.1 Physiography

2.1.1 Topography and Nature of Coastline

The Ballito – Salt Rock coastline includes both rocky, primarily dolerite or sandstone headlands and sandy, aeolian-derived dunes within "half heart bays" (Tinley 1985). The rocky headlands and shelves are concentrated between the area of Thompsons Bay, north towards Sheffield Beach, while open sandy beaches are more prevalent to the south and north of these points.

The rocky shoreline and cliffs form some of the highest prominences along this stretch of coastline and include near vertical wave cut cliffs, as well as scattered, boulder strewn beaches.

In the vicinity of Salt Rock, red sand cliffs are to be noted which exhibit a steep frontal earth cliff face, differing distinctly from the rocky cliffs and white sand dune systems common to the area. This geological variability results in a coastline with variable bearing or aspect, leading to differing site specific environmental factors (Fig 2)

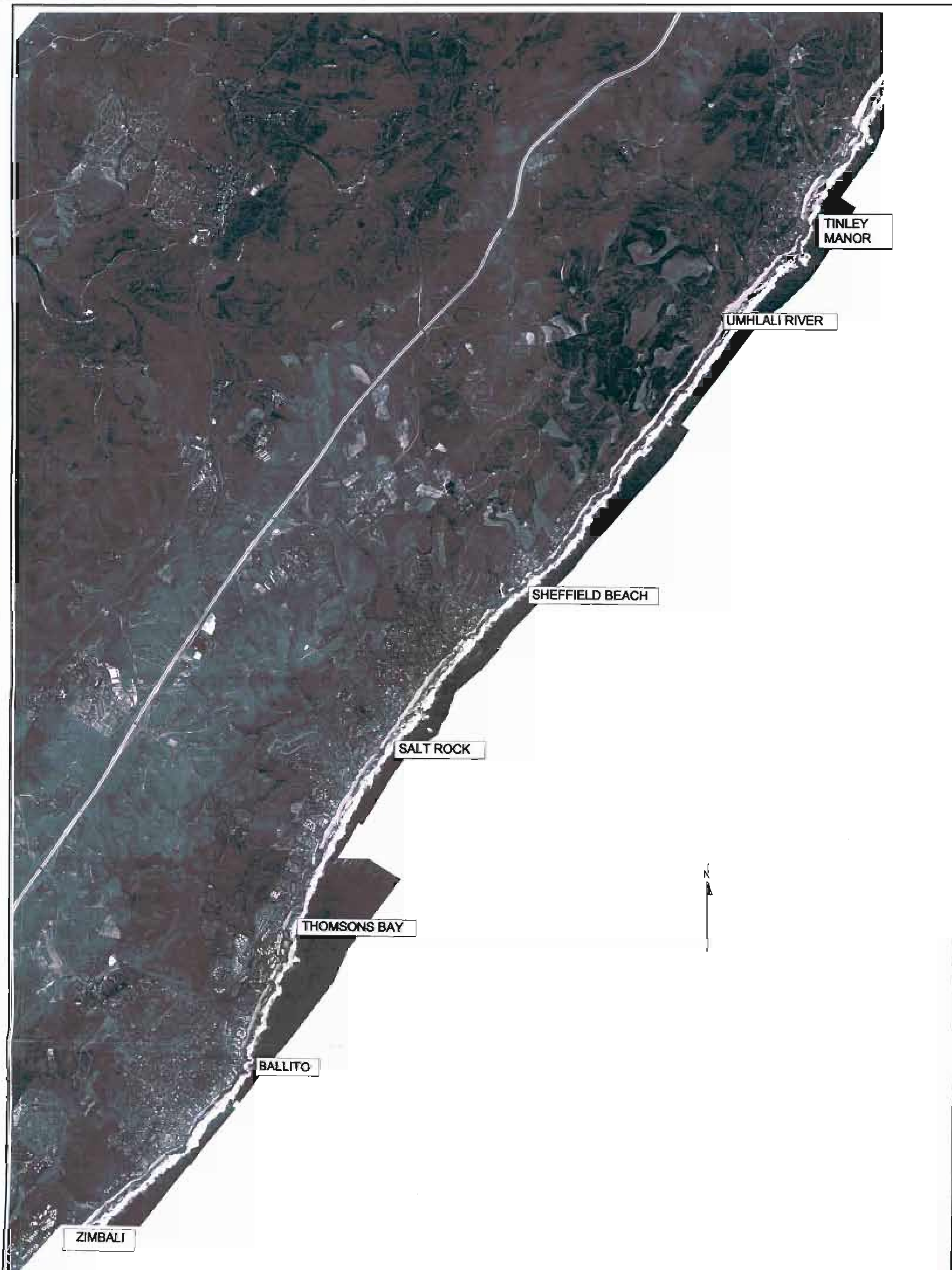

FIG. 2 STUDY SITES IN REGIONAL CONTEXT
NOT TO SCALE

2.1.2 Geomorphology and Geology

As indicated the coastline comprises of a number of "half heart bays" with the variable geology of the area comprising sandstone of the Karoo formation and less erosive dolerite intrusions, creating a variable coastline, which in turn, provides for variable aspect or bearing in terms of seaward facing dune and cliff.

Most areas of the coastline comprise of sandy beaches of sediment derived from weathered sandstone. Modern dune systems within the study area are relatively young, being primarily from the Quaternary period or younger (6000 years) (Bird 1990). Larger rivers, including the Umdloti, Tongaat and Umhlali River are suggested as being the primary sources of beach sediment in the area, while other sediment sources may be derived from deeper marine sediments, more distal terrestrial sources and less significantly, proximal sources such as extremely mobile dunes.

2.1.3 Temperature

According to the Department of Environmental Affairs Weather Bureau, a mean annual temperature of 20.2°C is experienced in the Durban region. Maximum temperatures recorded include 40.8°C recorded in October 1958 and a low of 2.6°C in July 1969.

2.1.4 Wind

The prevailing wind in the region is a north easterly wind (varying from NNE to ENE), which is noted by the DEAT Weather Bureau in Durban to predominate for over 20% of the year. (Fig 3). Other predominating winds are the south westerly winds (SSW and SW), which predominate for approximately 16 % of the year. Calms or periods of little or no wind are noted to occur for 37% of the year (CSIR 1989).

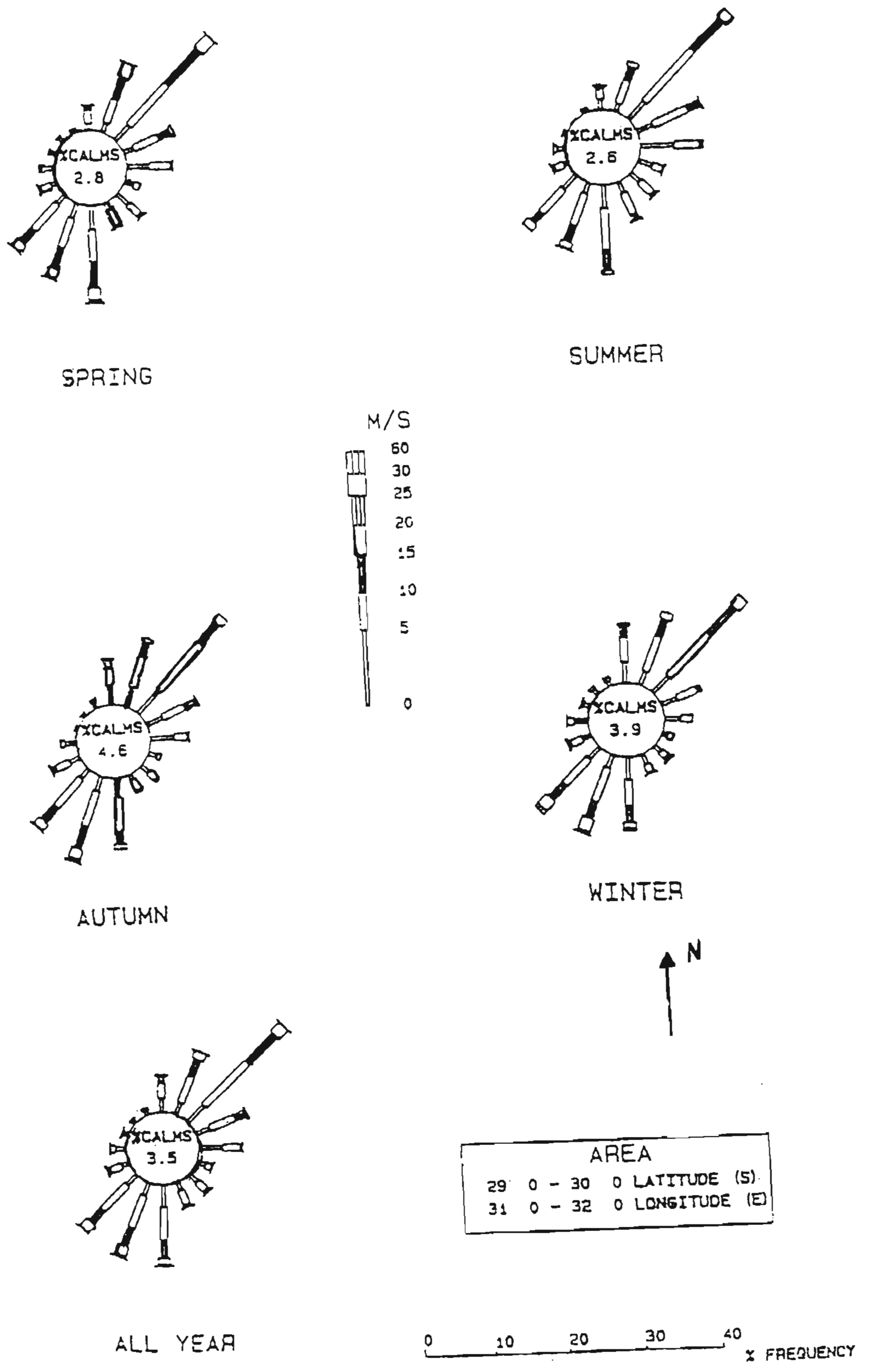

Fig 3 Wind rose as Compiled for Study Area Source CSIR Dept of Oceanography 1989

2.1.5 Precipitation

The rainfall within the study area is erratic and is subject to intermittent periods of above average rainfall, followed by periods of below average rainfall. Camp has indicated that the average rainfall for the coast is between 820mm and 1423mm per year. Table 2 derived from the South African Sugar Association (SASA) extension station, indicates that between 1999 and 2004 most years had experienced a low or below average rainfall, thus indicating that the study area had been in a period of low level drought, with possible botanical impacts being associated with such drought. The effect of such drought conditions must be borne in mind when considering the results associated with this investigation.

Table 2 Rainfall figures as recorded at Umhlali (source SASA Extension Offices, Umhlali)

Umhlali SASA							
Year	1998	1999	2000	2001	2002	2003	2004
Total Rainfall mm	738	999	1355	1063	925	602	356

The most significant effect of low rainfall within the study site may be on the recruitment of primarily the ephemeral psammophytic species of zone 1, where recruitment of individual species may be hampered at the germination and seedling establishment stage. (Brown and MacLachlan 1990)

2.2 The Nature of Development and Development Impacts

Development of primarily residential and tourist related infastructure has accelerated in the Ballito – Salt Rock region since 1999. Since this date some R149 million (Kwa Dukuza Municipality 2003) has been invested in development, the bulk of which has been in close proximity to the frontal dune systems.

There are effectively two phases associated with a development that may influence either the topography of a dune or the vegetation associated with a dune. The construction phase results in a large amount of disturbance to the dune sediment, often with the importation of soils or alternatively extensive "cut and fill" operations. In moist areas, drainage of sites may occur through the use of piping and the attenuation of small streams. At the post construction phase other influences on dune vegetation include intrusion by pedestrians into and over the dune system (often leading to the establishment of pathways), canalization and focused discharge of stormwater and the impact of landscaping and other activities. The consequences of such actions may vary from property to property and are likely to be influenced by the same bio-physical factors as described above, however these anthropogenic influences may in turn alter the synecology of the dune flora and fauna.

2.2.1. Residential Developments

Until recently most residential developments within the study area had been built utilizing the town planning zone, '*special residential*', which allowed for the establishment of a single dwelling accommodating between 5 and 8 persons. Developments were generally of low density not occupying more that 30 % of the property with limited hardtopped surfaces. Due to the increase in land prices, property owners and developers have identified the opportunity to profit from rezoning such properties to accommodate more homesteads, that is rezoning to '*medium density zones*'. Such developments usually entail the establishment of one or more storeys and an increase in the area of the property under hardpan, in order to accommodate additional vehicular and human traffic.

2.2.2 Tourism Developments

Tourism development includes the establishment of hotels, restaurants and related structures, which are built to accommodate holidaymakers on a generally larger scale that can be accommodated in residential developments. Such structures are limited within the study area, but where they do occur, occupying significant areas of land adjacent to frontal dune systems. Within the study area only two hotels are present, while a few residential developments have converted to smaller "hotel type" accommodation, generally known as 'Bed and Breakfast' facilities.

2.2..3 Other Infrastructure

A number of other developments have ensued along the frontal dune system of the study area. More particularly and notable is the establishment of a pathway or promenade that extends for approximately 2.5 kilometres from Willards Beach to Salmon Bay in the south. This structure, a paved brick and cement pathway approximately 2 metres in width, was commenced in 1987 and was constructed in phases concluding in 1999. The latter phase was undertaken as a raised wooden walkway some 1 m to 1.5 m in height above the surface of the frontal dune.

With the establishment of hardpanning within various developments and along roads and parking areas in the study area, the associated stormwater management network has resulted in the establishment of a number of stormwater outlets which are found at low points, often between dunes at the egress of blind rivers and streams. Often at these points, stormwater outlets may be accompanied by sewerage pump stations due to their low level, allowing for the collection of sewerage by gravitational feed, before such sewerage is pumped to treatment works further inland.

Most developments, both large scale resorts and individual residences have access paths to the beach often traversing the frontal dune system. In many cases these access points are concretized creating an impermeable barrier to saltating sands and often exhibiting differing synusia on the leeward and windward side of such structures.

Related to the establishment of developments, particularly dense residential developments, is a concomitant increase in recreational utilization of the adjacent beaches. Complexes and higher density residential developments indicate that a greater number of people are likely to be visiting and utilizing the beach. Such an increase in human activity on the beach indicates a high probability of impacts on beach flora, particularly zone I flora, which may be subject to trampling and similar impacts.

III METHODS

3.1 Data Collection.

Field data collection was undertaken between June 2003 and January 2004.

Data were collected in sites (quadrats) located at twenty one pre-selected locations in the study area. Locations were selected by referring to aerial photographs and selecting settings with as wide a range of abiotic variation and human influence as possible. These locations were selected to ensure that dune systems experiencing low developmental impacts were included in the data, as well as sites adjacent to varying forms of development, including single residential units, complexes and parking facilities. The environmental factors considered include beach and dune gradient, aspect or bearing and distance of first dune from the development.

Sites that were avoided in the assessment included areas of frontal dune, where extensive moisture was available including streams and stormwater outfalls. Brown and MacLachlan (1990) has indicated that extensive nutrient input may arise in dune systems as a result of their proximity to rivers, as well as areas that were considered to exhibit an abundance of rock at both the intertidal and beach levels due to the high likelihood of non-psammophytic synusia being present. The primary criterion for the selection of sites was the presence of expansive, vegetated, sandy dunes.

At each location utilising position on the dune face, indicator species as well as form (Table I), three zones were identified on the face of the first vegetated dune and sites (quadrats) were established within each zone. Zone I was at the base of the slope, Zone II half way up and Zone III on the dune crest. Within Zone I, a site of 1m x 1m was established, in Zone II a site of 5m x 1m, and in Zone III, a site of 2m x 10m was sampled. The site sizes varied to accommodate larger species as well as to include variations in topography, not generally encountered in the zones found more proximal to the beach. At some locations, due to fencing and other obstructions, zone III could not be sampled.

In each site (quadrat) crown or canopy cover ['relative cover'] was estimated. Crown or canopy cover was suggested as the most appropriate means of establishing dominance of species due to the general nature of dune vegetation (CJ Ward pers comm.). In recording cover the Domin scale was utilized (Willis, 1973). The advantage of the Domin scale is that decisions relating to "what constitutes an individual plant" did not have to be undertaken. This avoids confusion during such assessments that may arise from rhizomatic dune species.

Three sites (quadrats) at 21 locations were sampled. Twenty seven species were recorded in zone I, 48 species in zone II and 52 species in zone III. All data was collated into a table where environmental and anthropogenic variables were recorded together with species within each site.

For each site (quadrat) a selection of abiotic and anthropogenic variables were measured or estimated. These included :

1. Distance of edge of vegetation from high water mark. (Measured)
2. Distance of quadrat from seaward edge of vegetation (Measured)
3. Distance of quadrat from edge of development (including tended garden, walls and fences and other structures. (Measured)
4. Bearing or aspect (Measured using compass)
5. Slope of dune – (calculated using plumbline)
6. Slope of beach - (calculated)
7. Nature of intertidal zone - rocky or sandy (estimated through observation)
8. Nature of dune sediment (fine, coarse of medium grained sand, estimated through observation).
9. Human impact (general count of number of people on beach, at time of assessment and comparison with other beaches, ie 'high' 'moderate' or 'low' use. General understanding of beach utilization was also considered in light of public facilities provided by the local authority, eg. ablutions, patrolled bathing areas etc.)

3.2 Analysis

3.2.1 Twinspan Analysis

Data were analysed using Two Way Indicator Species Analysis (Hill 1987). From the analysis, a dendrogram and table of species within each quadrat was compiled and abiotic and human influences related to the classification

3.2.2 Ordination

Canonical Correspondence Analysis (CANOCO software Version 3.1) was used to identify trends associated with the varying environmental factors and the sites and locations assessed. Canonical correspondence analysis is a simple method used to relate species to environmental variables if the relationships are assumed to be unimodal (ter Braak 1987).

Subsets of the data were analysed separately after initial analysis of the total data set. Filtering of data was undertaken following consideration of the graphic generation of trends for all sites and with further guidance from information supplied by the Twinspan dendrogram. Such 'filtering' was particularly focused on differentiating between natural or bio-physical factors and anthropogenic factors.

3.2.3 Biological Spectra

Biological spectra according to Raunkiaer's life form classification (Table 3) were compiled for zones I, II and III separately. Averages for all quadrats in each zone were expressed as a percentage of the total number of species in the community (Willis, 1973).

Table 3 Raunkiaers Lifeforms as defined by Willis (1973)

Life form	Abbreviation	Definition
Phanerophytes	Ph	Trees or shrubs with buds more than 25cm above soil surface
Chamaephytes	Ch	Perennating buds above soils surface to 25cm
Hemicryptophytes	H	Plants with perennating organ at soil surface
Geophytes	G	Perennating organ below soil surface
Hydro-helophytes	Hh	Water plants with perennating organ in water or mud below water surface
Therophytes	Th	Annuals
Stem succulents	S	Cacti (also epiphytes)

IV RESULTS & DISCUSSION

4.1 Classification (Two Way Indicator Species Analysis)

In order to determine the species composition of the identified zones at the selected localities, as well as whether any bio-physical and anthropogenic factors may be influencing the species composition of such zones, a TWINSPAN analysis was carried out.

The dendrogram (Fig. 4) and Table 4 constructed from the Twinspan analysis indicates that there is a definite distinction in species composition between sites in Zone I and Zone III, where all sites considered to be in Zone III were isolated to the right hand side of the dendrogram.

To the left hand side of the dendrogram 87.5% of the sites selected were zone I, while the balance (12.5%) were sites deemed to be within zone II. No sites from the zone III data were identified in the first dendrogram division.

When comparing the right hand side of the dendrogram, 14.2% of the sites in zone I were grouped with 45.2% of the group being zone II and the balance of the first dendrogram division, (40.6%) being zone III (all zone III sites).

While form is a visual indicator of zones, (Table 1) there is a clear difference in species composition between Zone I and III, while comparatively, Zones I and II and II and III have fewer differences . Zone II appears to be an intermediate, transitional distribution of both Zone I and Zone III species, where either Zone I species are prevalent due to extensive maritime influence or Zone III species are invading and possibly beginning to dominate in a zone I region, where the presence of Zone I species has led to the amelioration of maritime influences.

Such findings are supported by the research of Musila et al (2001) who, utilizing TWINSPAN analysis of vegetation from dunes near Malindi, Kenya concluded that "generally two major subdivisions of plant communities were identified according to the stability of the sand". They further note that between the two extremes in vegetation communities, an intermediate zone or mixed community may be noted on semi-stable dunes.

Further consideration of Table 4, below, indicates that there are a number of anomalies relating to species composition, (presence or absence) in relation to both environmental factors and anthropogenic impacts upon specific sites.

In considering some of the more dominant species, it is evident from Table 4 that the Gramineae specifically, *Sporobolus virginicus,* is common in 66% of all sites (Zones I, II and III) surveyed while the liane, *Cynanchum obtusifolium* is common in 63% of all sites (Zones I, II and III). These two species are the most common species within the sites investigated. However, it is evident that both these species are conspicuously absent from sites 2,3 and 10, which are high human impact sites in Zone I and may have been ousted by *Gazania rigens*. Ward (1980) has indicated that *S virginicus* is not shade tolerant and thus may be ousted by species such as *G. rigens* which are also salt spray tolerant, to a degree. When comparison with sites 4, 9, 11, 16 and 17 is made, the absence of *S. virginicus* and *C._obtusilfoium* is varied, where *S. virginicus* is present in sites 4 and 17 and *C. obtusifolium* is present in sites 4 and 9. *G. rigens* is however, absent from sites 4 and 16. *S. plumierei* may also be considered to be conspicuous within sites 2 and 10, this species was noted in both sites, as well as sites 4,5,16 and 31. In the case of sites 2,10 and 11, it could be suggested that some association between *S. plumieri* and *G. rigens* may be evident, although this is not supported by all sites. *S. plumieri* has been noted to be present in generally unstable sands where it is limited by the reduction in wind velocity. Wind velocity has been noted by Ward (1980) to be limiting in respect of propagule dispersal of *S. plumieri*, although lateral vegetative growth is also considered significant. Further to the above, Ward has suggested that in the Isipingo region of Kwa Zulu Natal, that *S. virginicus* also occurs with *S. plumieri* but implies that such occurrence is subseral, being established on dunes where cover of existing vegetation has occurred.

When consideration of Zone III species is made a number of species specific changes can be identified. It is notable that most Zone III sites show the presence of *Asystasia gangetica* (84 % of sites) and *C. obtusifolium* (68%). Ward (1980) noted the presence of *C obtusifolium*, together with the liane *Rhoicissus digitata* (recorded in 52% of zone III sites) in the Zone III synusia while *A. .gangetica* was suggested as being related to *Stenotaphrum secundatum* in open stable dunes, as part of a grassland succession. Such comments are supported in Zone III sites 45, 55 and 62, where together with high to moderately high human impact localities such as sites 13 (Zone I), 55 and 61 (Zone III), *A gangetica*, *S. secundatum* and *S. virginicus* are associes. Site 45, unlike sites 55 and 62 indicates the absence of *S. virginicus*, this absence may be a consequence of additional shade as a result of the presence of canopying species such as *Mimusops caffra*, *Ackokanthera oblongifolia* and *Ficus burtt*-davyi or competition with the Gramineae_*Stenotaphrum secundatum*. However, human impact may also be responsible for the loss of such species, where *S secundatum* is noted in many of the moderate to high human impact sites within Zone III.

Further to the above, it could be noted that within sites 55 and 62, *G. rigens* a species indicative of Zone I synusia, is present, possibly indicating some seral attenuation or reversal within these Zone III sites.

Within the Two Way Indicator Species Analysis, sites 43 and 58 were closely associated (Table 4). These two sites showed the presence of three closed canopy species, namely *Mimusops caffra*, *Brachylaena discolor* and *Chrysanthemoides monilifera*. These species are noted by Ward (1980) as forming associes within Zone III and are associated with the transition from 'scrub" to "forest proper".

Site 59, as in sites 43 and 58 also recorded the presence of *M. caffra* and *C. monilifera*, although *B. discolor* was absent. The presence of *Gloriosa superba*, in this site, a common liane in Zone III, is indicative of this synusia and is typically associated with the *M. caffra* and *C. monilifera* association. (Ward 1980). The absence of *G. superba* from any of the sites of high human impact may be indicative of the ousting of this species under the effect of increased human activity. The liane *R. digitata* is notable within many high and moderate impact sites, such as site 52, where *G. superba* does not show a presence.

Site 50, although not closely correlated in the dendrogram, does however show some commonalities with sites 43, 58 and 59. Species common to these four sites include *Asystasia gangetica* and *Chrysanthemoides monilifera*, although the woody species *M. caffra* is absent from this site. The absence of a canopy-forming species such as *M. caffra* may explain the presence of *A. gangetica*, as well as other field layer species, such as *Laportea peduncularis*, noted by Ward as being common to the Zone III synusia. Site 50 was noted to be closely associated with sites of low human impact. With further reference to Table 4, the correlation between sites 43, 58 and 59 and the selected environmental factors listed at the foot of the figure is undertaken. All sites show relatively higher distances between natural vegetation and developments, where such developments are often, but not always, developments that could be considered to be low in terms of human presence or factors such as hardpanning, often associated with residential complexes (i.e. the sites are open parkland or agricultural lands).

It can be suggested that the Two Way Indicator Species Analysis does provide evidence that human impacts such as pedestrian movement adjacent to the dune system or through the dune system, as well as the type of development, may play a role in altering seral routes through the ousting of species not generally tolerant of direct and indirect factors associated with human presence. Such responses within the various frontal dune synusia may include in Zone I, the ousting of Gramineae species such as *S virginicus* and replacement with species such as *G rigens*, while in Zone III the loss of canopy species such as *M caffra* through extensive disturbance may result in dominance by species common to Zone I and therefore reversal or attenuation of the seral route. Musila et al indicated in their research on dunes in Malindi, Kenya that any activity on the dunes that may increase sand instability, will greatly affect vegetation distribution (Musila et al 2001). As such, both the bearing of a particular dune and anthropogenic impacts may be seen to lead to sand instability. This suggestion is further tested utilizing biological spectral analysis and ordination.

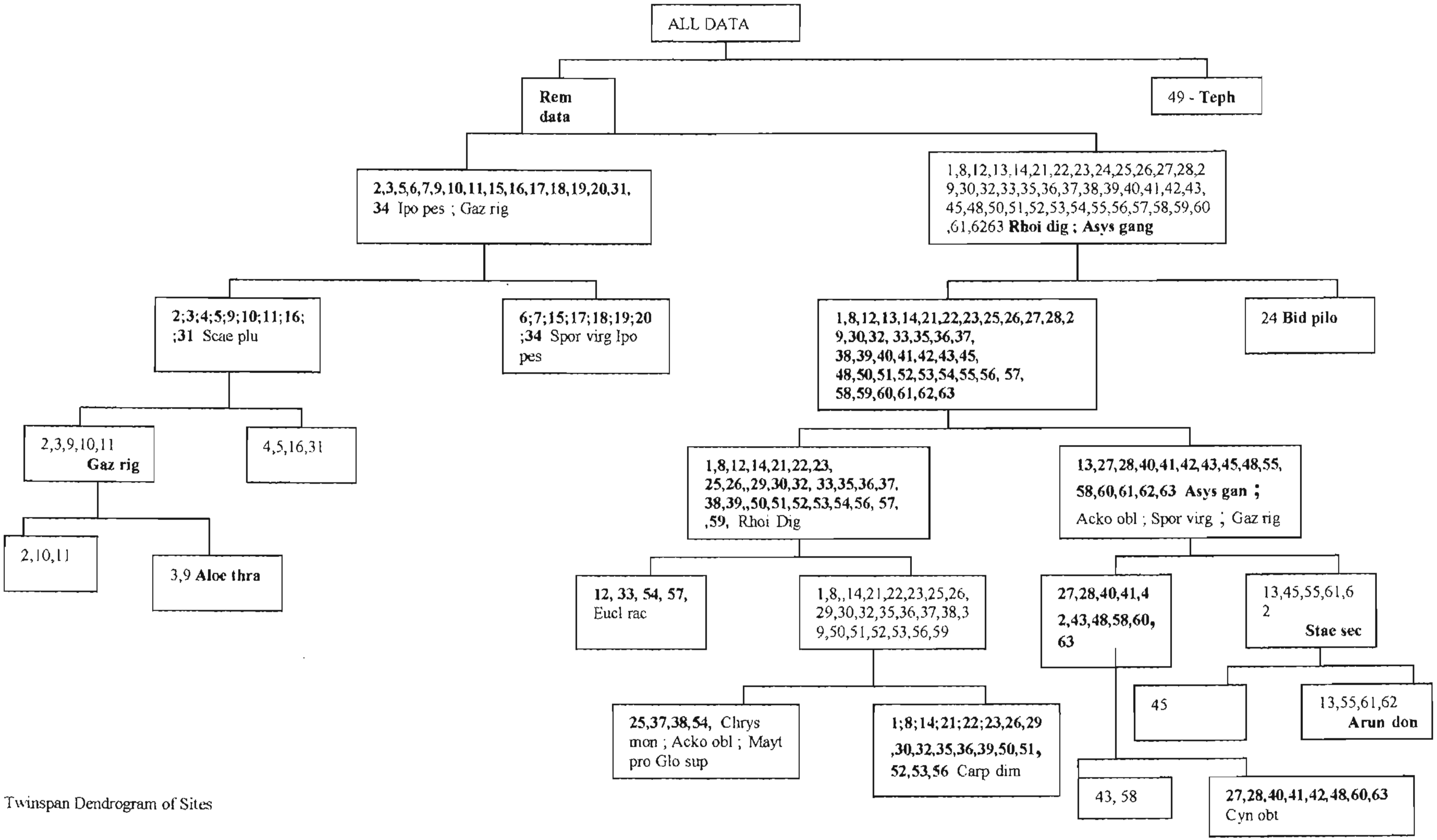

Fig 4 Twinspan Dendrogram of Sites

			11 13 112 1131355233512222233333555554522444466156642 4	
			201394561779065842347578918412369025690123638780128033512549	
32	Gaza	rig	43353-1---1-12-11-------------------------------23------113---	1111
48	Phyl	car	------1-2--------------------1------------------------------	111011
14	Cana	ros	---3------------------1-------------------------------------	111011
10	Barl	obt	-----3---------------1--------------------------------------	111011
51	Scae	ser	3---	111010
50	Scae	plu	344--2334-4------2-------2----------------------------------	111010
25	Cype	nat	3-------11--------1---------------------1--2-1--------1-----	11100
5	Aloe	thr	---243----------------1----------1-----------1------3------	11100
53	Spor	vir	-----32-1332442342 1-1111--1411-3113111-12-1--232211-23122---	110
37	ipom	pes	----1--136363-443-------------3-----------1----1-------2------	110
56	Teph	pur	------------------------------2---------------1--------11--6	10
46	Opun	spp	------3-------------3-------------1-3--2--------------------	10
16	Carp	dim	--431-1------3343---2--2-353543416453-334-41-54442---434----	10
49	Rhoi	dig	----4------------246142---3-311343443434534-1------11-----1-	01
45	Mimu	caf	-----242---------5--32314-----53--3-4--224133 2--2-111----2--	01
23	Cyna	obt	----111-1----112-111111-133131--11211221131--11232132--22---	01
1	Acko	obl	---------1---3-----------33-4-------------------3234-3434--2-2--	01
21	Comm	ere	--------------------1---------1--111----1---1---1---1-12-	00111
47	Oxal	cor	---11-	001101
43	Mari	mac	--1-	001101
41	Lyco	esc	--3-	001101
38	Ipom	pur	--3-	001101
24	Cyno	dac	-------------------------------------1----1-----------3-2-5-	001101
15	Card	gra	--3-	001101
12	Bide	pil	--1-	001101
35	Hydr	bon	--1----1--21-	001100
54	Stae	sec	----------------1-------------------------------------443341-	00101
60	Cype	div	--2-------	001001
58	Phra	com	--1-------	001001
57	Vign	ung	---1--	001001
55	Stre	nic	---1------1--1-----1--	001001
42	Maer	edu	------------------------------1--------------11---1---------	001001
36	Indi	suf	---2--	001001
26	Drac	hoo	---------------------1------------------------------1----1--	001001
19	Chro	odo	---2--	001001
18	Cent	asi	---1--	001001
13	Boug	spp	----------------------------------1-----------------2-------	001001
11	Brac	h di	-------------------------------1----------252---2---2-1--1--	001001
9	Asys	gan	---------1----------1--1-----3---1-21122111 3-23--44443132 1--	001001
7	Arun	don	---1--	001001
4	Aloe	bai	--1--1--	001001
44	Mayt	pro	---------------------21-1-------------------3----2----------	001000
40	Lapo	ped	--------------------------------------13-12----------132----	001000
30	Ficu	bur	---------------------1-----------------------------------1--	001000
3	Agav	spp	------------------------------------1-----1-----------3-----	001000
59	Pasp	not	--------------------------------------3-----------------1---	0001
22	Carr	mac	-----------------------3-----------3------1----1------------	0001
20	Chry	mon	--------------------13554-3--2--4---314---231-1------------2---	0001
52	Sene	tam	--------------------4---------------------------------------	00001
27	Eucl	ras	-----------------3432---------------------------------------	00001
17	Cass	equ	-------------------32---------------------------------------	00001
33	Glor	sup	----------------------111-11--------1-----------------------	000001
29	Euge	cap	----------------------1123---4--11--------------------------	000001
39	Lamt	cam	---1------------------	000000
34	Meli	dec	--------------------------------1---------------------------	000000
31	Flag	gui	--------------------------------1---------------------------	000000
28	Eucl	nat	---------------------1-----------33-------2-----------------	000000
8	Aspa	fal	--1-------------------	000000
6	Arct	pop	--------------------------1-----2----3----------------------	000000
2	Adyr	asp	------------------1-------1-----2-----11-1------------------	000000
			000000000000000000000000000000000000000000000000000000000001	
			00000000000000000111111111111111111111111111111111111111111	
			000000000111111110000000000000000000000000000000000000000001	
			0000011110000111100000000000000000000000000011111111111111	
			00011 0000111111111111111111111110000000000111111	
			00001111111111111111111100111111110000 1	
Bearing			122222222333233222223333132212332222332221333332232222321 13	
Human Activity			hhmlmlmlhmlmmmmmmmmmmmmmh111lmmml11mmmmmmmmmmmhmml1mmmmmmmmmmmmmmmmhhm	
Nat veg - deve			211225881181111111111 88831113 111111111113811111111111122 1	
Type of deve			rrarrrorrrorrarrcrrrrrooo arrcarrrarrrrrrar aoarrrcarcccrrrrrr	
Zone			111111112111111121233222311112222222222333333322222333133332 3	

Key

Bearing 1 = 315° - 45° ; 2 = 46° - 125° ; 3 = 126° - 325°

Human Activity H = high M = Moderate L = Low

Edge of Nat Veg – Development 1= 0-10, 2 = 11-20; 3 = 21-30 ; 4 = 31-40 ; 5 = 41 –50 ; 6 = 51 – 60 ; 7 =61 – 70 8 =/>71m

Type of Development r = residential c = complex or higher density residential ; a = undeveloped, agriculture or park ; o = other (eg road).

TABLE 4

4.2 Ordination

A direct ordination, Detrended Correspondence Analysis (DCA) of the sites in each zone at each location / site, using the complete data set was undertaken (Figs. 5, 6 and 7) highlighting specific environmental factors for each site.

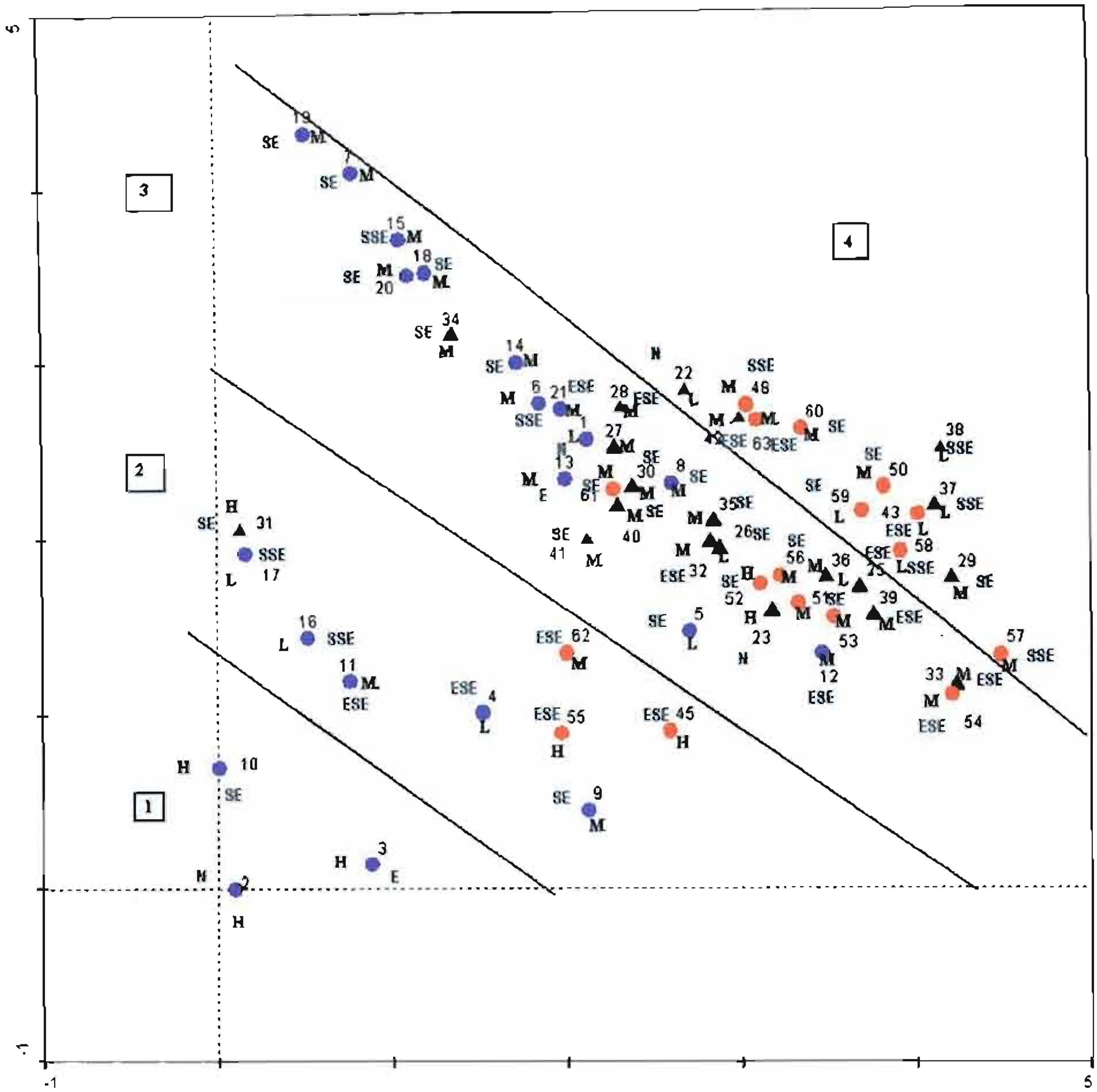

Fig. 5 Detrended Correspondence Analysis of all sites indicating the level of human impact associated with each site. ● = Zone I ; ▲= Zone II ; ● = Zone III H = High Human Impact M = Moderate Human Impact L = Low Human Impact. Bearings N = North ; SE = South East ; ESE = East South East; SSE = South South East.

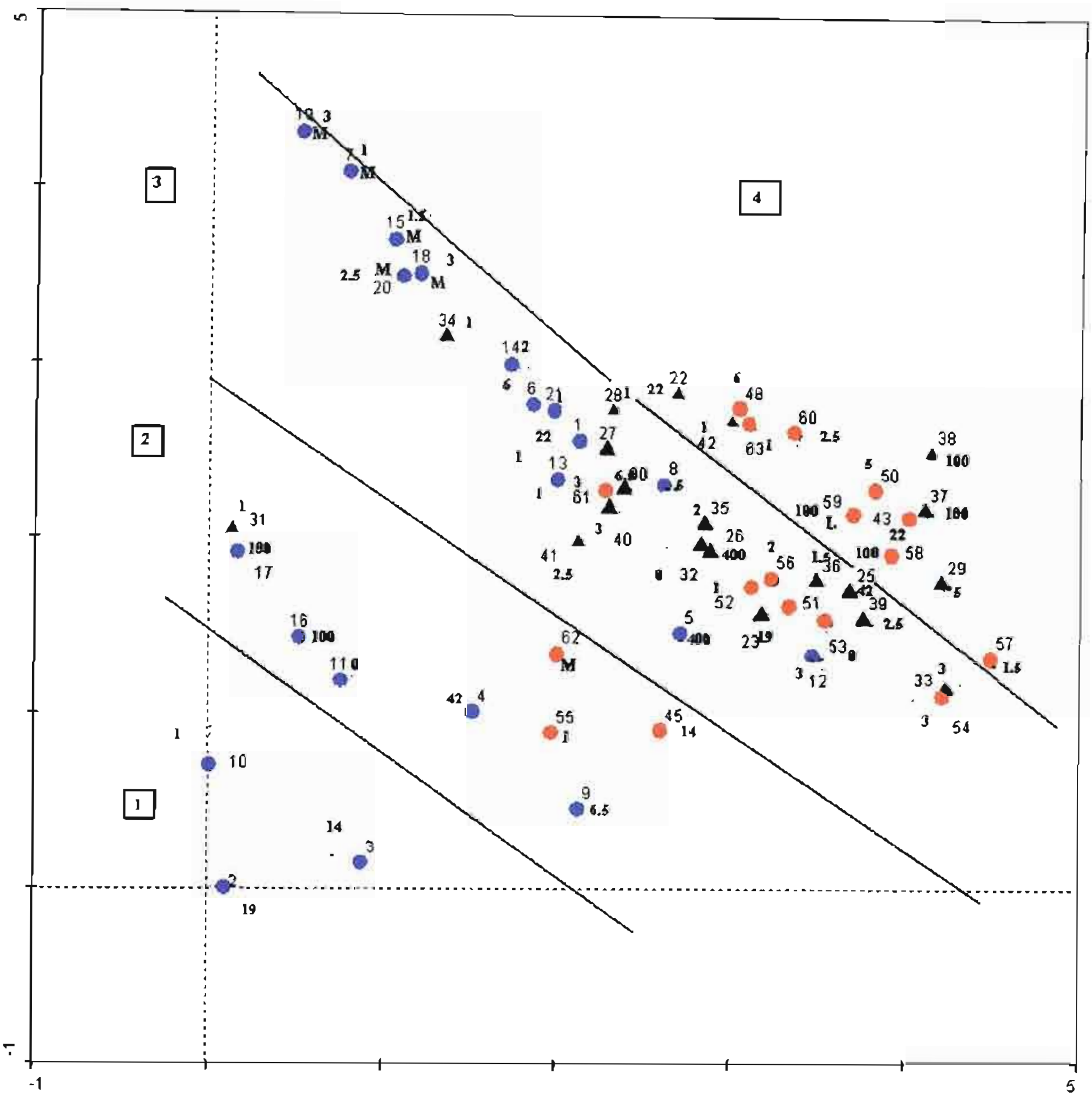

Fig. 6 Detrended Correspondence Analysis of all sites indicating distance between the developed areas and commencement of "edge of natural vegetation" (value in metres) associated with each site. ● = Zone 1 ; ▲= Zone II ; ● = Zone III .

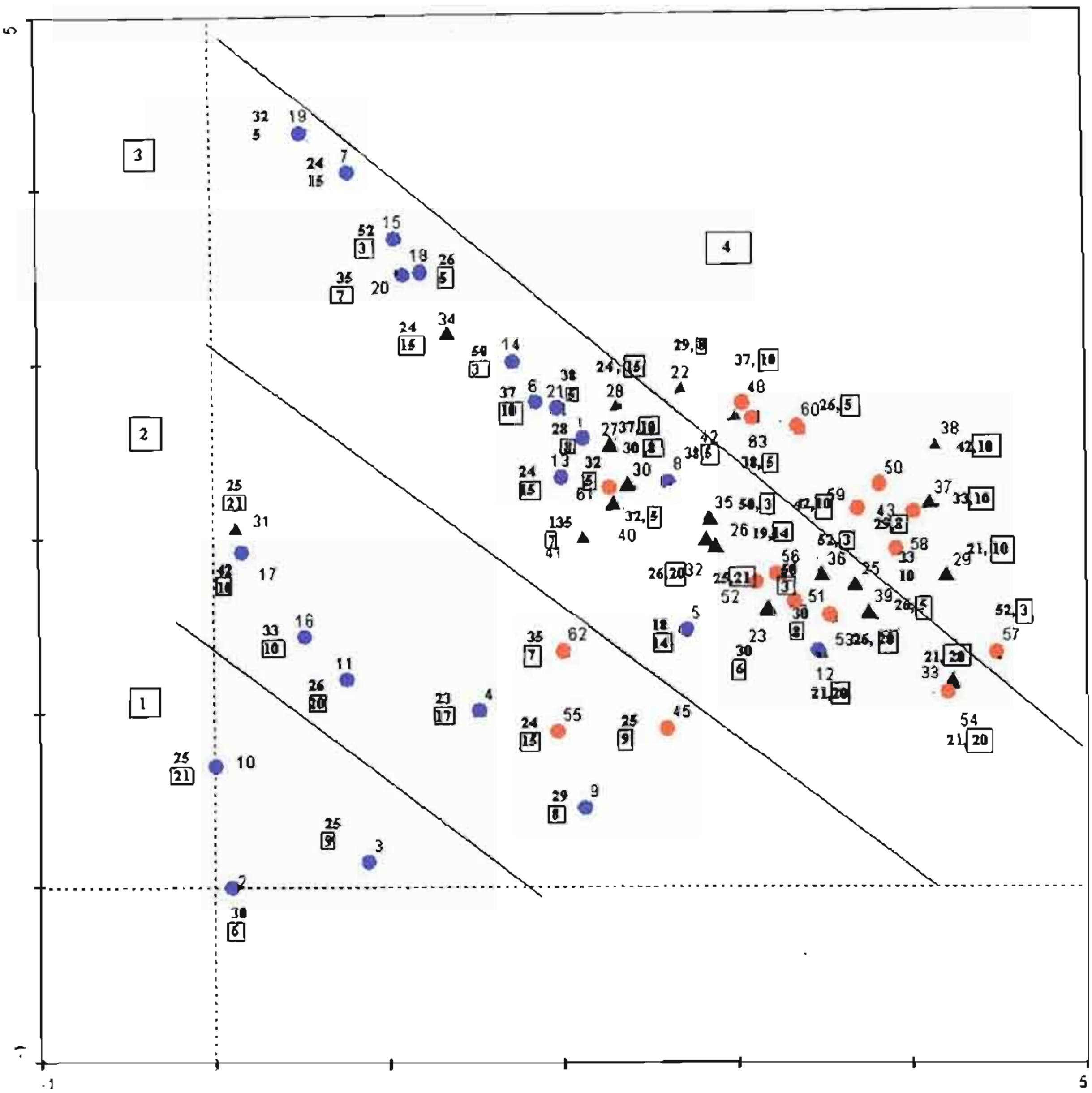

Fig. 7 Detrended Correspondence Analysis of all sites indicating the length of beach face (value in metres) and slope of beach [in box] , (value in degrees) ● = Zone 1 ; ▲= Zone II ; ● = Zone III .

The arrangement of sites in the ordination diagram fell into four distinct groups labeled 1,2, 3 and 4 (Figs 5, 6 and 7). When each site was labeled using different symbols for each of the three zones the four groups are seen to be made up of 3 Zone I sites (group 1), 5 Zone I, 1 Zone II and 3 Zone III sites (group 2), 13 Zone I, 14 Zone II and 6 Zone III sites (group 3) and 5 Zone II and 8 Zone III sites (group 4)

Careful examination of the ordination diagram indicates that for each Zone the distribution of sites is split into 3 distinct sets. (This is clearly seen for Zone I sites in groups 1, 2 and 3). Sites in each set or group are arranged in a more or less linear sequence along a gradient joining equal values on the two ordination axes.

When each site is labeled with the environmental factors mentioned in the Methods (Figs. 5,6 and 7), a detectable pattern of sites with different intensity of impact by humans (anthropogenic impacts) is observed. The pattern observed in the distribution of sites related to different levels of the other variables however is weak.

The intensity of impact by humans appears to be responsible for the 3 groupings for each of the Zones. The 3 sites in group 1 are all high Human Impact, Zone I sites. The linear arrangement of the sites between the two axes appears to be related to bearing or aspect, with the SE oriented site closest to ordination axis 2 and the northerly oriented site closest to axis 1.

The sites in group 2 are either Zone I sites with low to moderate impact, 1 Zone II site with high impact and 3 Zone III sites with high impact. The inclusion of the 1 Zone II and the 4 Zone III sites with high impact in this Zone I swarm with low to moderate impact, indicates that the effect of high human impact on Zone II and III species is to revert the mix to a similar composition to the Zone I sites with low impact. The linear arrangement of sites between the two axes appears to again be weakly related to aspect with SSE oriented sites close to axis 2 and ESE sites closer to axis 1. The Slope of the Beach Face and the Length of the Beach (Fig. 7), are weakly related to bearing in that the prevailing SW, SSW and S winds result in shorter, steeper beaches with a steep beach face on SSE and SE facing slopes. However, factors other than bearing such as the Distance of Natural Vegetation from Development (Fig. 6), appear to also have influence, resulting in a loose relationship with any one factor in the ordination diagram.

Group 3 also shows a clear effect of Human Impact. Most of the Zone II sites with moderate to high impact in this group are included in the lower tail of the swarm of Zone I sites with moderate impact. The 6 Zone III sites with moderate to high impact are also included in this tail. As before, the inclusion of the high to moderate impact Zone II and III sites in the Zone I moderate impact swarm indicates that the species composition has reverted from the low impact Zones II and III species mix, to a mix similar to that found in Zone I under moderate impact. Again, the linear arrangement of sites between the two axes appears to be weakly related to aspect with a weak gradient from more southerly to more easterly and northerly sites.

Group 4 sites are those Zone II and Zone III sites with low to moderate impact. A noticeable grade from left to right in this group is attributed to bearing (North to SSE) but with a prevalence of low to moderate human impact zones. No high human impact zones were noted within this group, although all low human impact Zone III sites fall within Group 4. The distance of the development from the edge of natural vegetation is also significant (Fig 8) amongst the swarm to the right of Group 4.

In order to determine the effects of the other environmental variables more precisely, a Canonical Correspondence Analysis (CCA) was carried out. In the first analysis anthropogenic influences were excluded to examine the effects of the measured abiotic variables only.

Fig. 8 indicates that bearing influences species composition across all zones. The weak relationship between aspect, the Length of the Beach Face (wider beaches on southerly aspects) and the Slope (flatter beaches on more southerly aspects) is also illustrated in the ordination diagram. These are the variables associated with the main gradient in the data. Dune Slope separates out the Zone I, II and III sites. This is because the slope is flatter on dune crests (Zone III) and steeper at the foot of the slope (Zone I).

Sites 1, 22, 43 and 2, 23 in the upper portion of the graph lie between 326° and 5° on a *north facing* aspect, while sites 18, 39, 60 and 15, 36 , 57 and 19, 40, 61 and 18, 39, 60 located in the lower portion of the plot lie between 121° and 131° degrees and have a *south-easterly facing aspect*. Sites 2, 23 and 1, 22, 43 have northerly aspects, with steeper beaches. Sites 11, 32, 53; 12, 33, 54 and 3, 45 have easterly aspects on moderately steep and wide beaches. The rest of the sites are arranged from ESE through SE to SSE aspects with increasingly wider and flatter beaches.

Bearing clearly has a major influence on species composition within the sites. Bearing, dune slope and beach slope are related, as the angle at which wind strikes the land (coast), as well as the strength of the wind have a direct influence on dune topography. Bird (2000) notes that where prevailing winds strike the shore at right angles, dunes are steep , while those striking the shore in an oblique manner give rise to gentle slopes, yet longer dunes. (Bird, 2000). Lubke (1983) reported that sand movement as a result of the changes in wind direction, together with other variables, makes the establishment of plants on dunes in the Port Alfred area, very sporadic, indicating the significance of the direction from which coastal prevailing winds meet the coastline.

The distance of the specific Zones from the seaward edge of vegetation is also apparent, where Zone III and some Zone II sites are located to the right of the figure, while Zone I sites are located to the left. Notable anomalies in Fig. 8 are identified in site 43, 45 and site 62, where distinct "shifts" by these Zone III sites to the left of the figure are indicated. Similar "shifts" to the right of the diagram are noted in Zone I sites16 and 17, where low human impacts have been identified.

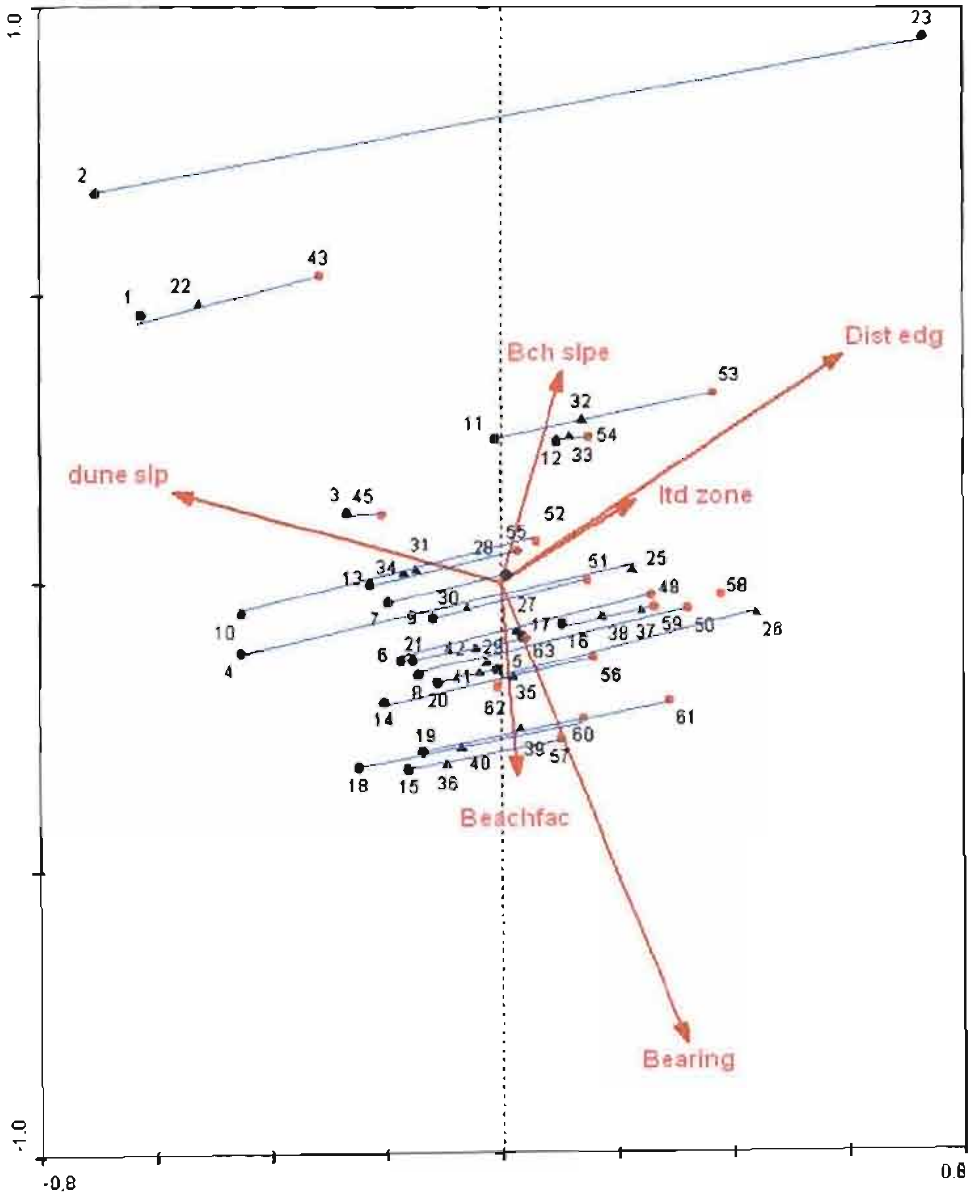

Fig. 8 Ordination biplot of sites and environmental variables produced from a Canonical Correspondence Analysis of species abundance and environmental factors. Dist edg – distance of site from seaward edge of vegetation ;Dune slp – slope of dune, Itd zone – type of intertidal zone prevalent on site, Bch slpe – slope of beach Beachfac - beachface. Connected sites are the quadrats in the three zones at one locality. Sites 1 -21 are Zone I, Sites 22 – 43 are Zone II and 44 – 65 are Zone III.

To determine what effect anthropogenic factors had on species composition a further Canonical Correspondence Analysis was undertaken that included, human activity, the distance of the development from natural dune vegetation and type of change associated with the site (Fig. 9).

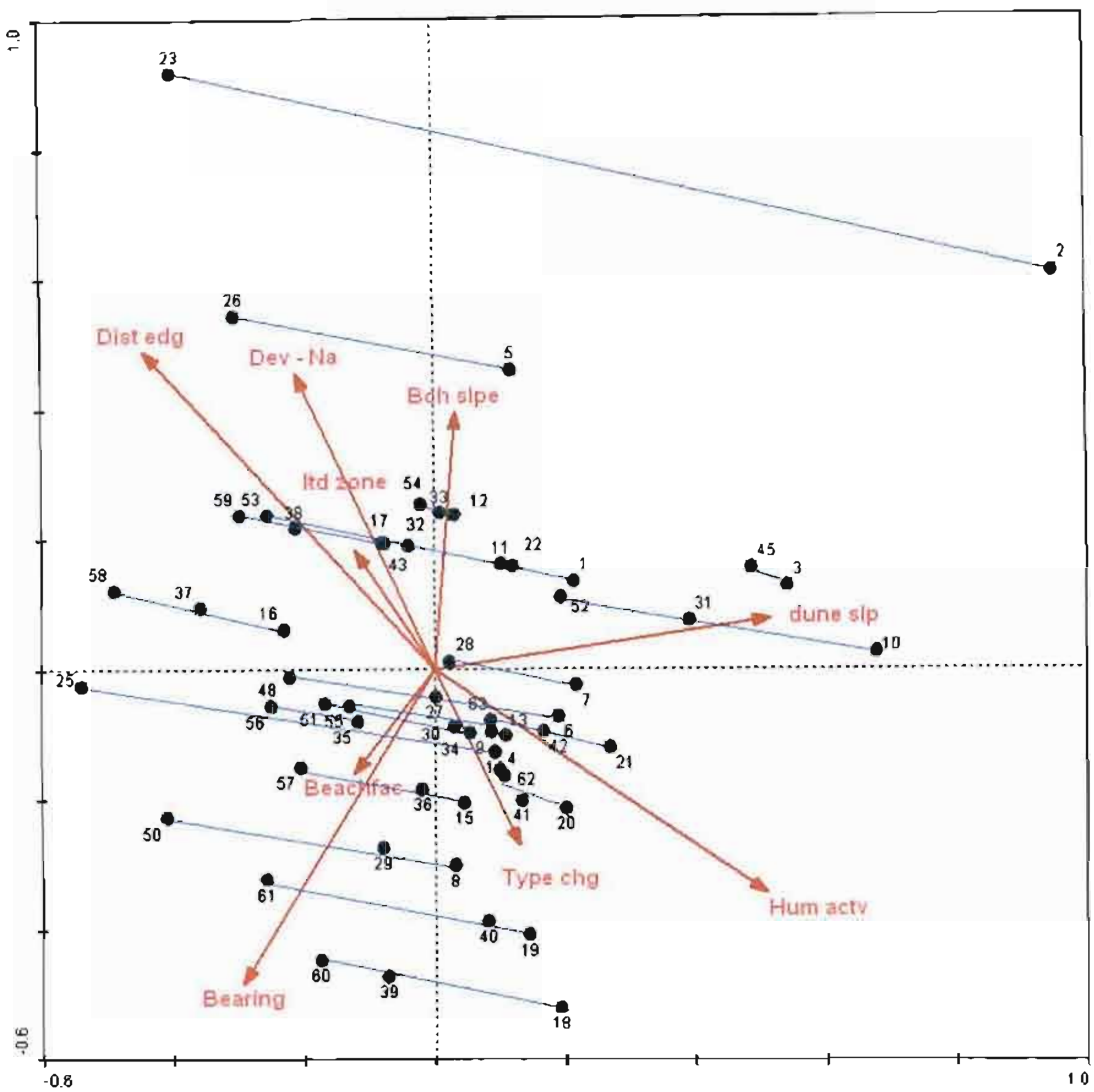

Fig 9 Ordination biplot of sites and environmental variables with abiotic and anthropogenic factors included, produced from a Canonical Correspondence Analysis of species abundance and environmental factors. Dist edg – distance of site from seaward edge of vegetation ;Dune slp – slope of dune, Itd zone – type of intertidal zone prevalent on site, Bch slpe – slope of beach Dev – Na – Distance of development from natural vegetation, Type chg – type of land use identified, Hum actv – Human Activity. Connected sites are the quadrats in the three zones at one locality. Sites 1 -21 are Zone I, Sites 22 – 43 are Zone II and 44 – 65 are Zone III.

When anthropogenic factors were included in the analysis, the influence of bearing was still apparent, but the significant anthropogenic influences on species composition is apparent (Fig.9).

The effect of repositioning of high impact Zone II and Zone III sites in the Zone I and Zone II swarm observed in the DCA is observed again in the CCA. High Impact Zone III sites 52, 45, 62, (Zone III), 31, 42 and 40 (Zone II) as well as Zone I sites, 3, 10 and 21 have been positioned more to the right of the ordination diagram, amongst the Zone II swarm. Subsequently, these Zone III sites are associated with Zone II sites and Zone II sites are associated with Zone I. Zone I sites 2, 3, 10 and 18 are positioned well to the right of the figure, distinctly separated from the swarm of Zone I sites.

Sites 3, 24 and 45, situated at Thompson's Bay which displays an easterly aspect, is one of the most visited beaches in Kwa Zulu – Natal (Kwa Dukuza Coastal Zone Recreational Use Plan Nov 2002), while also being subject to infrastructural development as far back as the early 1900s. Tiffany's Beach (sites 2, 23 and 44), is a long beach of some 1.5 km to 2 km and is subject to an influx of tourists emanating from nearby hotels and accommodation facilities, as well as residential developments. Tiffany's Beach exhibits a northerly bearing.

Fig. 9 indicates that when human impacts are high, differences between sites in the same zone and with the same aspect are accentuated. Zone III sites on southerly aspects when subjected to high human impact revert to a composition similar to Zone II or Zone I sites with a more easterly to northerly aspect.

The overall results of the canonical correspondence analysis and detrended correspondence analysis indicated that sites of low human activity, namely sites 43, 50, 58 and 59 differed significantly in terms of species composition from sites 45, 55 and 62.

4.3 Biological Spectra

In ascertaining the influences of both physical and anthropogenic factors on the data, the development of biological spectra for each of the zones was undertaken. The spectra indicated herein were developed using an average for all species within each zone expressed as a percentage.

The spectra for Zones I, II and III are depicted in Table 5.

Table 5 indicates that hemicryptophytes made up the majority of all species in Zone I. The hemicryptophytes were most commonly represented by such species as *Scaevola plumieri* and *Phylohydrax carnosa*, typically those species with their perennating bud placed close to ground level or under certain circumstances often covered by sand. Therophytes also proved to be common within Zone I, more particularly *Sporobolus virginicus*.

The Zone II spectrum showed that hemicryptophytes were still dominant in Zone II, however, some shift towards increased prevalence of chameophtyes indicates invasion by "woody" specimens such as *Chrysanthemoides monilifera*. Therophytes were still apparent, however, possibly due to competition with other lifeforms, through shading and other influences, their prevalence declines in comparison to Zone I.

Within the Zone III spectrum, therophytes are considered to be low in presence, while hemicryptophytes, chameophytes and phanerophytes are dominant. Thus the canopy effect of vegetation becomes apparent, where hemicryptophytes, are ousted and the amelioration of maritime influences allows for more robust vegetation to develop.

If the above spectra are considered to be generally reflective of life-form structures within each of the zones, it is evident that where anomalies occur within sites not generally conforming with such spectra, that some or other factor may be acting upon the identified site leading to a variation in the spectrum.

From the spectra analysis it is to be noted that high human impact locations, including sites 2,3 and 10 show dominance by hemicryptophytes, while low human impact locations at sites 4, 9, 11, 16 and 17 show mixed life-form representation.

However, it is notable that sites 4 and 11 show 3 lifeforms (phaneropthytes, hemicryptophytes and therophytes). In addition, it should be noted that sites 4,9 and 11 differ by up to 20 from sites 16 and 17, in terms of bearing, where sites 16 and 17, although positioned distally from any developments and considered to have low human impacts, have only two lifeforms represented (28%).

In the spectral analysis for Zone III, it is evident that the sites of low human impact, such as sites 43, 50, 58 and 59 generally show a higher presence or coverage by phanerophytes, (e.g. 57% in sites 58 and 59) compared to lower coverage in sites 45, 55 and 62 (62 = 10%, 45 = 33%). Interestingly, low human activity site 50 showed no phanerophyte presence although chamephytes are common.

The results from the spectral analysis ostensibly support the Two Way Indicator Species Analysis findings that human activity serves, in association with bearing, to impact upon the seral routing of various sites often leading to a reversion or attenuation of seral processes on frontal dune systems. It is suggested that the loss of phanerophytes or chamephytes, often providing shading from both wind and allowing for the establishment of subcanopy species, may open areas to further maritime influences generally associated with Zone I synusia. This observation is supported by Donnelly and Pammenter (1983) in their work n dune vegetation zones in Beachwood, Durban. Furthermore, the mix of Zone I, II and III species is expected, in terms of what is known about dune succession. The prevalence of Zone I synusia within an area such as that associated with, or expected to be a Zone II habitat (such as sites 8, 5 and 12) may indicate differences in the abiotic conditions at different sites, or alternatively that continuous impacts are being experienced within a particular area and that *changes* may have commenced with the establishment of the structures adjacent to the site (i.e. construction of buildings), as well as possible continuous anthropogenic impacts emanating from the buildings such as pedestrian movement onto and off the adjacent beach.

Zone 1\Site	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	Average
Phanerophytes	25		25	33	12.5	20	20		17			33				33						10.4
Chamaerophytes									15												20	1.7
Hemicryptophytes	75	75	50	50	62.5	60	40	51	68	100	100	33	60	75	75	66	75	80	50	66	60	65.3
Geophytes		25	25		12.5		20	34				16										6.3
Therophytes				17	12.5	20	20	17				17	40	25	25		25	20	50	33	20	16.3
Zone 2\Site	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	
Phanerophytes	12.5	28.6		45.5	33.3	12.5	12.5		28.6		14.3	16.6		20	20	33.3	22.2	10	12.5	25	25	17.7
Chamaerophytes	25	28.6	36.4	18.2	22.2	25	25	22.2		16.6	28.6				10	11.1	22.2	20	37.5	12.5	12.5	17.8
Hemicryptophytes	37.5	28.5	36.4	18.2	33.3	37.5	50	66.6	57.1	66.6	42.9	66.6	60	60	60	44.4	44.4	40	37.5	37.5	50	46.4
Geophytes	12.5	14.3	9.1	9.1		12.5								10								3.2
Therophyles	12.5		18.2	9.1	11.1	12.5	12.5	11.1	14.3	16.6	14.3	16.6	40	20	10	11.1	11.1	20	12.5	25	12.5	14.8
Zone 3\Site	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	
Phanerophytes	40		33.3			28.6	50		20	12.5	12.5	33.3	24.9	18.2	25	57.1	57.1	24.9	11.1	10	37.5	23.6
Chamaerophytes	20		20			28.6	50	28.6		12.5	37.5			9.1	8.3	28.6	14.2	16.6	11.1	10	12.5	14.6
Hemicryptophytes	40		20			28.6		71.5	60	62.5	50	66.6	33.2	45.5	49.8	14.2	28.6	50	55.5	40	37.5	35.9
Geophytes			13.2			14.3			10				16.6	9.1	8.3							3.4
Therophytes			13.2						10	12.5			24.9	18.2	8.3			8.3	22.2	40	12.5	8.1
Bearing	5	126	87	118	124	142	130	131	120	124	115	115	106	123	143	141	150	121	127	120	108	
beachface (m)	29	29.5	25	23	19	37	24	20.3	29.1	25	26	21	24	50	52	33	42	26	32	35	38	
beach slope	8	8	9	17	14	10	15	10	8	21	20	20	15	3	3	10	10	5	5	7	5	
Intertidal zone	rshel	r/shel	sand	r/shel	r/shel	sand	sand	sand	sand	rock	sand	sand	r/shel	r/shel	rocks	sand	sand	rock	rock	r/shel	rocks	
Sand type	mod	mod	mod	mod	crse	mod	mod	mod	mod	mod	mod	mod	mod	mod	mod	mod	crse	mod	mod	mod	mod	
Human activity	L	H	H	L	L	M	M	M	M	H	M	M	M	M	M	L	L	H	H	H	M	
Nat veg - develop	22	18.9	14	42	400	6	1	5	6.5	1	0	3	1	2	1.5	100	100	2.5	3	2.5	1	

Table 5 Biological Spectra for Zones I, II and III

4.4 Compatibility with the Intermediate Disturbance Hypothesis

In concluding the assessment of the species data collated, such data was tested for compatibility with the Intermediate Disturbance Hypothesis (IDH) (Connell 1984). The Intermediate Disturbance Hypothesis states that species diversity will be highest at sites that have had an intermediate level and frequency of disturbance and will be lower at sites that have been subject to low or high level frequencies of disturbance (Schwilk et al 1997).

The number of species within Zone I, II and III from each site were counted. Each locality was identified as a low, moderate or high human impact site. The average number of species for each grade of human impact was computed. Low human impact sites recorded an average of 17.8 species per site, moderate human impact sites recorded an average of 18.6 species per site and high human impact sites recorded an average of 16.3 species per site. The results are thus seen to be compatible with the Intermediate Disturbance Hypothesis, however the variation between the various localities is possibly too small for any conclusion to be drawn.

4.5 Visual Appraisal of Sites.

A visual review of some of the sites considered to be of low human impact and those considered to have high or moderately high human impacts, as well as the zonal vegetation associated with such sites is provided below.

Sites of low anthropogenic influences include Zimbali South, Zimbali Lodge and Christmas Bay. (sites 4, 11, 16 and 17) Fig. 10, below indicates clearly the typical nature of Zimbali lodge, where development has been kept distally from the beach and frontal dune system, while human activity on the beach is generally low.

Fig. 10 Zimbali Lodge – 2003. Locality where low anthropogenic impacts are noted due to distance and limited human activity on beach.

In Fig. 10 at least three zones are evident with the low level of human impact upon the beach as well as the distance of built structures from the frontal dune vegetation.

Comparison with Thompson's Bay (sites 3, 24 and 45) and the extensive encroachment by developments onto the dune system as well as the high human activity on the beach may be considered to support the findings provided above, where human intrusion onto the beach, as well as the proximity of built structures to the frontal dune vegetation is evident.

Fig. 11. 2003 Thompson's Bay, where high anthropogenic impacts are noted both due to proximity of developments to beach and high human activity on beach.

A number of locations and sites may be influenced by factors not identified in this investigation. A case in point is at Catfish and Tiffany Beach (sites 6, 7, 8, 13, 27, 28, 29 49, 50, 51) where it is suggested that impacts arising from sources such as septic tanks may influence the composition of the various vegetative zones of the frontal dune system.

Boorman has suggested that the "raising of overall nutrient levels led to a decrease in species diversity with those species best able to respond to the higher nutrient levels becoming dominant" (Boorman 1975). The sites, for sites 12, 33, 54 for example is a site adjacent to single residential dwellings, where septic tanks are utilized, possibly providing additional nutrient levels to the vegetation of these sites. Lubke (1983) noted that the zonation of plants along transects in the Port Alfred areas can be explained in terms of the slight differences in soils conditions and climatic factors.

V. CONCLUSIONS

The above results allow for a number of possible conclusions to be drawn regarding vegetation zones and the impact of bio-physical and anthropogenic activities on dune plant communities. These conclusions can be summarized as follows. :

1 Species composition is different in the three zones sampled.

2 Some species occur in all three zones and others are confined to one zone only.

3 Bearing and the associated influence of wind, the slope and length of the beach, and the steepness of the dune face all influence the species composition at any particular site.

4 The influence of anthropogenic activities on dune synusia is such that human influence on one species may disrupt associations between species and may result in attenuation or reversal of seral movement.

5 Anthropogenic impacts influence species composition at different sites by causing some species to decline or disappear from a site and others to invade or oust established species. In Zone I the species that appear to be most affected by human

activity is *Gazania rigens*, which appears to dominate in sites of high human activity, at the expense of *Sporobolus virginicus*. In Zone II under high human activity species such as *Cynanchum obtusifolium*, *Rhoicissus digitata* and *Sporobolus virginicus* dominate, while the woody species *Mimusops caffra* and *Eugenia capensis*, as well as the liane *Gloriosa superba* appear to decline or be ousted from this Zone. In Zone III, *Asystasia gangetica*, is a dominant species where low to moderate human impacts are encountered, while where human impacts are high, species common to Zone I, such as *G. rigens* may become prevalent, ousting *A. gangetica* and grasses such as *S. virginicus* may be ousted by more competitive species such as *Stenotaphrum secundatum*.

It is thus concluded that human activities in and around the frontal dune system may be influential in re-inforcing aeolian impacts on sites with bearings affected by strong prevailing winds. As wind and sand movement are considered the primary factors associated with the establishment of vegetation zones (Lubke 1983 ; Donnelly and Pammenter 1983) high levels of human activity on beaches may influence sand movement. In light of this, coastal management policy and practices should take note of bearing and vegetation zones on frontal dune systems when considering developments that intrude into this dynamic area.

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