COASTAL DUNE DYNAMICS AND MANAGEMENT AT THE BUSHMAN'S RIVER MOUTH, KENTON-ON-SEA

CLAIRE FRASER

COASTAL DUNE DYNAMICS AND MANAGEMENT AT THE BUSHMAN'S RIVER MOUTH, KENTON-ON-SEA

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Claire Fraser

Department of Botany

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ABSTRACT

A study of the dynamics and functions of a coastal dunefield at the Bushman's River Mouth in Kenton-on-Sea was conducted to provide essential information for the formulation of a management strategy based on an ecosystem approach. Bi-monthly tacheometric surveys were undertaken at the Westbourne Road Car Park dunefield to investigate the sedimentological processes. Changes in the topography, the amount and rate of sand accretion were monitored. Accretion and progradation were the dominant long-term sedimentological processes at the site. Long-term spatial variation in these processes corresponded to the temporal pattern of sedimentation in the river mouth while short-term variation resulted from dynamics inherent to the types of dunes present. Factors affecting aeolian accretion at the site are topography, river mouth configuration, dune types and the presence of vegetation as well as the seasonal wind regime. A vegetation study, recording species present, cover and abundance of the plants along the surveyed transects, was also conducted to examine the progressive establishment of vegetation. Five plant communities were discerned namely, saltmarsh, pioneer, enriched pioneer, open scrub, closed scrub and scrub-thicket communities. The spatial distribution of these communities coincided with the north-westerly development of the sandbank. A successional trend in community change occurred along a gradient of increasing diversity, complexity and age. Initially, autogenic changes wrought by pioneer species facilitated the recruitment and survival of other species and commenced succession at the study site. Multiple successional pathways were discussed in relation to subsequent species establishment that occurred after facilitation. The amalgamation of ecological data with a social study in the form of public perception surveys allowed for a greater understanding of the present interactions between the ecosystem and the demands placed on it. The area primarily functions as a recreational site that offered numerous beach and water-related activities. A lack of information regarding the ecology and management programmes influenced public perception of the environment and management issues in general. Different management perspectives and the use of the information presented in this study were also discussed.

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CHAPTER 1
INTRODUCTION

South Africa boasts 3000km of coastline that is home to over six million people and approximately 500 species of wildlife (Heinecken & Malan 1994). Approximately 80 % of this coastline is comprised of sandy beaches and their associated coastal dunes (Tinley 1985). Coastal dunes are ecotonal habitats that facilitate the interaction of seaward beaches and a variety of landward terrestrial communities (McLachlan *et al*. 1996). As an interface between the terrestrial and marine environments, coastal dunes are unique and attractive areas for human activities. The value of the dune environment does not end with aesthetic appeal though, they are multifunctional systems and their importance stems from a variety of uses such as water and mineral extraction, paleo-environment information, conservation, education, research, recreation, residential and subsistence functions (Tinley 1985; Avis 1992; Coetzee 1994; Deacon 1994).

The most prominent feature of coastal dune systems is the persistence of formative processes resulting in a dynamic state of existence. Beaches and foredunes are constantly adjusting toward a state of equilibrium in response to ever-changing regimes of waves, winds and tides and are thus in a constant state of flux (Tinley 1985). This inherent dynamic results in dunes being highly sensitive to a wide array of impacts both natural and human. The need to manage coastal dune systems becomes apparent when considering the wide utilisation and sensitive dynamics of the dune environment (La Cock & Burkinshaw 1996). Attempting to manage these systems therefore requires the characteristics, both ecological and physical to be considered to allow effective and feasible management strategies to be implemented (Wanders 1989; Avis 1992). Often conflict arises as to the best management approach especially where dunes have overlapping functions such as recreation and conservation as is the case at Bushman's River Mouth.

The Bushman's River Mouth is a popular residential area and holiday destination at the heart of Kenton-on-Sea. During the past fifty years, a number of changes occurred that prompted concern regarding the future of river mouth in terms of its aesthetic, recreational and ecological value to Kenton-on-Sea.

Changes included the migration of the main watercourse from the eastern to the western bank and the subsequent silting up of the eastern channel of the river. The development of a sandbank along the eastern channel led to the formation of a series of vegetated ridges and hummocks. This was possible through the stabilisation of the sandbank by vegetation. In addition to the development of a dunefield along the bank, the stabilisation of a headland bypass dune system also occurred. Speculation regarding the cause of these changes is far reaching and encompasses everything from the construction of farm dams and a causeway upriver, to the stabilisation of sand surrounding a water extraction plant, to changes in the wind regime. It is more likely that the changes evident in the river mouth are a result of a combination of these factors.

The need to formulate a management strategy for the area is apparent when considering the long-term changes at the study site and the effect they exert on the present and future functions of the estuary. The management strategy required should also be one that reflects the ecosystem and its functions as a whole.

1.1. Concepts in coastal dune management – The Ecosystem approach:

In the past, dune management techniques tended to be conservative and protective in character with a utilitarian ethic based on the philosophy that conservation is for man (De Raeve 1989; Avis 1992; Hellström 1994). Concerning management, under this attitude, priority was often given to human utilisation of the ecosystem. Management plans were implemented to safeguard or establish recreational use, social and economic value above ecological functioning (Avis 1992). Many of these early attempts at dune management were a “quick fix” to a momentary situation with a total disregard for the ecological implications that the reactive plans may have had on ecosystem functioning. Management practices focussed on maintaining existing spatial patterns in attempt to stabilise the current situation and thereby neglect the essential dynamic functioning of coastal dunes (Davies *et al.* 1995). These techniques were largely unsustainable. They incur great expense in finding engineering solutions to natural phenomena such as the dynamics of littoral sediment transport, only to discover that the solution itself promotes degradation or alteration of the very ecosystem it claims to protect (Avis 1992).

In light of these failed attempts at coastal dune management coupled with the understanding that dune ecosystems are highly complex and dynamic, a 'hands-off' approach to dune management was briefly adopted (Rust & Illenberger 1996). For example, Cullen and Bird (1980) advocated the construction of setback limits that prevented development within a designated distance from sensitive area as well as strict controls to limit activities in these areas. This sort of approach is unsustainable, impractical and infinitely difficult to enforce under "ponderous bureaucratic procedures, economic pressures and political machinations." (Rust & Illenberger 1996). The need to find a sustainable, practical solution to dune management problems was eloquently stated in the "Blueprint for Survival". "If we plan remedial action with our eyes on political rather than ecological reality, then, very reasonably, very practically and very surely we will muddle our way to extinction" (In: O'Riordan & Turner 1983).

In recent years, it has been recognised that the dune landscape is highly variable, spatially and temporally, and that the need for a strategic, sustainable and dynamic approach to management is essential (Wanders 1989). This had led to a shift in attitude and philosophy behind environmental ethics, management policies and procedures and the development of a holistic and dynamic approach to ecosystem management (Hellström 1994). This approach emphasises the need to understand pivotal ecosystem processes whilst considering and amalgamating the social and economic functions of the system in question (Eagles 1984; Wanders 1989). The concept is wholly sustainable in that it integrates and prioritises all aspects of the ecosystem by assigning the highest priority to the best achievable ecosystem functioning followed by recreational use, social value and lastly economic value. The fundamental principle behind this philosophy is as ecosystem managers, we are held accountable for our actions and that our primary goal is to find a means of living with instead of against nature (Avis 1992).

Numerous studies have been conducted endorsing the ecosystem approach to management. In his study of the Outerbanks in North Carolina, Dolan (1972) acknowledged that periodic disturbance to uncontrolled natural systems created serious management issues but that a dynamic approach was required to allow for the maintenance of geological and ecological systems.

La Cock & Burkinshaw (1996) found that as a result of poor planning and disregard for the dynamics of the Oyster Bay – St Francis Bay dunefield, the St Francis Bay village and marina are under threat. They concluded that a holistic approach to the cumulative problems experienced is required. McLachlan *et al.* (1994) concluded that "dunes and beaches form interdependent components of the coastal sand transport system and must be managed as a whole". Eagles (1984) comments regarding a more holistic approach to management are that the role of the "individual in society to influence decision making processes" should not be underestimated. Furthermore, that "the attitudes of society towards natural ecosystems are part of the decision-making matrix in all countries and must be considered before plans can be developed or implemented". In addition, the holistic or ecosystem approach to management is acknowledged and advocated by Wanders 1989; van der Meulen *et al*. 1989; Avis 1992; Hellström 1994; Davies *et al*. 1995.

1.2. Dune management system:

Davies *et al.* (1995) identify three main elements of the management system under the ecosystem approach. These are: Strategic analysis, where an understanding of the context of the ecosystem is sought, strategic choice, where a possible course of action is chosen and strategy implementation whereby the chosen option is put into operation. Intrinsic to the formulation of such a dune management system, is the availability and integration of qualitative and quantitative information. This allows for aspects that influence the dune system to be identified and management responses to subsequently be initiated (Davies *et al.* 1995; Hellström 1994).

Central to the dune management system are the present and future functions of the site. In addition to the intrinsic ecological functions of the system, the social and economic functions are usually determined through interested and affected parties or by general policy, for example, recreational or residential functions. The output of the dune management system is the influence the manager exerts on the dune ecosystem itself (Figure 1.1, van der Meulen 1989). In order to effectively manage the system, an advanced understanding of the underlying biological and physical processes that shape the dune ecosystem as well as the factors that influence these processes is required (Wanders 1989; Eagles 1984; van der Meulen *et al.* 1989). The role of research in providing information to allow for a holistic and dynamic approach to dune management is therefore indispensable (van der Meulen *et al*. 1989).

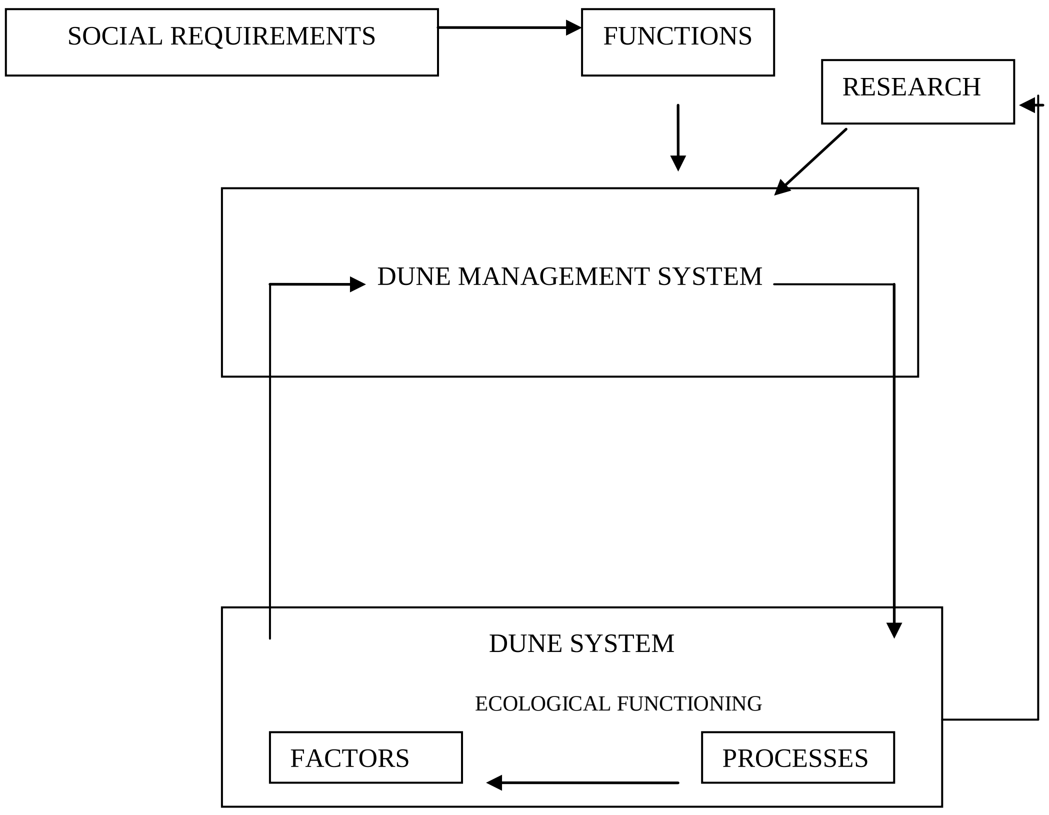


Figure 1.1: The decision-making environment of the dune manager (Adapted from van der Meulen *et al.* 1989).

1.3. Aims and objectives:

The primary objective of the study was to provide the information regarding the ecological functioning and social utilisation of the study site as required for the formulation of a dune management strategy under the ecosystem approach. The goal of adopting this approach is to ensure that future management strategies are holistic and dynamic.

The study was divided into three components. The first two components, namely sediment and vegetation dynamics, were associated with the ecological functioning of the study site. The third component related to public perception regarding the utilisation and demands placed on the river mouth. Meetings with interested and affected parties also highlighted some concerns relating to each of the components. These concerns as well as the information required for planning a strategy, were then used to formulate specific hypotheses for each section which are discussed in detail in the relevant chapters. A brief overview of the objectives for each section follows:

Sediment dynamics:

Sand accumulation along the eastern bank and the development of the Westbourne Road Car Park (WRCP) dunefield raised concern regarding the natural functioning of the Bushman's River Mouth (Figure 2.2). These accumulations restricted access to the river and resulted in a recreational loss and possibly, a decrease in property value in this area. An investigation of the sedimentological processes and factors that influence these processes over both a long and short-term period was required. Changes in topography, sand volume and rates of accretion were examined to document variations and patterns in processes. Specifically, variations both spatially and seasonally were investigated by comparing differences in static and dynamic measures of volume across the study site and for the duration of the study.

Vegetation description and analysis:

Vegetation stabilised the sand accumulated at the river mouth and was perceived to prevent the natural transport of sand out of the eastern channel thereby compounding the problems associated with accretion. In addition to the stabilisation of the bank, the presence of vegetation initiated dune formation and development at the site. The dunes were not considered a component of the natural functioning of the system and further restrict access to the river and even the beach area. This study provided a site-specific quantitative overview of the dune vegetation at the Bushman's River Mouth. An examination of spatial and temporal changes in the structure of vegetation communities were also conducted to identify the process of succession that results in the establishment of vegetation at the site.

Public perception:

The importance of community based resource management is emphasised in the ecosystem approach to dune management as discussed earlier. The objective of this study was to provide such information to facilitate the involvement of the community in future management decisions at the study site. Since no prior study existed regarding the social demands and utilisation on Kenton-on-Sea's coastal resources, it was necessary to conduct a survey to examine these aspects. Specific aims of the study were to determine the functions of the beach through the investigation of public utilisation of the area and its facilities as well as to elucidate perception of the environment and reveal opinion regarding the proposed and past management strategies. An assessment of social standing, awareness and knowledge was also necessary in order to validate their responses.

CHAPTER 2

INTRODUCTION BUSHMAN'S RIVER MOUTH

2.1. Location:

The Bushman's River Mouth is situated at 26° 41' 45"E and 33° 39' 50"S along the Eastern Cape coast of South Africa and is approximately 125km east of Port Elizabeth and 150km west of East London. It is flanked by two towns (separate municipal districts) namely Boesmansriviermond to the west and Kenton-on-Sea to the east (Figure 2.1).

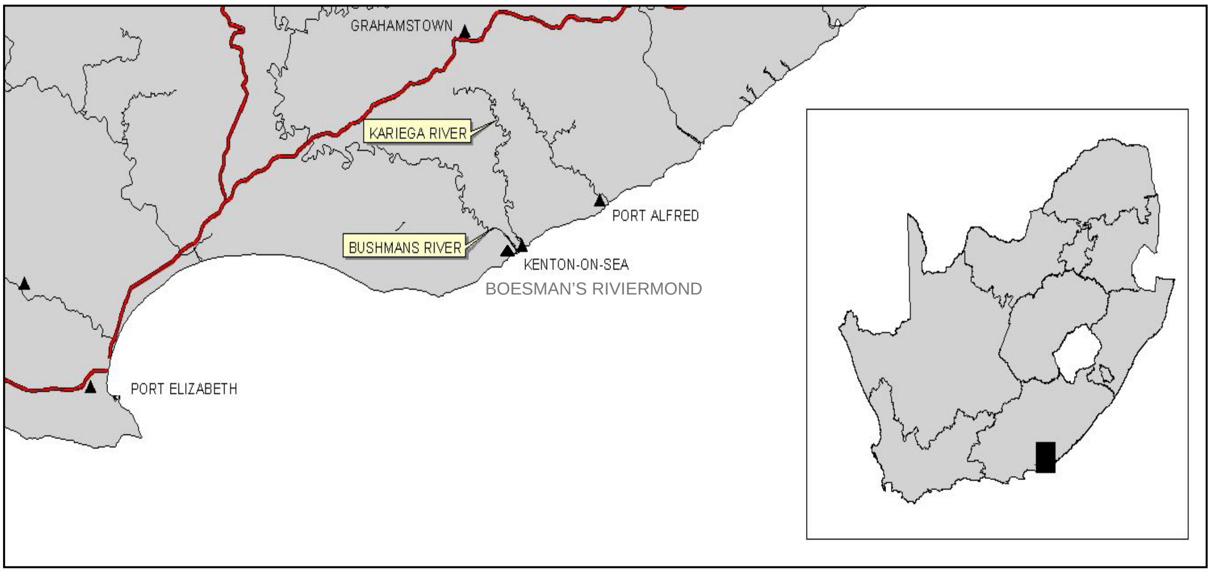


Figure 2.1: Location of Bushman's River Mouth along the Eastern Cape coast of South Africa.

The study site encompassed a stretch of beach approximately 550m in length from north to south along the eastern bank of the Bushman's River Mouth that falls under the Kenton-on-Sea municipal jurisdiction. It incorporates a crescent-shaped dunefield referred to as the Westbourne Road Car Park (WRCP) dunefield (Booysen 1995a; Figure 2.2).

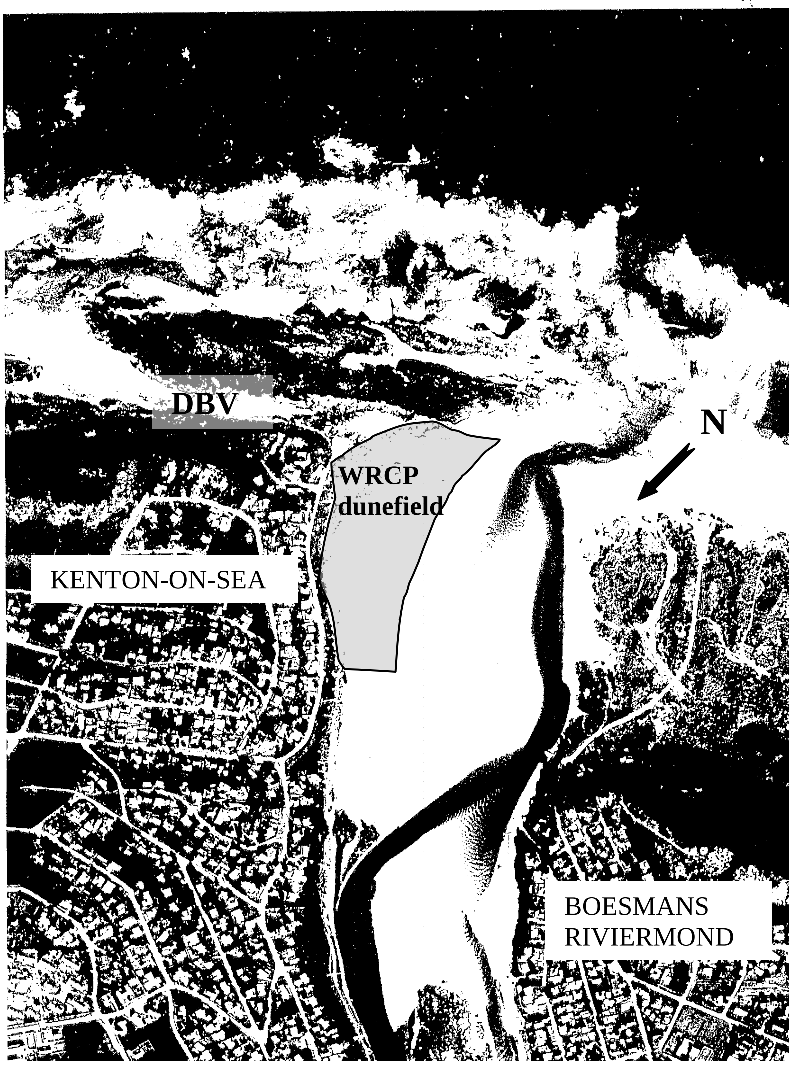


Figure 2.2: Study site is situated along the eastern bank of the Bushman's Rivermouth, Kenton-on-Sea. Abbreviations: DBV – Dry Bones Valley, WRCP – Westbourne Road car park.

2.2. Climate:

The climate of the area is described as subtropical with mild winters and summers (Tinley 1985). Similar to that of Port Elizabeth, the study site experiences persistent, year-round westerly winds interspersed in summer by easterlies (more detailed description in Chapter 3). Due to the topography of the site and the Bushman's River valley, the influence of north-westerly wind may be increased as a result of wind channelling down the river valley (Burkinshaw *pers comm.*). Annual rainfall ranges between 500 – 1000 mm p.a. with a bimodal pattern of maximums recorded at equinox periods (spring and autumn). Drier periods are recorded during mid-summer and mid-winter. The mean annual temperature is approximately 18°C with a temperature range of 10°C – 22°C (Kopke 1988).

Berg winds can result in temperatures reaching 40°C during January and February. This phenomenon results from anti-cyclonic circulation around a high pressure in the interior feeding an offshore low-pressure cell at the coast. As air descends from the escarpment, it is heated 1°C for each 100m descended resulting in hot, dry and windy conditions along the coast. Minimum temperatures up to 0°C can be recorded in winter as a result of the passage of cold polar low pressure cells moving east along the southern and eastern cape coasts (Stone *et al*. 1998).

2.3. Geology and geomorphology:

The study area consists of three major geological units. The oldest of these units are the sandstone and shale deposits of the Bokkeveld Group. The deposits are over-lain with sandy limestone and marine deposits comprising the Alexandria Formation and above this formation are late tertiary to quaternary deposits of aeolian beach and dune sands (Rust 1998; Stone & Reynders 1984; Figure 2.3).

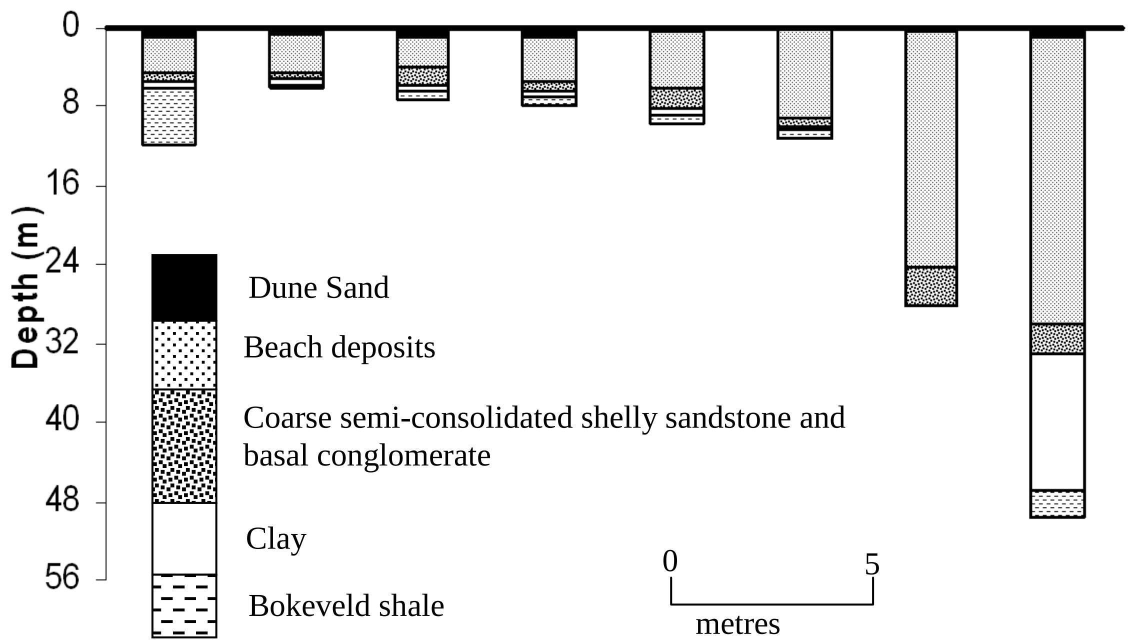


Figure 2.3: Geological cross-section of the Bushman's River Mouth (Adapted from Stone & Reyders 1984).

The most prominent geomorphic features at the study site are a small headland bypass system at Dry Bones Valley (DBV) in the south. A system of vegetated ridges and hummocks (WRCP dunefield) was also situated along the bank of the river mouth, north of the bypass system. Aerial photographs taken in 1942 show that the DBV bypass system was an active conduit for the eastbound aeolian sand transported from the eastern bank of the river mouth to Middle beach, Kenton-on-Sea. The progressive establishment of vegetation from the western entrance of DBV eastward along this conduit is evident since 1955 and has resulted in the stabilisation of the sand transport corridor. The headland bypass system at DBV is presently inactive (Burkinshaw 1999).

The WRCP dunefield was thought to have initially developed immediately upwind of DBV as low vegetated dune hummocks. It prograded in a north-westerly direction along the bank as a result of an increase in the amount of sand available for aeolian transport. This was due to the build-up of a sand bank along the eastern bank of the lower river mouth (Burkinshaw 1999). See Chapter 3 for more information regarding the sedimentology of the study site.

2.4. Sedimentation and channel history

The Bushman's Riveris 230 km in length and has a catchment of 2670 km^2 that supports extensive stock and limited crop farming (Reddering & Esterhuysen 1981; Jacob 1993). The New Years River Dam is the only major impoundment within the Bushman's River catchment although numerous farm dams and weirs are present on the Bushman's River itself. The river mouth is considered to be both a wave and tide-dominated system and is estimated to have formed approximately 17000 years ago (Jacob 1993). It has tidal reach of 32 km and a tidal prism of $1.9 \times 10^6 m^3$.

The sedimentation recorded in Bushman's River Mouth is the result of natural processes intrinsic to the functioning of estuaries (Reddering & Esterhuysen 1981; Jacobs 1993). Estuaries and river mouths form natural traps for marine and fluvial sediments. Sediment accumulation in estuaries is influenced by a short-term dynamic cycle of flooding (Reddering & Rust 1990). During flooding, channels widened and deepened in comparison to their pre-flood configuration and the river mouth is rejuvenated in terms of its dynamics. Between flood events, tidal circulation is the dominant process that serves to bring sediment into the river mouth (Jacobs, 1993).

Baird *et al.* (1979) concluded from mineralogical and grain size studies that the sandbars that extend from the inlet upstream for approximately 3 km are of marine origin. These sediments entered the inlet with the tides and were deposited as sand bars in the lower river mouth. Such sediments deposited along the eastern bank nourish the adjacent dunefields through aeolian processes. Aerial photographs dating back to 1942 documented the historical development of sedimentation in the river mouth. In 1942, a navigable channel along the eastern bank of the river mouth was formed due to the migration of aeolian sand from the Boesmansriviermond beach south-west of the tidal inlet (Figure 2.4). By 1955, the main channel returned to the western bank of the river mouth but it is believed that the eastern channel remained navigable. In subsequent years, the eastern channel gradually filled with sand (Figure 2.4) resulting in the present day configuration at the river mouth.

2.5. Vegetation:

The vegetation of the Southern African coastline is strongly influenced by the climate (in particular temperature and rainfall) as well as vegetation types from the adjacent hinterland (Avis 1992; Hellstrom 1994; Lubke & Van Wijk 1998). The vegetation of the south-eastern coastline exhibits aspects from the Cape biome in the coastal fynbos, while woody elements associated with the Tongoland-Pondoland biome are common in the thicket communities. The Afromontane biome is represented as coastal forest species while the Karoo-Namib flora is depicted by the presence of occasional succulent dune species (Peter 2000; Avis 1992 & Lubke & van Wijk 1998).

A zonation or succession of plant assemblages for the Southern African coastline and other parts of the world has been described by numerous authors (Tinley 1985; Doing 1985; Lubke *et al*. 1997; Avis & Lubke 1996; Henriques & Hay 1998). These assemblages form a discontinuous zonation and are distributed along unique successional gradients that are related to environmental conditions (Oosting & Billings 1942; Donnelly & Pammenter 1982; Parrish & Bazzaz 1982; Everson & Tainton 1984; Moreno-Casasola 1986; Houle 1997 and Henriques & Hay 1998). They run parallel to the shoreline and are categorised into four zones by Tinley (1985).

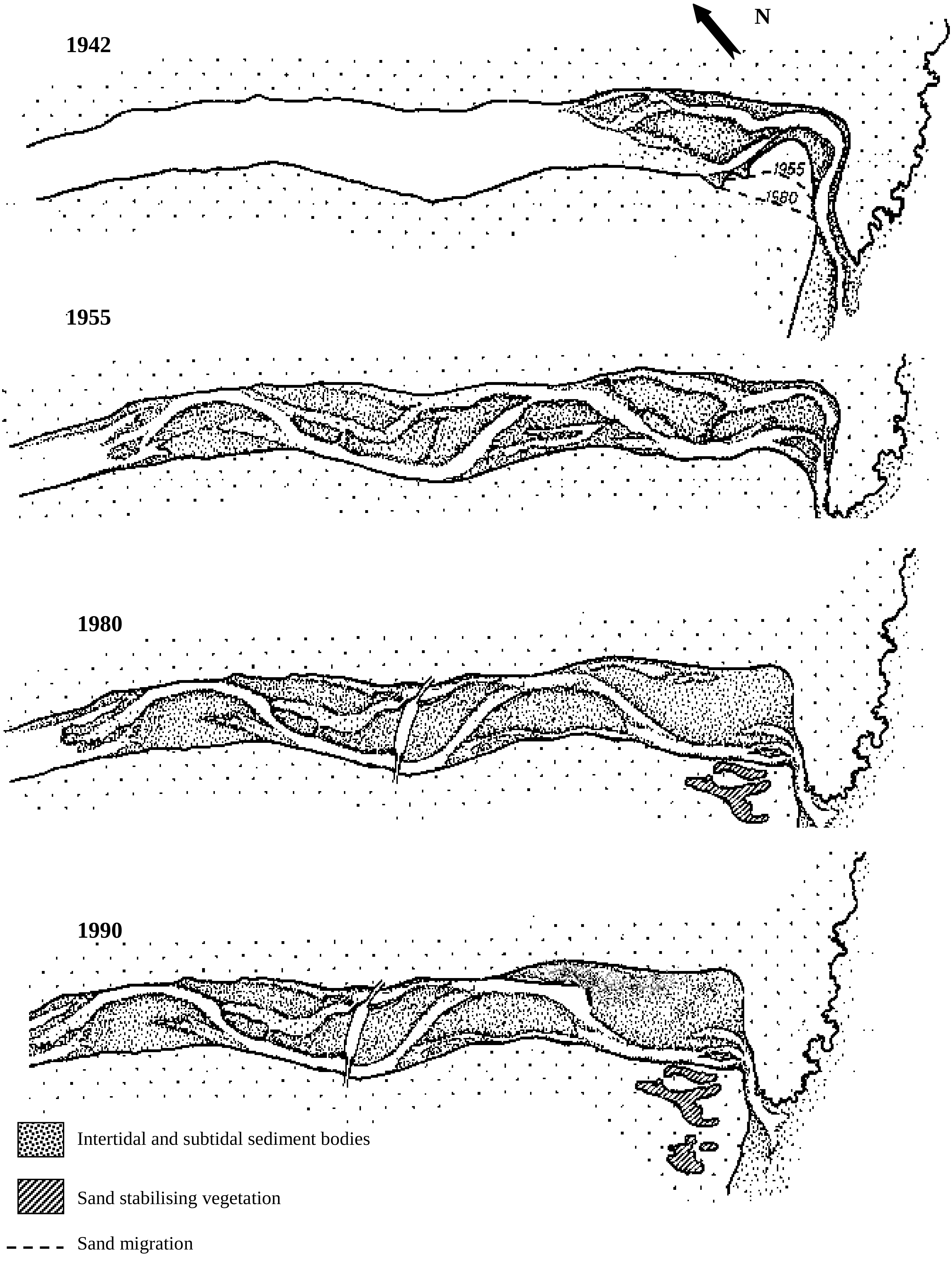

N
1942
1955
1980
1955
1980
1990
Intertidal and subtidal sediment bodies
Sand stabilising vegetation
Sand migration

Figure 2.4: Channel migration in the lower Bushman's River Mouth from 1942 to 1998 (after Reddering & Esterhuysen 1981).

The pioneer community (Zone I) is situated nearest the high water mark and is characterised by low creeping grasses and succulent leafed herbs (Tinley 1985). These species are the primary colonisers of bare, mobile sand and show a positive growth response to burial by sand (Maun 1998). Pioneer species are also responsible for creating the first embryonic dunes in the foredune zone. Species richness and diversity is typically low and cover, sparse for this community (Avis 1992). This community is also known as littoral strand vegetation, pioneer plants, dune margin scrub, ephemerous tidemark community and perennial tidemark community (Tinley 1985; Lubke & Wijk 1998; Doing 1985).

The most common pioneer species at Bushman's River Mouth is *Erharta villosa*, a perennial grass with creeping rhizomes. The rhizomes form single culms or small clumps in the rear dunes and sheltered areas while large monostands of culms are evident along foredune ridges (Plate 2.1). Other pioneer species at the site include *Arctotheca populifolia*, a thick-stemmed herb with silver-grey leaves that are covered by white, woolly leaf hairs (Lubke & Van Wijk 1998). This species forms small hummock foredunes in the perennial tidemark zone (after Doing 1985; Hesp & McLachlan 2000; Plate 2.2). The third pioneer species at Bushman's is *Sporobolus virginicus*, an erect, creeping, perennial grass (Lubke & Van Wijk 1998; Plate 2.2). Like the other pioneer species, *S. virginicus* is also found in the perennial tidemark zone and is capable of building hummock dunes (Doing 1985).

A scrub community dominates the secondary zone (Zone II) situated behind the primary foredunes. Although the most life forms are represented, this community is dominated by shrubs and herbs that form an open canopy of approximately 2-3m in height (Avis 1992). Common species of this zone at Bushman's includes *Helichrysum cymosum, Stoebe plumosa, Helichrysum praecinctum, Solanum americanum* and *Senecio elegans*. This community is also referred to as a shrub community, dune margin scrub, open or closed scrub (Tinley 1985; Lubke & Van Wijk 1998; Avis 1992). A more dense and diverse community known as the scrub-thicket (Zone III) follows the scrub community. Herbs, shrubs, grasses and trees are all found within this zone and form a compact canopy between 3m-5m in height but may be pruned by wind and salt spray (Avis 1992). Species at Bushman's include *Passerina rigida, Metalasia muricata, Allophyllis natalensis, Sideoxylon inerme, Leonotis leonurus* and *Salvia africana-lutea*. The most mature community, coastal forest or tall thicket (Zone IV) occurs furthest from the high water mark. Trees are the dominant life form with a dense understory of creepers and herbs (Tinley 1985).

All four zones are found along moist regions of the coast but complete zonation is rarely seen. More typically, only two zones are evident and may occur discontinuously due to erosion by wind and sea. Interruptions of communities are also attributed to blowouts, slumping, clearing of bush and fires (Tinley 1985). For a complete species list of the study site, see Appendix 1.

Plate 2.1. An established monostand of *E. villosa* along a foredune ridge.

Plate 2.2. The silver-grey dune pioneer, *A. populifolia* in the foreground and the short, erect culms of *S. virginicus* in the background.

2.6. Landuse:

Extensive livestock and limited crop agriculture occurs down the length of the Bushman's river catchment. Stock farming includes cattle, sheep and goats while the main crops are restricted to pineapple, lucerne and chicory (Jacobs 1993 & Reddering & Esterhuysen 1981). The immediate surrounds of the river mouth encompasses recreational, residential and conservation areas. Along both the eastern and western bank of the river, numerous houses have been built. The western bank falls under the Boesmansriviermond municipality and the eastern bank under the jurisdiction of Kenton-on-Sea (Figure 2.2). Beaches on either banks of the river are extensively utilised during holiday season (April & December) for swimming, sunbathing and fishing. On the Boesmansriviermond side of the river, a slipway allows boats to be launched onto the river.

The Joan Muirhead Nature Reserve was established to fulfil the wishes of the residents of Kenton for the retention of the vegetated coastal fringe between the Bushman's and Kariega rivers. The reserve includes pristine coastal vegetation in particular, dune fynbos that occurs on two rocky promontories, south of the study site. Nature trails exist through the western portion of the reserve toward Shelly Bay and Kenton's Middle Beach via DBV and prove popular both in and out of season. The reserve also boasts a variety of fauna that includes the common duiker, tortoise, rabbits and numerous bird species.

CHAPTER 3
SEDIMENT DYNAMICS

3.1. Introduction:

Coastal dunes form where winds with an adequately high velocity strike sandy beaches that are regularly replenished by longshore currents and/or wave action (Tinley 1985; Burkinshaw 1998). The aeolian transport of sand represents the primary sediment input to dunes as well as an output from beaches. It is one of the most vital components of the process-response interaction between dune and beach systems (Nickling & Davidson-Arnott 1990). In addition to the ecological distinctiveness of coastal dune ecosystems, they are an integral part of the coastal sediment budget (Arens 1994; McLachlan *et al*. 1994). They serve to maintain coastal sediment transport especially where headlands disrupt longshore drift (Tinley, 1985; La Cock & Burkinshaw 1996). Dunes also have a protective role in that they act as a buffer against the sea and are, in some cases, the main means of preserving the coastline by counteracting erosion (van Bohemen 1996).

Numerous attempts have been made to classify dunes based on shape, number, slip-face orientation, resultant sand drift direction and mobility. The use of vernacular names as well as geometric and organic analogies for similar features across the world has led to some confusion in the terminology (Pye & Tsoar, 1990). For the purposes of this study, a brief review of the dune terminology used is summarised in Table 3.1 with an overview of synonyms from other published data.

Table 3.1: Summary of dune type terminology for this study site including description, and synonyms and authorities where appropriate.

TERM	DESCRIPTION	SYNONYMS & / AUTHORITY
Transgressive dune systems	Unvegetated, sand transport is dominant, mobile, unimpeded, migrating. Morphological types incl. transverse, barchan, parabolic, headland bypass dunefields, transgressive sheets.	Bare / free dunes (Tinley, 1985). Transgressive dune systems (Hesp *et al.*, 1989; Rust & Illenberger, 1996). Transgressive dunefields (Hesp & Thom, 1990)
Transverse dune	Parallel, straight to curved dune ridge. Convex dome. Axes at 90° to prevailing wind direction. Single or	Transverse (Tinley, 1985; Hesp *et al.*, 1989; Pye & Tsoar, 1990; Boxel *et al.*, 1999,

	alternating slipfaces dependent on uni- or bi-directional winds (reversing).	Van Dijk *et al.*, 1999).
Headland Bypass dunes	Development related to topographic barrier, migrating dunes crossing a plateau or plain of a headland. Predominant element is the transverse dune.	Headland bypass dunes (Tinley, 1985). Headland bypass dunefield (Burkinshaw, 1998). Bypass system (Burkinshaw, 1999).
Retentive dune systems	Vegetated. Sand accumulation within vegetation is dominant. Sand sink. Morphological types incl. hummock dunes, foredunes, vegetated dune ridges.	Rust & Illenberger, 1996.
Foredunes	Sand accretions forming in the most seaward sand surface behind beaches. Predominantly vegetated consisting of hummock dunes, incipient foredunes & foredune ridges.	Foredunes (Oosting & Billing, 1942; Donnelly & Pammenter, 1983; Henriques & Hay, 1998). Foredune-complex (Doing, 1985). Incipient foredunes (Hesp, 1983, Burkinshaw, 1999).
Hummock dunes	Irregularly shaped mound of sand, wholly or partially vegetated. Isolated or clumped, rounded, oval.	Embryo dunes (Ranwell, 1960; Doing, 1985). Strand plant foredune hummock, driftline embryo dunes, parallel beach ridge hummocks (Tinley, 1985). Hummocks (Moreno-Casasola, 1986; Pye & Tsaor, 1990). Type 1b incipient foredunes (Hesp, 1983).
Foredune ridge	Aeolian accretions within a laterally continuous zone of vegetation. Produces an asymmetrical ridge alongshore.	Type 2a and 2b incipient foredunes (Hesp, 1989).
Vegetated dune ridges	In this study the term is used to describe coalesced hummock dunes, separated by deflation troughs where undercutting of the ridges by wind shear has occurred. Attain heights between 1-5m.	

Coastal dune management:

Coastal dune systems have a long history of mismanagement. Often the inherent dynamics and ecological importance of these dune systems were neglected. Such was the case near Port Elizabeth where the Driftsands headland bypass system between St Francis Bay and Algoa Bay was stabilised in 1897 to prevent encroachment on the early settlements at Port Elizabeth.

A gradual but increasing loss of sand from the city's beaches has been documented since the 1960's and is now a great cause for concern (McLachlan *et al.* 1994). Similarly, studies at St Francis Bay showed that stabilisation of a headland bypass dune system to protect housing development resulted in a loss of sand at near beaches (Lubke 1985; La Cock & Burkinshaw 1996). Ecological engineering approaches such as those described above are seen worldwide e.g. wide scale shoreline stabilisation programmes in North America that relied on engineering structures that allegedly protected barrier islands and shorelines (Avis 1992).

It is now acknowledged that an understanding of the sediment dynamics of dune systems and factors that influence these dynamics is a prerequisite in the investigation of the coastal dune environment and for the formulation of proactive management strategies (Sherman & Hotta 1990). The most important of these processes is the aeolian transport of sand. It is thus imperative that the fundamentals of sand transport are well understood to allow for the management of coastal dune systems and to that end, a brief review of the key concepts regarding these processes follows.

Aeolian sediment transport:

The entrainment and transport of sand particles results from the interaction between atmospheric, surficial and textural variables. Airflow is usually turbulent and characterised by eddies of varying sizes, velocities and directions when moving across a fixed bed at relatively high speeds. The wind speed near the surface of the bed is retarded due to viscous frictional effects (Nickling & Davidson-Arnott 1990). A bed comprised of very small particles or that is completely flat is referred to as aerodynamically smooth and a thin laminar flow layer develops directly adjacent to the surface even though the air above is turbulent. If the bed is aerodynamically rough because of large particles or other obstacles like vegetation, this thin laminar layer breaks down and is replaced by a viscous sub-layer. The velocity profile of this layer is dependent on the height above the surface, the characteristic roughness length or height of the surface and the shear velocity. The velocity profile of this layer is still not well understood (Hotta 1988; Nickling & Davidson-Arnott 1990; Sherman & Hotta 1990).

Sand grains are set in motion when the wind speed reaches a critical threshold velocity that is sufficiently high to overcome the retardant forces acting on the particles (Nickling & Davidson-Arnott 1990). These forces include fluid drag, lift, momentum, and weight as well as inter-particle cohesion.

Sand particles rise and fall rapidly once disturbed by wind because the particles are denser than air. Consequently, the bulk of sand transport occurs close to the sand surface as particles seldom are transported at higher elevations (Hotta 1988).

Three modes of sand grain motion exist, namely suspension, saltation and surface creep. Very small sand particles are transported within the air column by suspension. Relatively large particles are transported by saltation. The saltation of large particles occurs when these particles are ejected into the air stream and are carried by the wind in smooth trajectories after which they fall back to the surface. On impact, the particles either rebound into the air or eject another particle from the surface. Less exposed or larger particles roll, or are pushed by saltating grains along the surface. This mode of particle transport is termed surface creep (Figure 3.1; Hotta 1988; Sherman & Hotta 1990; Nickling & Davidson-Arnott 1990).

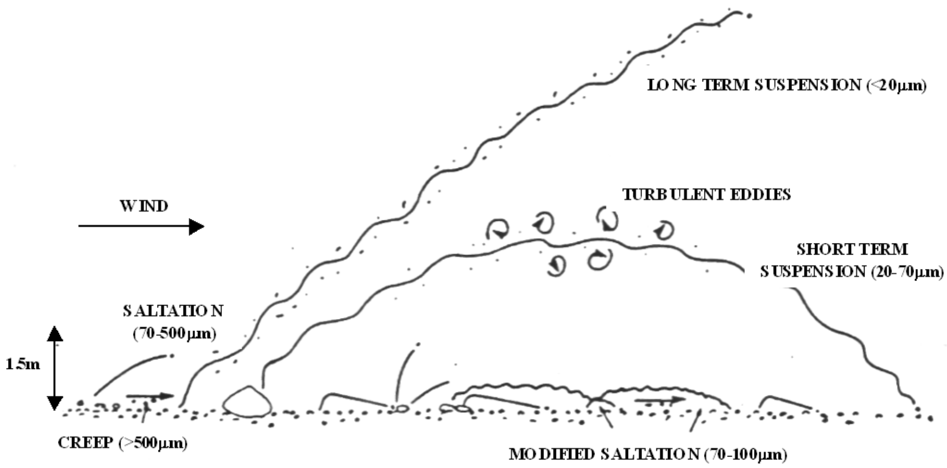


Figure 3.1. Modes of particle transport by wind including ranges of particle size during moderate wind events (from Nickling & Davidson-Arnott 1990).

Factors influencing aeolian sediment transport in the dune environment are those that influence the determinants of the process (Sherman & Hotta 1990). These factors can be grouped into three categories (Table 3.2):

1. Factors controlling the features the wind field e.g. surface roughness or topography; fetch length i.e. total area subject to exposure to winds.
2. Factors controlling the threshold velocity required to initiate sediment transport e.g. moisture conditions.;

3. Factors associated with the physical characteristics of the sediments e.g. size, shape, sorting and cohesion properties (after Nickling & Davidson-Arnott 1990).

Table 3.2. Factors influencing aeolian sediment transport in the dune environment (From Nickling & Davidson-Arnott (1990).

WIND PROFILE	SURFACE	SEDIMENT
Fetch length Fetch surface characteristics	Roughness: Height : Spacing	Texture: Height : Size : Packing
Turbulence Density: Temperature : Pressure : Humidity	Vegetation cover Obstructions	Specific gravity Moisture content Bonding agents
Viscosity	Temperature	Crust development Soluble salts
	Beach slope Topography	Algae Silt and Clays

The influence of vegetation on sediment transport is particularly pertinent when considering that the presence of vegetation is one of the essential elements for the development of coastal sand dunes (Arens, *et al.* 1994). Vegetation influences sediment transport in a number of ways. Aerial shoots form a physical barrier that intercepts wind-borne sand particles. Roots bind the surface sand layers thus reducing the surface area exposed to airflow. Local airflow is influenced by the presence of vegetation resulting in an increase in surface roughness and the reduction of wind-induced drag. The humus derived from vegetation increases both the cohesiveness and water retention properties of the sand (Van Dijk *et al.* 1994; Pye 1982). A number of studies have been completed regarding the influence vegetation has on sediment transport and it's subsequent effect on dune formation.

Hesp (1989) investigated the effect of plant height, width, flexibility and shoot density on airflow, dune formation and morphology. He found that sand is trapped over a shorter distance and in a greater volume over higher vegetation density zones than over lower density zones. Van Dijk *et al.* (1999) included vegetation height as a dynamic variable in their study of modelling sediment transport and profile development. Arens *et al*. (1994) concluded that as a result of seasonal variation in vegetation density, dune profile development also varied seasonally. The study showed that landward sand transport is limited in the spring and autumn when density is at it's highest.

The aim of this study was to describe the sedimentological processes and factors that influence them at the WRCP dunefield. The investigation included an assessment of the long and short-term topographical and volume changes that reflected dominant processes at the dunefield. Variations in these processes, both seasonally and spatially were also examined to explain the long-term development of the dunefield as well as assess short-term trends in sedimentological processes in hopes of predicting the future development of the dunefield. The information provided a gross approximation of the sediment budget for the area to be used as baseline information upon which a dune management strategy could be formulated.

3.2. Methods:

A previous study of the vegetation and topography of the study site was conducted in 1989 but not completed. During this study, eight belt transects of approximately 100m long and 1m in width were established (Unpublished data, figure 3.2). These transects were located and re-sampled in 2000 and 2001 as a continuation of the original study.

Six of the 1989 transects, 50m apart along the bank, were initially orientated at approximately 90° to Westbourne Road for the purposes of a vegetation study (transects 1-6). As a result, these transects may not intersect major topographical features such as vegetated mounds or dune ridges at exactly 90° leading to slight exaggerations in the horizontal dimensions of these features on dune profile plots. In addition, two transects were orientated across the area west of DBV, extending in a north-westerly direction from the lower slope of a 30 m high fossil dune ridge located south of the study site (Transects 8 & 9, figure 3.2).

In 2000, a ninth transect was included to incorporate the westward extension of the sand transport corridor of the DBV headland bypass dune system and was orientated along the centre of the valley (Transect 7). This transect was positioned to bisect a mobile transverse dune at the western end of the transect at approximately 90 ° to the dune’s slipface (Figure 3.2). Transect 7 was divided into two parts referred to as transect 7A that extends between entrance of DBV and the base of the slipface base of the transverse dune. Transect 7B includes the transverse dune and extends westward up to the high water mark (Figure 3.2). The transects were sampled in both the sediment and vegetation studies. Specific sampling techniques, data capture, data processing and statistical analyses are discussed separately for each individual study hereafter.

Changes in topography at each transect were recorded by means of tacheometric surveys conducted at bi-monthly intervals in 1989 and 2000/2001. This method of recording topographical change was somewhat course due to the low-resolution capabilities of the equipment utilised and the relatively large lengths of the transect lines. Only fairly major increases / decreases (approximately 20-30cm) in surface height could be recorded.

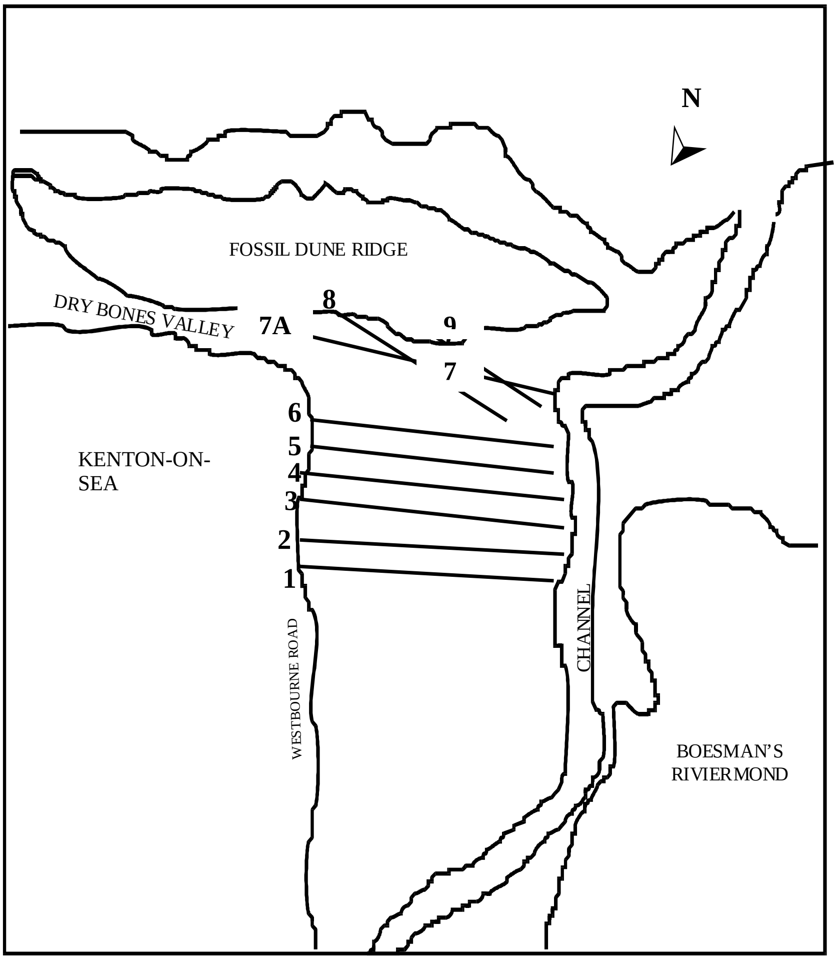


Figure 3.2. Schematic diagram of locality of transects at Bushman's River Mouth. Transects 1A – 5, 6A and 7 were established in 1989 and transect 6 was established in 2000.

Table 3.3. Sample dates spanning 12-year period from March 1989 to July 2001.

SAMPLE NO.	SAMPLE YEAR	SAMPLE MONTH	SEASON
1	1989	March	Autumn
2	1989	July	Winter
3	1989	December	Summer
4	2000	May	Autumn
5	2000	July	Winter
6	2000	October	Spring
7	2001	January	Summer
8	2001	March	Autumn
9	2001	June	Winter
10	2001	July	Winter

Data processing:

Topography of the dunefield was displayed from survey data as two dimensional dune profiles. By plotting successive survey intervals, temporal changes in surface elevation are shown along transect lines. Volume and rates of accretion were extracted from these plots (See Lubke 1985; Burkinshaw 1998 for examples of such extraction). Volume (m^3) was calculated using Simpson's rule. This rule calculates the area beneath the dune profile as per Figure 3.3 by assuming each 'segment' of the profile consisted of a triangle and a rectangle. Therefore, volume of that segment (VOL OF SEG) is the sum of the area of the triangle and the area of the rectangle multiplied by the profile's width (1m for this study). The volume of the entire profile is the sum of the volumes of each segment.

$$\text{VOL OF SEG} = ((0.5 \times (X1-X))(Y1-Y)) + ((X1-X) \times (Y1-Y))^{*} \text{ width}$$

The baseline y-value was selected in this study as the average elevation of the high water mark for the study period recorded at each profile.

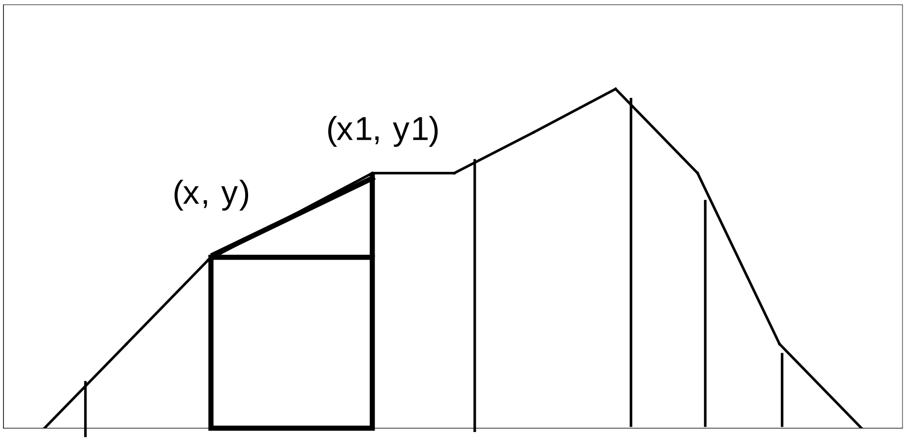


Figure 3.3. Application of Simpson's rule for the calculation of volumes of sand deposited or eroded between successive sample dates (from Burkinshaw 1998).

The rate of sand accumulation was calculated by the change in sand volume over time using the following equation:

$$\text{RATE} = (\text{VOL B} - \text{VOL A}) \div (\text{INTERVAL B} - \text{INTERVAL A})$$

Where: VOL B = volume of transect at Interval B

VOL A = volume of transect at Interval A

INTERVAL B = end of period e.g. year 2

INTERVAL A = start of period e.g. year 1.

Data analysis:

Average volumes, changes in volume and rates of accretion were analysed using Kruskal-Wallis Analysis of Variance (ANOVA) followed by the Newman-Keuls comparison-of-means test if significant differences were obtained in the ANOVA. All statistical tests were performed at the 95% confidence level, using STATISTICA (StatSoft ver. 5.5).

To examine of seasonal trends in the wind regime of the study site, wind velocity and direction data recorded at the Port Alfred weather station were analysed. An attempt was made to collect local wind data but this unfortunately failed due to a lack of suitable equipment and the inability to leave the equipment at the site unattended. Wind frequency and drift potential of each wind direction were calculated using Fryburger's method based on Bagnold's formula[1] of potential sand transport rate for the entire study period from July 2000 to July 2001. The same variables for bimonthly intervals that corresponded to the tacheometric surveys were also calculated.

Bagnold's formula: $q = C(d/D)^{1/2} (p/g) (V_*)^3$

Where: q = potential sand transport rate

C = empirical coefficient (~ 1.8 for well-sorted dune sands)

d = grain diameter

D = diameter of a "standard" grain (0.25mm)

p = density of air

g = gravitational acceleration

V_* = shear velocity.

Shear velocity (V_*) is calculated as:

$V_* = (V_Z – V_t) / 5.75 \log (z/k)$

Where: V_z = wind velocity at z

z = height in metres above the surface

k = surface roughness factor (10mm for rippled sand)

V_t = threshold velocity for wind measured at height k (4m sec^{-1}).

Bagnold (1941).

[1] Bagnold's formula calculates the rate of sand transport over ideal surfaces only and therefore has limitations when using for non-ideal surfaces hence referred to as potential sand transport.

3.3. Results

3.3.1. Sedimentology

Topography:

A change in the topography occurred since 1989 that was notable as increases in the width and in the average surface elevation of the Westbourne Road Car Park (WRCP) dunefield. In addition to these changes, the complexity of the dunefield has increased through the initiation and development of foredunes, vegetated dune ridges and a transverse dune.

The most prominent long-term change in topography was evident along transects 1,2 and 3 (Figure 3.4). In 1989, the WRCP dunefield consisted of a sandy beach as well as a young dune system. At the northern edge of the site, transects 1 and 2 traversed a salt marsh (see Chap 4.2 for community description) while a flat, sparsely vegetated sandy beach existed adjacent to the marsh at transect 3 (Figure 3.4). Over twelve years, the average distance from the Westbourne Road embankment to the high water mark (the length of transects) increased from approximately 50 m to 100 m while the surface elevation increased up to a height of 3 m. A comparison of the March 1989 beach profiles and the May 2000 profiles shows that sand dunes have also formed along each of these transects during this period, namely a foredune ridge (FDR) backed by hummock dunes (HD, Figure 3.4).

In 1989, further south along the bank, transects 4,5 and 6 traversed a young dune system that consisted of small, vegetated hummock dunes around 1m high. Similar to transects 1-3, the width of the WRCP dunefield increased by approximately 30m and the average elevation increased since 1989 (Figure 3.5). Over twelve years, a substantial increase in the height of the hummock dunes (HD) was recorded at transects 4-6. These hummock dunes coalesced to form a foredune ridge (FDR 1989 & 2000/01) seen on the profiles of transects 4-6 as well as on the profiles of transects 1-3 in 2000/2001 (Figure 3.5 & Plate 3.1).

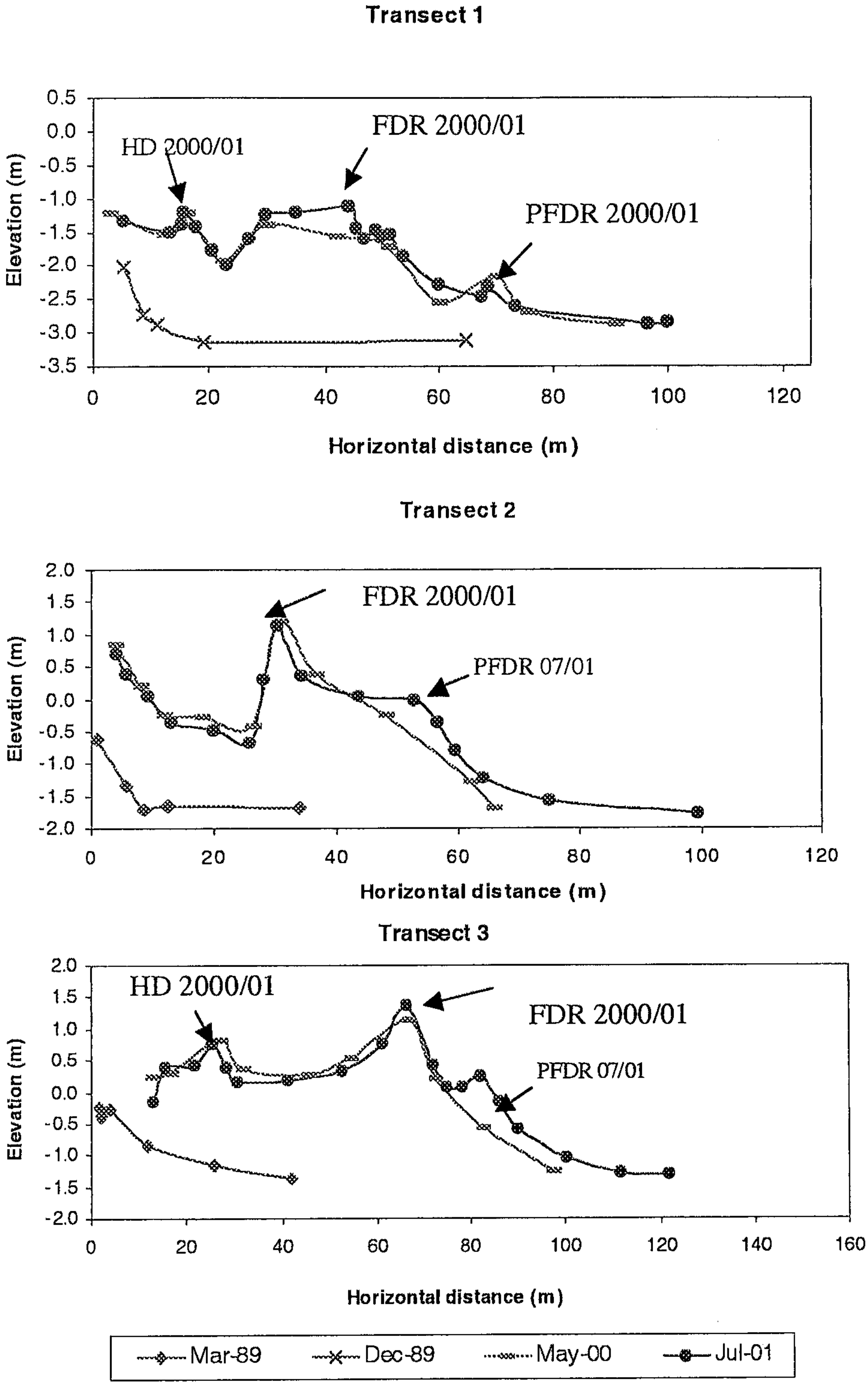


Figure 3.4. Topographical changes observed from repeated theodolite surveys from March 1989 to July 2001. Abbreviations: FDR = Foredune ridge; PFDR = Progradation of foredune ridge; HD = Hummock dunes. Note: different horizontal and vertical scales are used in above figures.

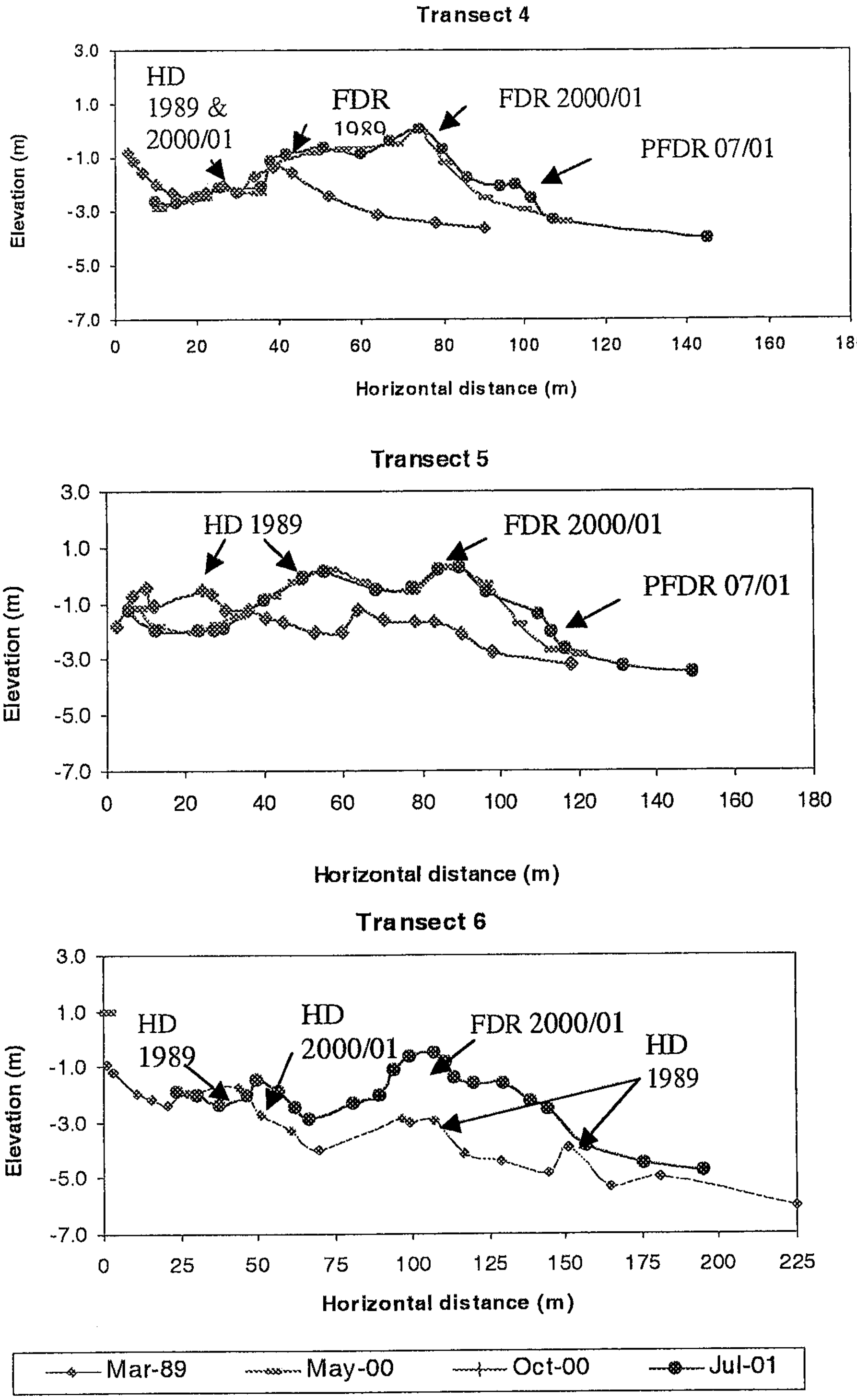


Figure 3.5. Topographical changes observed from repeated theodolite surveys from March 1989 to July 2001. Abbreviations: FDR = Foredune ridge; PFDR = Progradation of foredune ridge; HD = Hummock dunes. Note: different horizontal and vertical scales are used in above figures.

Plate 3.1. Vegetated dune ridge situated along the eastern bank of the river mouth.

In 1989, transects 8 and 9 traversed an area of hummock dunes (HD) between the high water mark and the fossil dune ridge situated in the south of the study site. These hummocks increased in height and pre-empted the formation of the vegetated dune ridges that lay perpendicular to the river mouth at these transects in 2000/2001 (Figure 3.6). The upper sections of the transects, where the 1989 and 2000/2001 profiles overlap; reflect large fluctuations in elevation and complexity. This most likely the result of discrepancies in the 'fit' of the lines where the location of the 1989 transects could not be exactly matched in 2000/2001. The topographical changes described are therefore a gross approximation of the development of these profiles. The greatest topographical change occurred at the mid and lower sections of the transects i.e. closest to the high water mark. The formation of large vegetated dune ridges (VDR 2000/01) at transect 8 and a similar, but smaller ridge (VDR 2000/01) at transect 9 illustrates the expansion of the dunefield through progradation at these transects for the duration of the study (Figure 3.6).

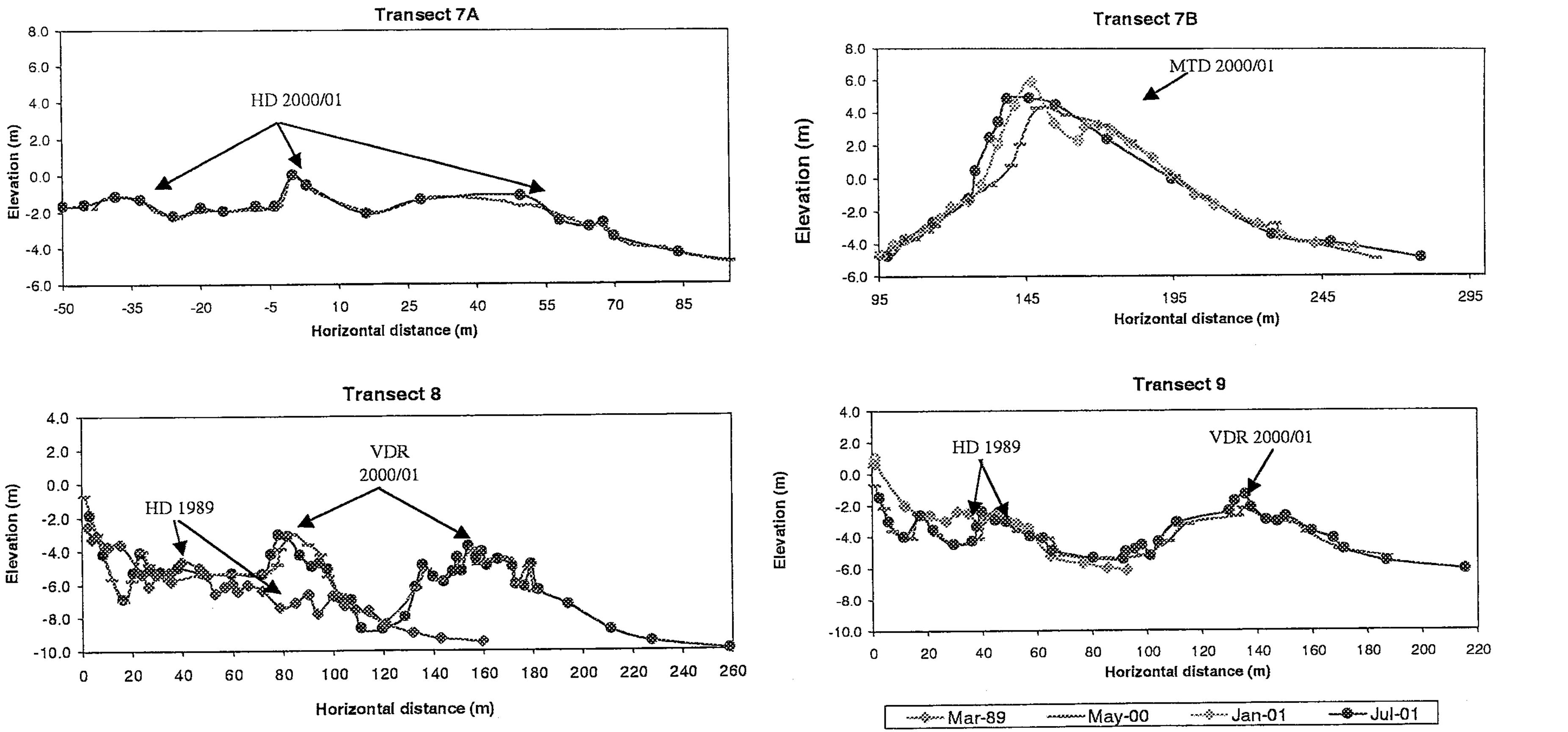


Figure 3.6. Topographical changes observed from repeated theodolite surveys from March 1989 to July 2001. Abbreviations: HD = Hummock dunes; MTD = Mobile Transverse Dune; VDR = Vegetated dune ridge.

Topographical change over the shorter monitoring period, from May 2000 to July 2001, was also observed. A slight increase in surface elevation was recorded at all the transects yet no increase in the length of the transects (width of the WRCP dunefield) was observed during this period. The greatest change in topography occurred along the foredune ridge that was intersected by transects 2-5. It appears that a second ridge began to form during 2000/2001 at the windward slope of the foredune ridge and manifested as an increase in elevation of the windward slope on transects 2-5 (PFDR 07/01; Figures 3.4 & 3.5). Transects that did not intersect the foredune ridge, namely transects 1,6,8 and 9, showed little change in topography over the short-term (2000/2001 monitoring period) apart from a slight increase in elevation over their lengths.

The area west of DBV (transects 7A & 7B) was first sampled in May 2000 therefore only short-term topographical changes can be discussed for these transects. This area consisted of two separate geomorphic features: a mobile transverse dune (MTD) at the western end (transect 7B) and a tract of vegetated hummock dunes (HD, transect 7A) that occurs directly east of the dune (Plates 3.2 & 3.3). No topographical changes were discerned along this tract over the short-term monitoring period although distinct changes in the shape and position of the transverse dune occurred during the study (Figure 3.6).

Plate 3.2: Mobile transverse dune overriding small, vegetated hummock dunes situated adjacent to the entrance of DBV.

Plate 3.3: Vegetated hummock dunes east of the transverse dune and west of the DBV entrance.

The seasonal patterns of accretion due to variation in wind regime are examined later (Chapter 3.3.3) but are discussed briefly to explain topographical changes at transect 7B. The onset of the westerly winds from May 2000 – July 2000 and March 2001 – July 2001 caused the shape of the dune crest to flatten and round. This resulted in a decrease in dune height (Figures 3.6 & 3.18). The effect of the easterly winds was to 'push' the crest into a 'pointed' shape thereby effectively increasing the dune height (Oct 2000 – Jan 2001). The crest and slipface of the dune were more conspicuous during the westerly wind season than the easterly season (Figure 3.6). Successive dune profiles also show that the slipface of the transverse dune migrated 9 m eastward, in accordance with the prevailing wind direction. Unusually this advance is not echoed at the windward slope and base of the lee of the dune after May 2000. The lack of typical dune advance patterns was attributed to the fact that the migratory path of the transverse dune was vegetated. The vegetated hummock dunes downwind of the dune would effectively block the passage of the dune until such time that the vegetation is overwhelmed and the retained sand released and amalgamated into the dune (Plate 3.3.).

Changes in the topography reflect the effects of aeolian processes at the study site. Both the long and short-term topographical changes show that accretion has occurred along the eastern bank of the river mouth. Evidence of progradation of the dunefield and increased beach width of the bank also support this finding. The investigation of volume and volume change are used to confirm and describe this process.

Sand volume at the study site:

A comparison of mean volume for each transect showed that volumes were significantly higher in 2000/01 than that recorded for 1989 ($p < 0.05$). This indicates that the sediment input into the system exceeded the output and confirmed that the dominant, long-term sedimentological process was accretion for the duration of the study (Figure 3.7).

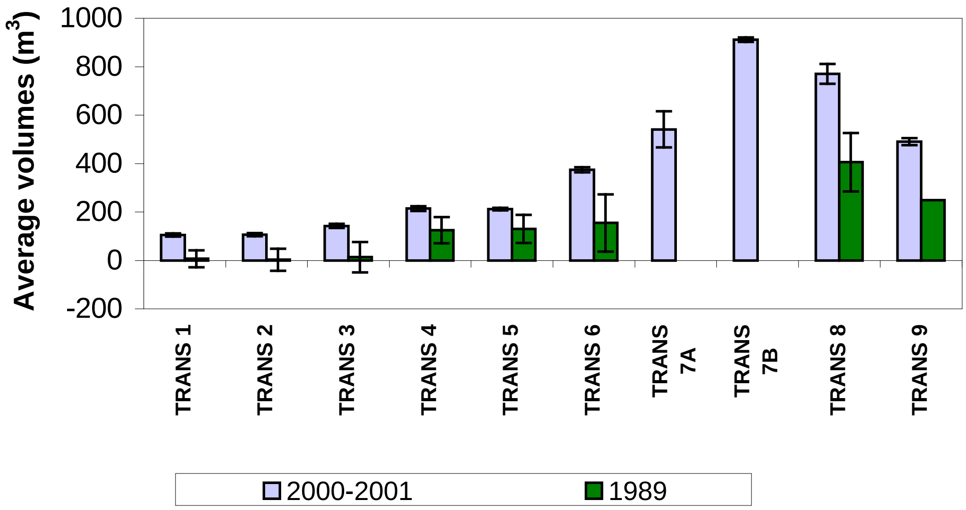
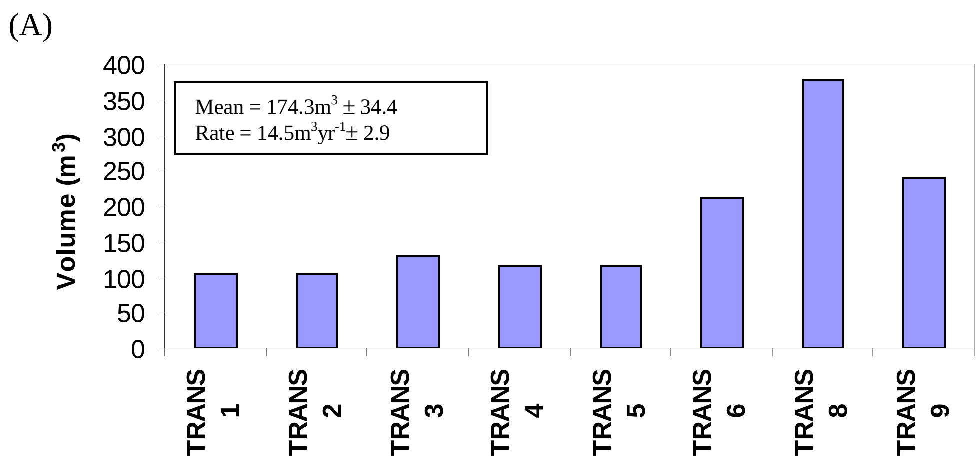


Figure 3.7. Accretion reflected by mean volumes (± S.E.) for 1989 and 2000/01. Significant differences were obtained by Kruskal-Wallis ANOVA ($p<0.05$).

Over 12 years, from March 1989 to July 2001, a net gain in volume occurred at all the transects. An average increase in sand volume of 174.3 m^3 (±34.4) was recorded at each transect (Figure 3.8 A). The greatest volume change observed was at transects 6, 8 and 9 followed by transects 1-5 where volume changes were fairly similar (Figure 3.8 A). The mean rate of accretion during this interval was 14.5 m^3y^{-1} (± 2.9).

Examination of volume change at the site over a shorter time span, from May 2000 to July 2001 revealed a similar pattern of sand accretion as that of the long-term study (Figure 3.8 B). During this time, all the transects exhibited a mean increase in volume of 12.7 m^3 (± 7.2). The rate of sand accretion for this monitoring period was 12.0 m^3y^{-1} (± 6.0). Transects along the bank (transects 1-6) accumulated similar volumes of sand during 2000/01. A negligible volume change was recorded at transect 6 and is attributed to the fact that the transect was not sampled in May 2000 and July 2000 due to the development of a property directly at the transect line.

The comparatively high changes in volume recorded at transect 4 may be linked to vegetation density. The transect was densely vegetated by *E. villosa* (Plate 3.1) and vegetation is known to increase the amount of sand trapped. This possibly amplified the volume of sand accreted in comparison to the other transects. The largest volume of sand accreted was recorded for transect 7B which consisted solely of the transverse dune (Figure 3.8 B). The vegetated hummocks at transect 7A, accumulated similar volumes of sand as transects 1-5 that are situated along the bank. Transects 8 and 9 also exhibited increases in volume from May 2000 to July 2001 albeit slightly less than the average increase of transects 1-6 (Figure 3.8 B).



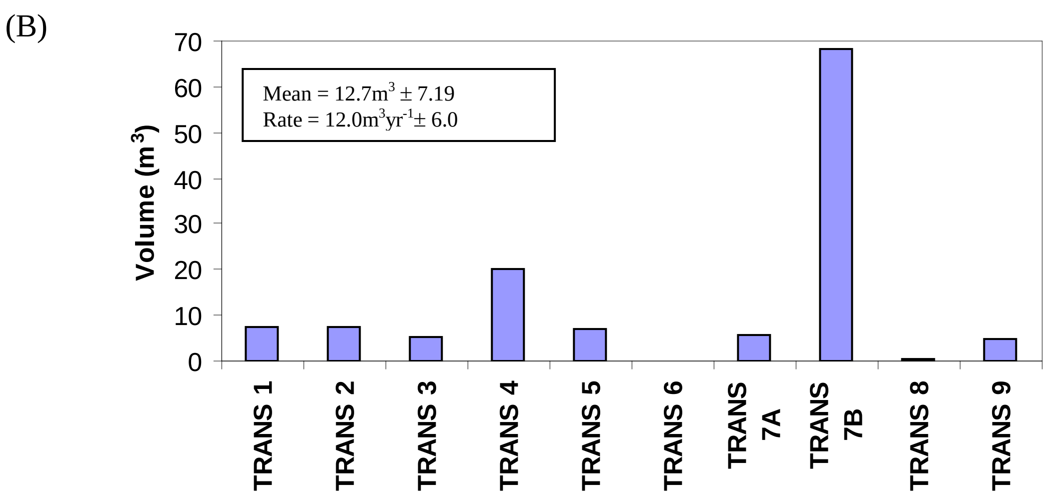


Figure 3.8. Volume changes at the study site for (A) March 1989 to July 2001 and (B) May 2000 to July 2001.

Measurements of long-term sand accretion and the rate of this accretion showed that the largest volumes and rates of accretion occurred in the south of the study site (transects 8 & 9, Figure 3.8A). This finding suggests that the WRCP dunefield might not have functioned uniformly. It is possible that, conceptually, two separate dune systems exist, one situated along the bank of the river mouth and a second adjacent to the entrance of DBV. The short-term volume changes did not seem to confirm this suggestion but rather appear to show a relationship between the amount of accretion, dune type and the presence of vegetation (Figure 3.8B). A further examination of the pattern of accretion at the site was necessary to clarify the dynamics of the site.

3.3.2. Spatial pattern of sand accretion:

North-South pattern:

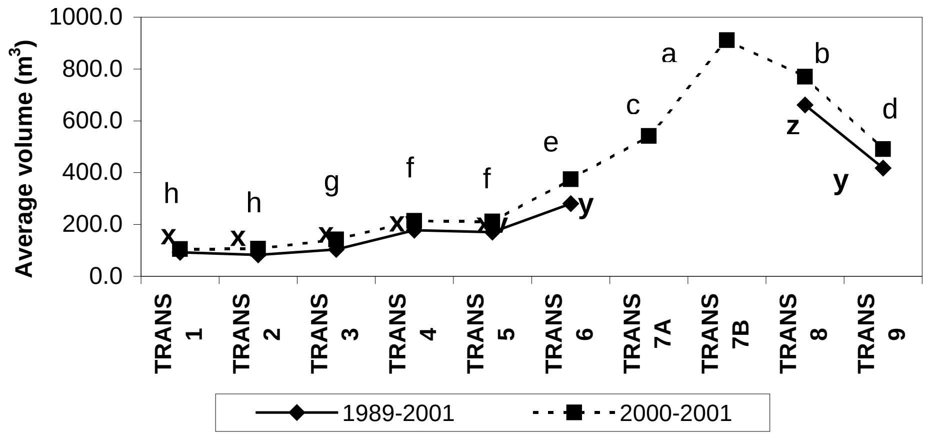
A variation in width of the WRCP dunefield (length of the transect lines) was observed that apparently follows a north-south pattern. This pattern suggests that a spatial gradient in sand accretion exists at the site. One possible explanation is that this spatial variation is related to the development of the dunefield i.e. older transects have had a greater the length of time in which to accrete sand. If this was the case then the beach width/ transect length was a function of time and not different rates of sand accretion and different transect lengths should be excluded from the study. It was equally feasible that the variation in beach width/transect line is an inherent product of the spatial variation in accretion processes and should be examined as such. To investigate and compensate for both scenarios, mean volumes per transect (Figure 3.9 A) and mean volumes per metre transect length (Figure 3.9 B) were calculated.

The pattern noted from the mean of volume of sand accreted per transect was exactly the same as that found for the mean volume of sand accreted per metre along the transect lines (Figure 3.9 A & B). A long-term trend in the volume of sand accreted is evident for transects situated along the bank of the river mouth. Mean volumes calculated for this period spanning 12 years, showed that sand volume increased from low values at transect 1 to higher values at transects 6, 8 and 9 ($p<0.001$, Figure 3.9). In general, no significant differences were recorded between transects 1-4 and 9 over the long-term although transects 1-3 contained less sand than transects 4,5, 6 and 9.

With the addition of transect 7A and 7B in 2000, the analysis of mean volumes accreted over the short-term period was extended to include the area directly west of DBV. The short-term data reveal the same trend as long-term data in that mean volumes increased exponentially from transect 1 to transect 7B. The volume of sand increased from low values at transects 1-3 to higher volumes recorded at transects 6-9. Transect 7B consisted exclusively of a mobile transverse dune that contained a massive volume of sand which was significantly different to volumes contained by all the other transects at the site.

Transects 8 and 9 were cross-sections of the study site with a south-westerly/north-easterly orientation in comparison to the east/west orientation of the other transects. Consequently, they are discussed separately since they were subject to different aeolian processes and therefore their volume calculations were not directly comparable to the rest of the site. Over both the long and short–term, transect 8 contained significantly more sand than transect 9.

(A)



(B)

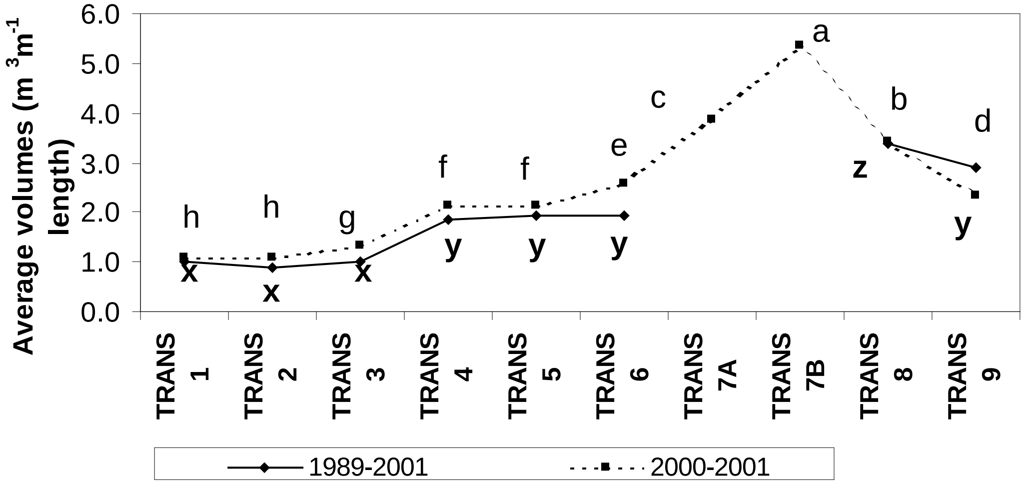


Figure 3.9. Mean volumes for (A) entire transect lengths and (B) per metre transect length over both long-term (n=7; $p<0.001$) and short-term (n=9; $p<0.001$) monitoring periods. Significant differences, if any, were obtained by Kruskal-Wallis ANOVA and Newman-Keuls post-hoc comparison of means and are denoted between transects of each series by unique letters.

Although a spatial pattern of sand accretion was evident from average volumes and average volumes per metre, these measures are static. As a 'snap shot' of average volumes calculated at a specific interval, they do not adequately reflect dynamic processes that result in the situation seen at that interval. A description of these dynamic processes was better obtained by the examination of spatial variation in sand volume over time i.e. rates of accretion, for the study area.

The long-term rate of sand accretion (March 1989 to July 2001) exhibited a weak exponential increase from north to south along the bank. The lowest rate of accretion was recorded at transect 1 and the highest at transect 6 ($R^2 = 0.57$, Figure 3.10 A). A very weak spatial trend in rate of sand accretion was observed over the short-term monitoring period from May 2000 to July 2001 ($R^2 = 0.36$, Figure 3.10 B). Transect 7B accumulated sand at the highest rate whilst transects 1-5 displayed similar rates of accretion. Unfortunately, transect 6 was not sampled in May and July 2000 due to the development of an adjacent property at this time and was therefore excluded in Figure 4.9B. Interestingly, transect 7A exhibited a rate of accretion comparable to that of the bank transects. This implied that differences in sand volume and rate of accretion at the site could possibly be linked to dune type and the presence of vegetation and not to a spatial gradient in these processes.

The spatial trend evident from the sand accretion rates explained the trend observed for sand volumes both per transect and per metre transect length. These trends suggested that the southern section of the site, adjacent to DBV was under the influence of different aeolian processes than the bank or northern sections. The differences in sediment dynamics were possibly a result of differences in the wind regime that arises from the topography of the area and the dynamics intrinsic to the type of dunes present. An investigation into the effect of the wind patterns on sand accretion was continued under seasonal patterns of accretion in this chapter.

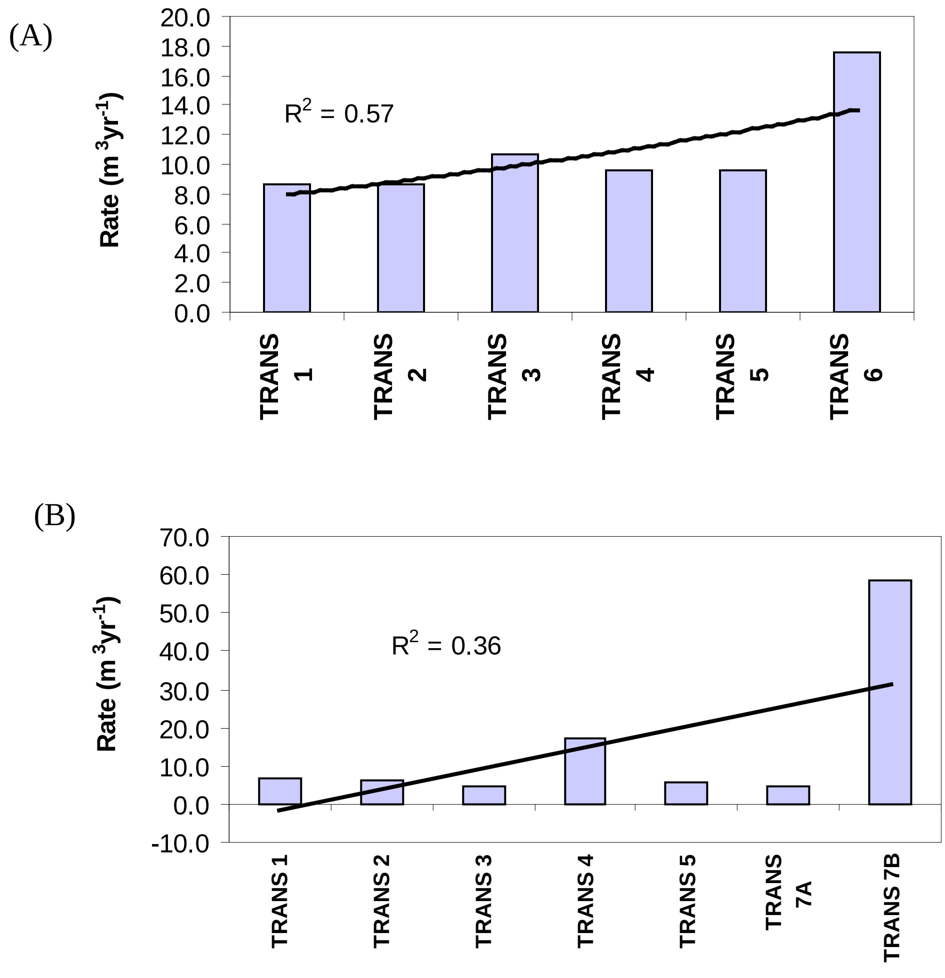


Figure 3.10. Rates of volume change for all the transects for period (A) March 1989 to July 2001 and (B) May 2000 to July 2001.

East-West pattern of sand accretion:

A distinct zonation of plant communities existed in an east to west pattern along each transect. This occurrence may be linked to patterns of sedimentation that extended from the Westbourne Road Embankment to the high water mark of the Bushman's River Mouth. An investigation of a volume change per ten metre interval during the 2000/2001 monitoring period, along each transect yielded 'active zones' where fluctuations in volume, both erosion and accretion, were most prevalent.

Along the eastern bank of the river mouth, fluctuations were evident from 10-50 m at transect 1, 20-70 m at transect 2, 10-90 m at transect 3. The active zone for transect 4 occurred from 30-100 m, 10-110 m at transect 5 and 30-130 m at transect 6 (Figure 3.11). These sections of the transects coincide with the most vegetated portions of each transect and in particular, with the dune ridge dominated by *E. villosa* (see Chap 4.2, Plate 4.2).

Active zones along transect 7A occurred between 10-60 m that consisted of vegetated hummocks (Figure 3.12). The section directly in the lee of the dune at approximately 80 m showed fewer volume fluctuations that indicated stability in this region of the transect. The transverse dune (transect 7B) was highly active as expected especially at the windward slope and slipface (120-240 m).

The upper sections of both transects 8 and 9, situated on the northern slope of a fossil dune ridge, were stable showing little change in volume. An active zone was however, evident from 30-80 m along transect 8 and was an area, comprised of vegetated hummocks, adjacent the entrance of DBV. The section spanning 90-140 m situated in the lee of a series of dune ridges, showed relatively small volume changes. A second active zone was evident between 150-190 m that corresponded to the series of dune ridges along this transect. Accretion occurred at the lower section of transect 8, in particular between 190-230 m (Figures 3.12 and 3.6). Transect 9 displayed a similar pattern of volume change along its length with fluctuations in volume occurring from 40-170 m. This finding supported the observation that progradation had occurred along this transect (Figure 3.12 & 3.6).

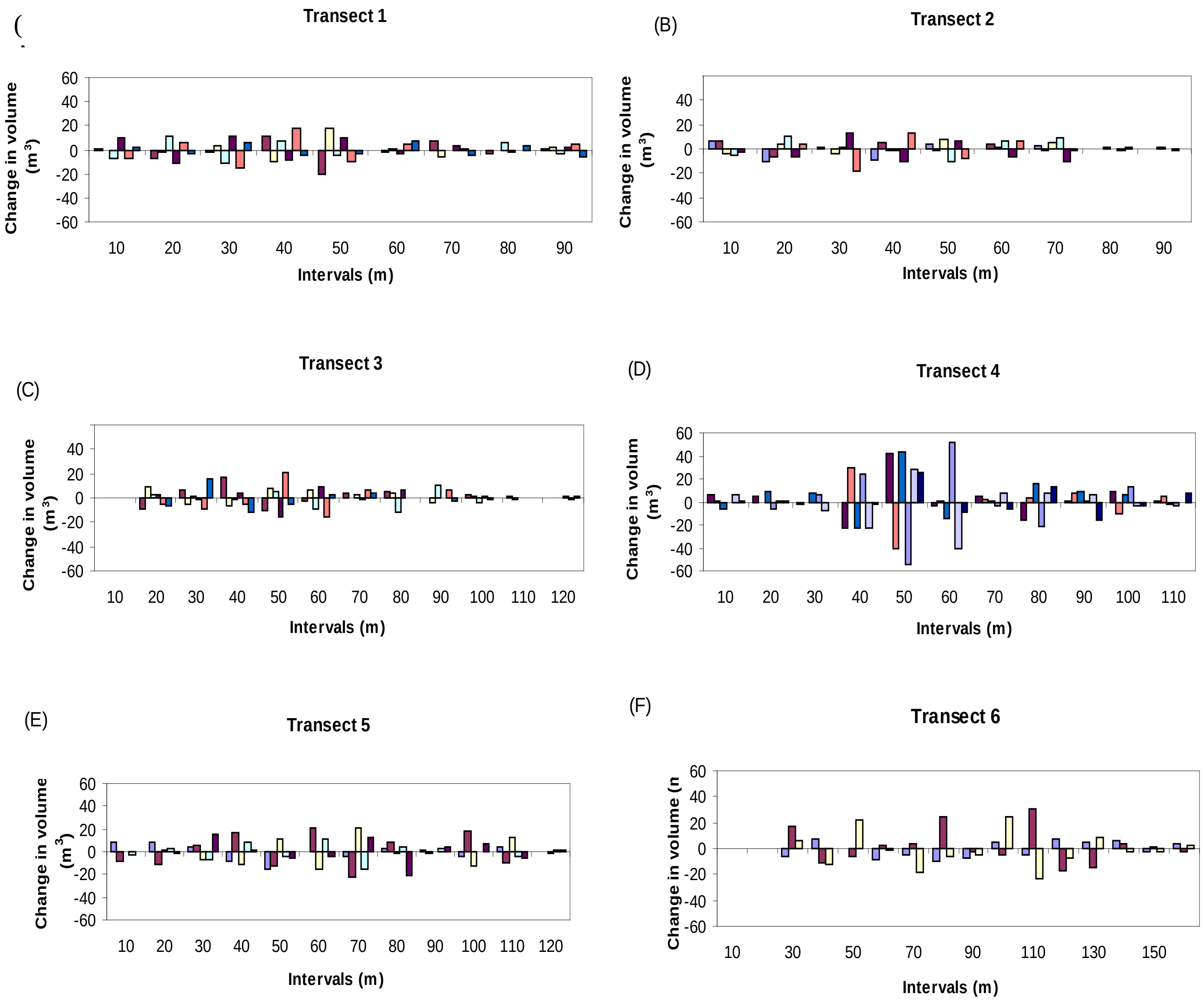


Figure 3.11: Volume fluctuations for transects 1-6 (A-F).

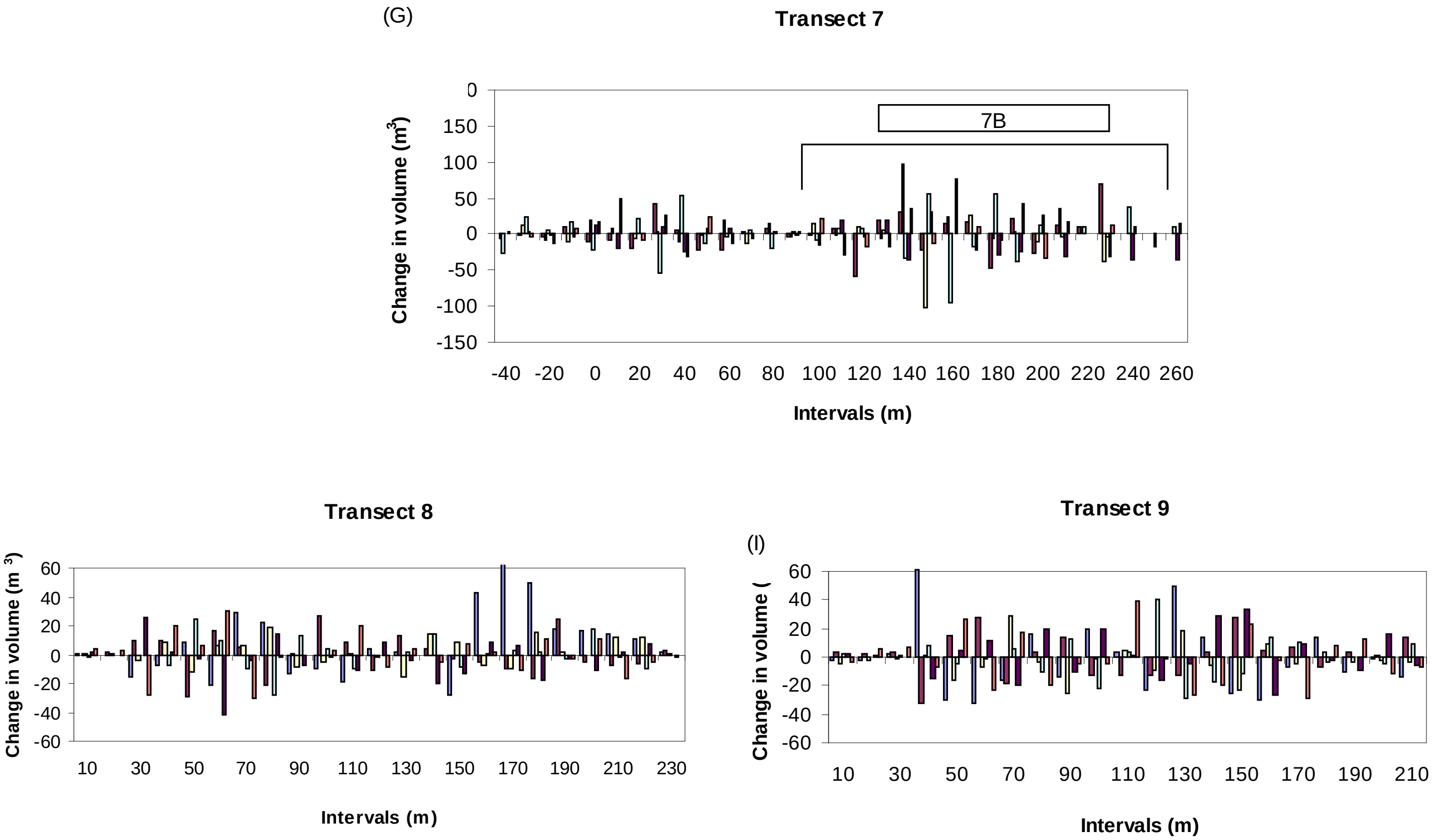


Figure 3.12: Volume fluctuations for transect 1-6 (G-I)

3.3.3 Seasonal patterns of accretion:

Wind regime from May 2000-July 2001:

Typical of the seasonal bimodal wind regime of the Eastern Cape coastline, the most frequent wind directions were the easterly and westerly winds respectively. However, the south-westerly and south-south westerly winds had a greater potential for sand transport or drift potential (DP) than the easterly wind with the highest DP recorded for the south-westerly wind at 18.8 m^3 per metre width during the study period (Figure 3.13).

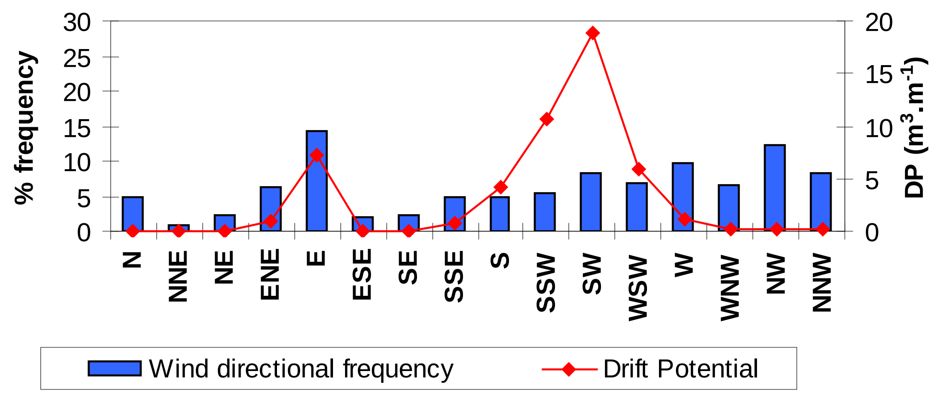


Figure 3.13: Wind frequency and drift potential (DP) for May 2000 – July 2001.

The wind regime for the study period was analysed for time intervals based on the interval between successive tacheometric surveys that loosely conformed to the seasons. This enabled a description of the wind directional frequency and potential for sand transport that corresponded directly to each specific interval between surveys and therefore explained the effect of those factors on the sediment dynamics at that time.

The north-westerly wind prevailed from May 2000 to July 2000 (Figure 3.14). The drift potential was minimal during this time and was driven by westerly winds. The period July 2000 to October 2000 appeared to be a transitional period with a prevailing westerly wind and an increased occurrence of easterlies in comparison to the previous interval. The DP of the westerlies remained dominant although the contribution of the easterlies was on the increase. The summer months from October 2000-January 2001, were dominated by the easterly wind while both the easterlies and westerlies had the potential to result in sand transport during this time.

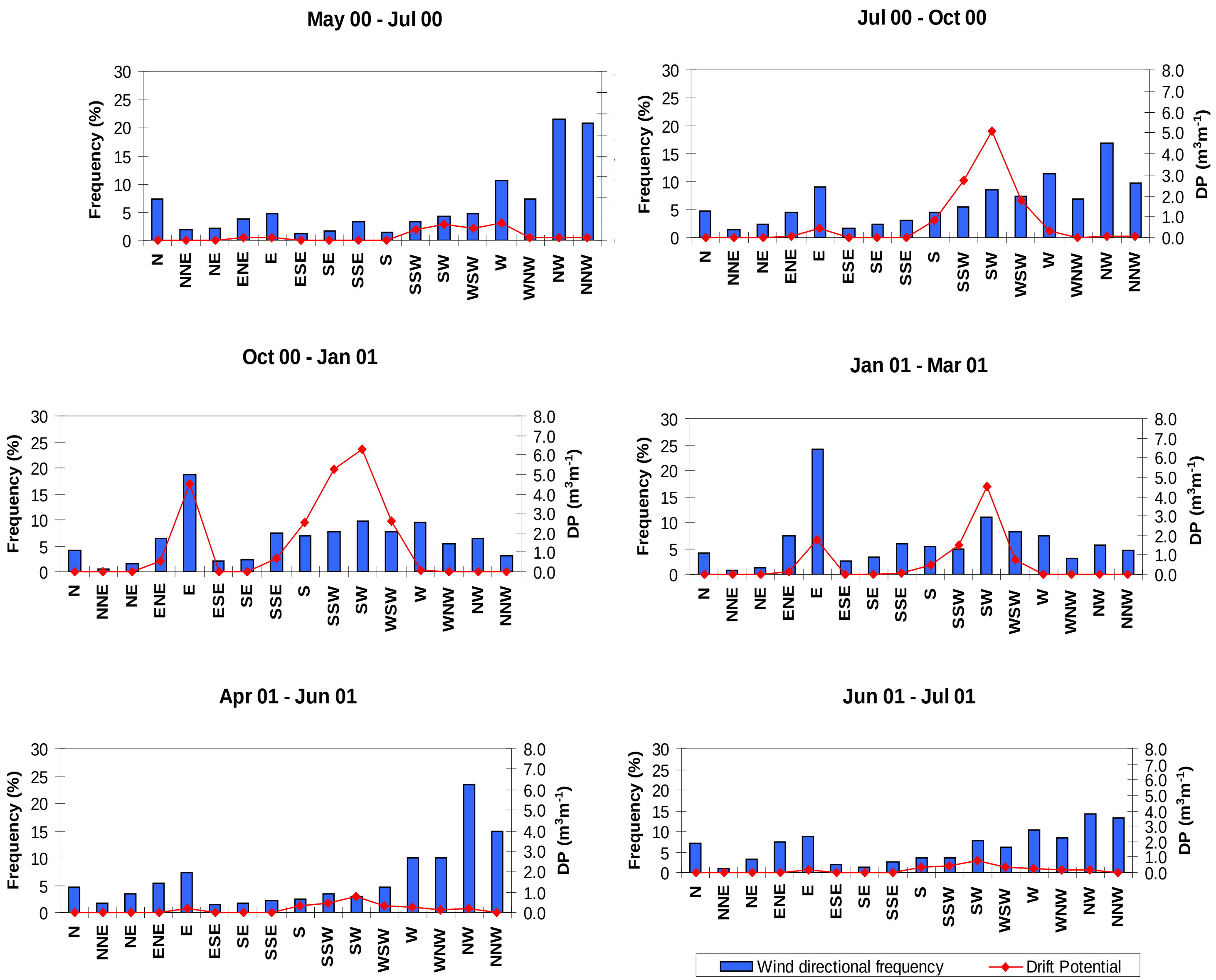


Figure 3.14: Wind directional frequency and drift potential for sample intervals beginning May 2000-July 2001.

The bi-directional affect of the wind on sand transport may result in little net change in sand volume for the period above. A similar pattern in the wind regime was seen for the interval from January to March 2001. The easterly winds prevailed whilst a concurrent high in DP for both the easterly and south-westerly winds was noted. The return of the north-westerly wind was evident during the following winter from April to July 2001. The DP over this interval was low and indicated that a diminished potential for sand transport occurred during this winter (Figure 3.14).

The Resultant Drift Potential (RDP) (Fryberger, 1979) reflects a more accurate measure of potential sand transport as it not only accounts for the strength of the wind but also the net effect of bi-directional winds on potential sand transport. The greatest RDP recorded for the study occurred from the end of July 2000 to the end of March 2001 (Figure 3.15). The highest value was recorded during October 2000 to January 2001 followed by July 2000 to October 2000 and January 2001 to March 2001.

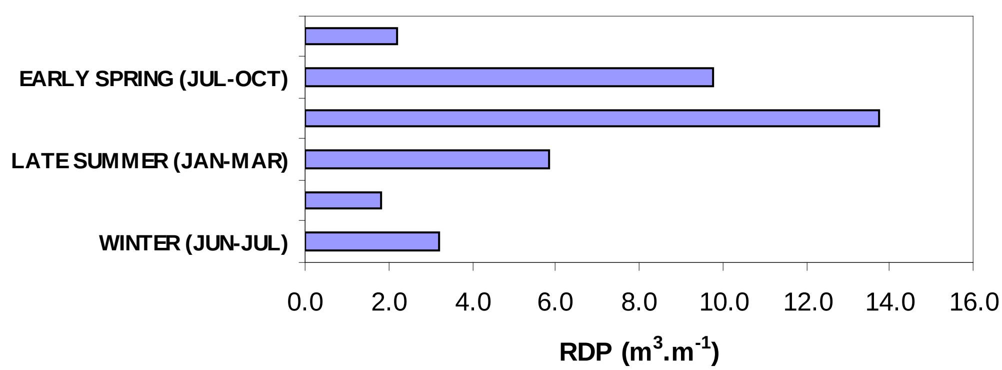


Figure 3.15: Resultant Drift Potential (RDP) for seasonal sample intervals for the study period spanning July 2000 to July 2001.

Seasonal volume changes recorded showed volume gains during early spring (Jul-Oct) and early summer (Oct-Jan). During late summer (Jan-Mar) and autumn (Mar-Jun) volume deficits were apparent for the site (Fig. 3.16). These volume changes loosely conform to seasonal changes in the wind regime but were not significantly different and no pattern of volume change emerged that linked seasonal changes in the wind regime to patterns of sand accumulation at the study site (Fig. 3.14 & 3.16). This resulted because the wind data presented were recorded at a weather station in Port Alfred, some 30km from the study site and although provides a general wind regime for the area, it cannot provide an accurate reflection of the wind dynamics.

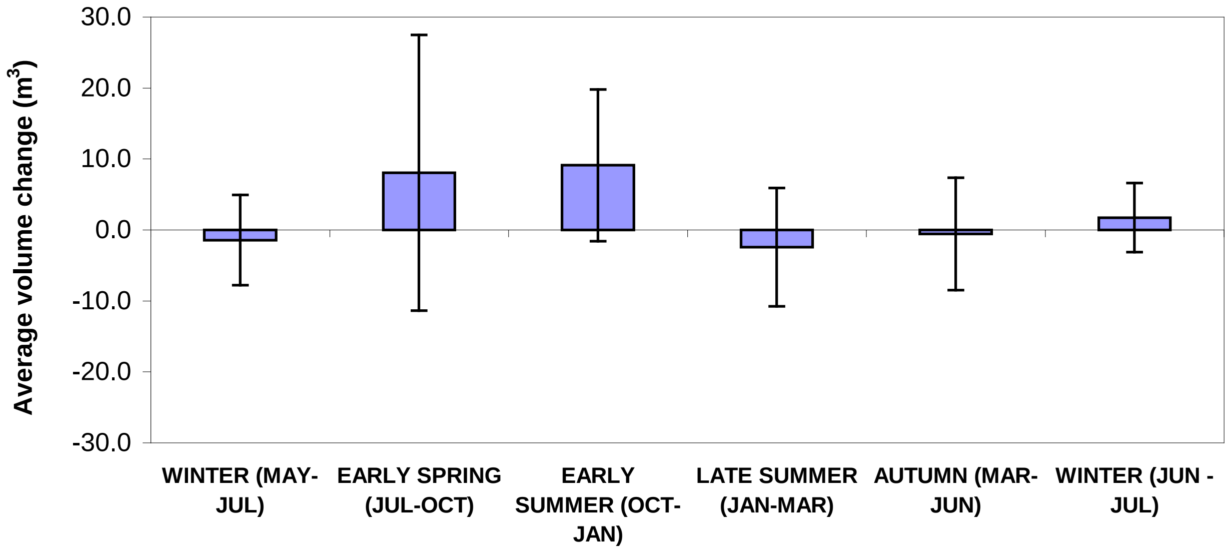


Figure 3.16: Seasonal mean volume changes for the study site beginning in May 2000 and ending July 2001.

3.4. Discussion:

Before 1955, the sediment dynamics of the study site are typical of a headland bypass system (Booysen 1995a). The analysis of aerial photos dating back to 1942 by Jacobs (1993) and Booysen (1995a) showed that sand was gradually deposited along the bank of the river mouth forming a sandy beach north-west of DBV. This expanse of sand, referred to as the WRCP dunefield, was found to be of marine origin (Baird *et al*. 1979) and was initially deposited by wave action in the south-eastern corner of the study site (Jacobs, 1993). It was thought that DBV then acted as a conduit for this sand and that it was transported to Middle beach, at the eastern end of the valley as 3 m – 4 m high transverse dunes (Burkinshaw, 1999).

The disruption of the sediment dynamics described above has manifested as a gradual and continuous accumulation of sand along the eastern bank as well as the subsequent development of the WRCP dunefield from these accretions. The dunefield has continued to expand and since 1989, the study area has experienced a total accumulation of sand. This accretion reflects as increases in the width, surface elevation and complexity of the WRCP dunefield.

The advance (or recession) of a shoreline is attributed to a prolonged imbalance between the influx and output of sand into a system (McCormick 1972). Although the sedimentation of the Bushman's River Mouth is the result of natural processes (Reddering & Esterhuysen 1981; Jacobs 1993), the accumulation of sand along the eastern bank is due to such an imbalance. The influx of sediment into the area exceeds the output of the system. The cause of this imbalance and the development of the dunefield have been attributed to a number of alterations to the surrounding environment, certain of these, natural and others, man-made. These include the following as listed by Burkinshaw (1999):

Wind field:
It was found that the wind field had a more southerly component between 1950 and 1982 at Port Elizabeth and Cape Town but returned to a more westerly component after 1982 (Schumann 1992). The implications of a more southerly wind at the site is that the wind would be deflected round the headland, decreasing the effectiveness of the south westerly wind in transporting sand down DBV (Burkinshaw 1999). Vegetation would then have been able to colonise and stabilise the sand transport corridor.

Stabilisation of the western bank:

In the early 1970's, transverse dunes on the western bank of the river mouth were stabilised using *Acacia saligna* (Port Jackson willow) and *Acacia cyclops* (Rooikrans). Prior to 1955, a dune spit located at the west bank of the river mouth was a vital component of the sediment dynamics of the area. It protruded into the river mouth forcing the channel north-eastwards and was an additional source of sand to the Westbourne Road sand bank (later the WRCP dunefield) as well as for the DBV bypass system (Jacobs 1993 & Burkinshaw 1999). Jacobs (1993) refutes the suggestion that the stabilisation of the western bank resulted in the westward migration of the river channel. Analysis of aerial photos in his study showed that the western channel was firmly entrenched prior to the establishment of the alien vegetation. The artificial stabilisation of the dunes on the west bank possibly resulted in a change in the DBV wind field causing deposition instead of the transportation of sand.

Stabilisation of entrance of DBV:

The accumulation of sand and the development of the WRCP dunefield have been attributed to the gradual stabilisation of the sand transport corridor at DBV (Booysen 1995a). Booysen emphasises the origin of the vegetation as a product of human intervention due to the stabilisation sands surrounding a well point in the west and a car park in the east. He also attributes the development of the WRCP dunefield to increases in the sedimentation in the Bushman's River Mouth and the consequent increase in height of the dunefield.

Effect of impoundments on flow volume:

Numerous farm dams and weirs have been constructed on the Bushman's River. These impoundments have resulted in a reduction in freshwater input into the river mouth to the extent that the river mouth is largely marine during non-flood periods. They also serve to decrease the number of flood events as well as the volume per flood event thus limiting the ability to flush sediment from the lower river mouth out to sea (Jacobs 1993). Tidal circulation returns sediment to the river mouth between flood periods and therefore without regular removal by small flood events, this sediment accumulates as seen along the eastern bank of the river mouth. Booysen (1995a) refers to this phenomenon as an "increase in the sedimentation in the river mouth" and thereby implies that sedimentation occurs at a greater scale than before. This, in fact, is not the case but rather stems from fewer removal events than an actual increase in amount of sediment deposited.

Effect of the road bridge:

A road bridge, constructed in 1959, crosses the Upper Bushman's estuary approximately 1.6km up-river from the mouth. Both the east and west tidal channels were spanned but an intertidal sand bar was filled. The bridge embankment constricts the river mouth to a quarter of its natural size and restricts the flow of water over the intertidal sand bar on which it is built (Reddering & Esterhuysen 1981).

Concern regarding the effect of the national road bridge on the sedimentation pattern was expressed but it was concluded that by Uncles *et al.* (in Reddering & Esterhuysen 1981) that the bridge does not effect the tidal dynamics of the river mouth in that the main tidal currents jet through the channels beneath the spans of the bridge. The effect of the bridge at flood discharges is unknown but it may be inadequate to allow for large flow volumes expected during these times (Reddering & Esterhuysen 1981; Jacobs 1993).

It is most likely that a combination of the above changes in environmental conditions led to the accumulation of sand along the eastern bank. The most notable observation evident from the continuous accretion at the site is that the sediment dynamics of the area has markedly shifted from that of a transgressive dune system to that of a retentive system (Rust & Illenberger 1996). The greater stability provided by these environmental changes facilitated the establishment of vegetation at the site – the single most important factor in the development of coastal sand dunes along the eastern bank of the Bushman's river mouth.

At present, the eastern shore of the river mouth supports a vegetated retentive dune system consisting of a variety of dune types that includes foredune hummocks, parallel beach ridge hummocks and a retention/precipitation ridge (Tinley 1985). It is a strongly accumulating environment that has evolved from a previously flat, sandy beach. The northern portion of the dunefield is comprised of a prominent foredune ridge backed by vegetated hummocks and smaller ridges (Figure 3.4 & 3.5). This area has gained significantly in sand volume that has resulted in an increase in surface elevation since monitoring began in 1989.

The initiation and evolution of these dunes are attributed to the interaction between sediment input into the system, wind and the presence of vegetation (Jacobs 1993; Booysen 1995a & Burkinshaw 1999). Once dry, sand deposited at the WRCP dunefield is transported through aeolian processes into the vegetation growing along the bank.

The vegetation then acts as a physical barrier to wind-borne sand particles while roots bind the surface layers of sand to reduce the surface area exposed to the wind. Surface roughness is increased while wind velocity and drag decreased through the presence of vegetation. This causes aeolian transported sand to be deposited within the vegetation resulting in dune formation (Wolfe & Nickling 1993; Willets 1989; Hesp 1989; Sherman & Hotta 1990; Carter & Wilson 1990; Pye 1982).

The colonisation of vegetation along the eastern bank has resulted in the formation of dune hummocks and the development of the dune ridge at the northern sections of the study site. The dune ridge is primarily colonised by *E. villosa* and an increase in the importance value of this species from 1989 to 2001 suggests that the abundance and cover of this species has increased (Plate 3.1, discussed later in Chapter 4.). This increase has lead to additional sand trapped and the subsequent increase in height observed along the ridge. Furthermore, the foredune ridge has begun to prograde westward since March 2001 as a result of the ability of *E. villosa* to colonise the bare sand deposited along the bank thereby initiating progradation (Figures 3.4 & 3.5).

The southern portion of the dunefield is distinctive as it features, in addition to a tract of vegetated hummock dunes, a mobile transverse dune that is not usually associated with vegetated dune systems (Figure 3.6). This dune was formed as a result of the destabilisation of an area previously colonised by *E. villosa*. Destabilisation possibly occurred because the vegetated hummocks were inundated by sand to such an extent that the vegetation could no longer survive burial and thereby released the entrained sand (Burkinshaw 1999).

The effect of the bi-modal wind regime of the Eastern Cape is obvious in the sediment dynamics of the transverse dune. Under the influence of the westerly winds, the dune develops a well-defined slipface, the crest flattens and rounds and the dune migrates eastward. The effect of the easterlies is to ‘push’ the crest into a ‘pointed’ shape thereby increasing dune height as well as retarding the dunes migration (Figure 3.6 & 3.18). The net movement of the dune remains easterly at a rate of 9.00 m yr^{-1} that corresponds to rates of migration from other studies of transgressive dunes of the south coast of South Africa (Hesp *et al*. 1989).

The apparent difference in the sediment dynamics between the northern and southern sections of the study site posed the question as to whether two separate systems, each with their own dynamics, were supported at the study site. A comparison of sedimentological processes revealed that a spatial variation in these processes did occur from north to south. Total volumes showed that the distribution of sand across the study site was not equal in that the south-eastern section contains a greater volume of sand than the northern section (Figure 3.9). Static measures such as absolute volume are not, however, an adequate indication of the dynamic processes as they simply represent a ‘snapshot’ in time. Volume change, i.e. the amount of sand accumulated, as well as the rate of accretion best represent sedimentological processes in this case.

Long-term volume change and rates of change at each transect indicated that a weak exponential increase in sand accumulation occurred along the bank only (Figure 3.10.A). Unfortunately, the area adjacent to DBV was not included in the original study rendering a long-term comparison between the bank and DBV section of the site impossible. The observed spatial variation of long-term volume and rate of change across the bank area was due to a combination of three factors.

Firstly, the sediment supply/deposition increases from north to south. Due to the configuration of the river mouth and the prevailing winds, the pattern of wave action in the river mouth results in the deposition of sand in a north westerly direction. The oldest portion of the WRSB is thus the south-eastern corner adjacent to DBV while recent deposits are situated sequentially from south to north at the foot of the Westbourne Road embankment. Assuming wave action has not altered, it is possible that this pattern of deposition continued over the last twelve years and that a slightly greater amount of sediment is still deposited in the south-eastern corner of the site.

Secondly, it is possible that differences in wind speed occur along the eastern bank of the river mouth. Observations during westerly wind events show that the study site is slightly more sheltered from these winds as one moves further north along the bank. A well-vegetated ridge and numerous houses on the western side of the Bushman’s river mouth could provide this shelter. A further study to determine a wind speed profile along the bank of the river mouth would confirm these observations.

The third factor that influences the pattern of accumulation observed is the hydrology of the Bushman's river. In 1989, a saltmarsh community was present at the northern end of the study site. The existence of this vegetation community strongly indicates that this portion of the bank area was still inundated by water. The removal of sediment from this portion of the sandbank is highly likely as a resulted of the tidal inundation. The volume change therefore recorded since that time reflects both erosion and accumulation although accumulation was dominant. In addition to a potentially greater sediment supply and less fluvial erosion, the presence of dune vegetation would have increased the amount of sediment accumulated and stored as early as 1989 further south along the bank.

Analysis of short-term changes in the amount and rate of accumulation shows a lack of any trend across the site (Figure 3.10. B). The results, however, show a discrete difference between transects are situated along the northern, bank area and the transverse dune in the south of the site. Transects located along the bank area accumulated similar amounts of sand at similar rates while the transverse dune shows a significantly greater gain in volume at a faster rate than the bank area. Differences in volume and rate of change between the two sections are attributed firstly to possible differences in wind regime caused by the topography of the area and secondly to the inherent dynamics of the dune types present.

The surrounding topography at the site is such that the northern section, hereafter referred to as the bank section of the site, is sheltered from the easterly winds by a ridge situated east of the study site. The influence of this wind direction along the bank (transects 1-6) is thus minimal as seen from changes in volume at these transects during the easterly wind season (Figure 3.16). The effect of the easterly winds is far more pronounced at the southern section of the site as DBV offers a largely unobstructed corridor down which the easterly wind is channelled. Seasonal change in the morphology of the transverse dune at transect 7(b) in response to the easterly winds reflects this influence (Figure 3.17).

A difference in the influence of westerly winds is also apparent at the site albeit to a far lesser extent. A ridge, similar to that found on the eastern side of the river mouth, exists on the western bank. This ridge may also dampen the full force of the westerly winds at the bank section as described previously. The westerly wind flows parallel to the coastline and is unimpeded along the southern portion or DBV section of the study site. This wind direction is responsible for development and migration of the transverse dune.

Contrary to expectations, the tract of vegetated hummocks (transect 7A) also situated adjacent to DBV, does not exhibit significantly higher volume or rate of change than the bank section (Figure 3.10.B). The tract lies between a bush pocket in the east and in the lee of the transverse dune in the west. These two features influence both the easterly and westerly wind to such an extent that the rate and volume of accumulation is similar to that of the bank. The bush pocket does not significantly influence the effect of the easterlies on the transverse dune because the dune is higher than the canopy of the vegetation and therefore experiences unimpeded flow above the vegetation canopy.

The dynamics intrinsic to the type of dunes present also explains differences between the bank system and the transverse dune. The bank dune system is a retentive dune system where sand accumulation within vegetation is the dominant sedimentological process. Retentive systems are comparatively static and act as local sand sinks storing sand in the littoral active zone (Rust & Illenberger 1996). By comparison, transgressive dune systems are characterised by the dynamic down-wind movement of sand and occur where sand transport is dominant. The main "morphologic element" of transgressive dunefields is the transverse dune, such as that found at transect 7B (Hesp *et al*. 1989). These dunes are highly dynamic and can often display rapid changes in morphology and position, which in turn, manifests as change in volume.

The mere presence of the transverse dune suggests that a difference in sedimentological processes occur between the bank area and the DBV area but biological factors such as the presence/absence of vegetation could also account for the existence of the dune. Although prevalent on the South African coastline, transgressive dunes are not as common on other moderate energy coasts for example, the Australian coast. Hesp *et al*. (1989) maintain this to be a consequence of the presence and growth of highly aggressive sand–trapping, pioneer species in Australia. In the absence of plants to trap sand and with the additional factor of a high sand supply, transgressive dunes form instead of foredune plains or parabolic dunes such as those found in Australia. The destabilisation of the area that now supports the transverse dune was the main factor that resulted in its formation. The success of *E. villosa*, the dominant pioneer species at the site is thought to be associated with a high water table and the availability of nutrients along the shoreline (Lubke, *per comm*).

It is possible that the hummock dunes colonised by *E. villosa* at this locality increased to an elevation that prevented the vegetation from accessing the water table. Consequently, the vegetation would die back, destabilisation occurred and the transverse dune was formed downwind.

The investigation of sedimentological processes at the site has thus revealed that a spatial variation in the sediment dynamics of the site does occur. Long-term spatial variation of processes reflects the temporal pattern of the development of the WRSB. The variation in sand accumulation and rate of accumulation across the site is related to the manner in which sand was deposited and transported along the eastern bank of the river mouth over twelve years. Factors that influenced the temporal development of the sandbank include the pattern of wave action in the river mouth that resulted from the configuration of the river mouth, hydrology of the Bushman's river, local wind regime and topography.

The spatial variation evident from short-term analysis of volume and rate changes at the site results from the unique sediment dynamics of the dune types present as well as the local wind regime. The one-year time span over which the analysis is conducted eliminates the long-term sedimentary processes of the river mouth. It therefore offers an insight into the current variation of processes that result in sand transport and storage such as the wind regime, sediment supply, presence and abundance of vegetation.

Whether the spatial variation in processes constitutes the presence of two separate dunefields is inconclusive. Four major coastal dune complexes are recognised in South Africa namely, foredunes, relict foredune plains, parabolic dunes and transgressive dunefields (Hesp *et al*. 1989). The evolution and morphology of these complexes determines whether a set of dunes is classified as a dunefield (Hesp *et al*. 1989; Tinley 1985). Tinley (1985) however, states that "many combinations of dune types exist and an almost endless number of varieties" and that most coastal dunes are compound or complex where two or more dune types occur together. The formation of the transverse dune upwind from DBV could be construed as the potential re-activation of the headland bypass system along DBV. It is more likely that the transverse dune and the vegetated dunes form part of a single complex dunefield (after Tinley 1985). The formation of a second transverse dune in the wake of the first would be stronger evidence toward a reversion in the dynamics to a transgressive system in addition to the retentive bank system.

An east to west spatial pattern of volume fluctuations (accumulation and erosion) was also observed (Chapter 4.1). The presence of vegetation has been found to reduce potential landward aeolian transport between 35% to 88% depending on the density of the vegetation on Israeli coastal dunes (Goldsmith *et al*. 1990). It was therefore expected that the greatest gains in volume would occur where sand-trapping is greatest for example, foredune zones. Findings showed only that the presence of vegetation resulted in the greatest fluctuations in volume along the length of the transect lines, in particular accretion. It is probable that due to the extremely localised nature of sand-trapping by vegetation and the short monitoring period (14 months) that the specific distribution of volume changes within successive plant communities could not be recorded at the scale of the surveys.

A seasonal variation in processes (accumulation) emerged when seasonal variations in wind regime and volume change were analysed. Although seasonal changes in volume were not significantly different between intervals, the trend can be linked to changes in the annual wind regime. The greatest changes at the bank area are recorded for periods during which the resultant drift potential was high i.e. when the potential for sand transport by wind (either direction) is at a maximum (Figure 3.15). The results also indicate that these periods coincide with intervals during which the drift potential of wind with a westerly component was higher than that of any other wind direction (Figure 3.14).

This occurs because the study site is relatively exposed to the westerly winds and during this season, sand-laden wind blows directly into the vegetation present along the bank where it is trapped and reflects as a gain in volume. Periods during which the resultant drift potential was low indicating that few wind events occurred at a sufficiently large magnitude to transport sand, showed the lowest changes in volume. As mentioned before, the effect of the easterlies at the bank section is decreased as a result of the immediate topography at the area. The comparatively unimpeded influence of the easterlies is however, evident at the transverse dune. Changes in morphology and position of the dune translate accordingly to changes in volume in accordance with the prevailing wind direction of that interval. The effect of topography on the influence of wind directions at the site is discussed earlier.

In summary, this study revealed that the sediment dynamics of the study site differed considerably from the headland bypass dune system previously documented from observation and anecdotal evidence. A retentive dune system developed through the interaction between sand, wind and vegetation. Factors that influence the past and present development of the retentive dunefield include the presence and vigour of vegetation, sand supply, topography, seasonal wind regime, configuration of the river mouth, dune type, wave patterns and hydrology of the Bushman's River. It is likely that the dunefield will continue expanding until a significant change occurs in one or more of the above-mentioned factors.

CHAPTER 4
VEGETATION DESCRIPTION AND ANALYSIS

4.1. Introduction:

Historically coastal dunes were perceived to be systems of low diversity and conservation importance but recently the intrinsic value of these ecosystems has been emphasised (Rickard *et al*. 1996; Kerley *et al*. 1996; Sanjeevi 1996; van Bohemen 1996; Verstrael 1996). They provide a good opportunity to study vegetation dynamics due to the continuous formation of new land through natural processes. (Hansen & Vestergaard 1986). Furthermore, dune vegetation plays a vital role in the formation and stabilisation of coastal sand dunes (Tinley 1985; Hesp 1983; Arens 1994; Musick 1996; Heyligers 1985; Carter & Wilson 1990; Hesp & McLachlan 2000). The establishment of vegetation on newly formed dunes creates environmental conditions that facilitate the colonisation and growth of a wider range of species thereby giving rise to subsequent inland coastal vegetation (Lubke & van Wijk 1998). Coastal dunefields are therefore highly relevant to the current debate on the conservation of biodiversity (Kerley *et al*. 1996).

In addition to the inherent ecological value of coastal dune vegetation, the majority of coastal management techniques pivot on the manipulation of dune vegetation to manage the entire system (Westoff 1989; Avis 1992; Hellström 1994; Kooijman *et al.* 1996; Lubke *et al.* 1996; Hertling 1997; Myerscough *et al.* 1996; Warren & Topping 1999; Shuwen *et al.* 2001; Jochimsen 2001). Dune plant communities are not static but are constantly changing in response to dynamic environmental processes in the coastal ecosystem (Lubke & De Moor 1998). These management strategies are therefore mostly concerned with the management of seral vegetation communities that result from active successional processes. The successful development and implementation of such strategies requires a comprehensive understanding of the underlying processes that result in and influence vegetation dynamics. This study attempted to provide decisions-makers at the Bushman's River Mouth with such an understanding of vegetation processes.

Coastal dune succession:

Through classifying patterns, processes and mechanisms of vegetation change, ecologists have tried to gain a greater understanding of vegetation succession (Glenn-Lewin *et al. 19*92). Succession remains as the oldest, most basic and controversial of ecological concepts. Philosophies of succession have undergone much review since it's inception by Cowles and Clements early last century, yet no single paradigm has been adopted as a framework for vegetation change. McCook (1994) conducted a review of successional theory as follows:

Early conceptual trends explained succession as a system of unidirectional, sequential processes leading to the development of climax vegetation communities. The sequential dominance of certain species was thought to arise from the modification of the environment making it more favourable to new invading species (McCook 1994). The facilitation models consisted of a number of sequential processes. Processes included, nudation of an area creating a 'bare' site for potential colonisation by species; migration and establishment of species as well as interactions between different species and species and their environment. In each case a stable state or equilibrium was reached in the climax. The main assumption of this school of thought is that the physical environment remains constant for extended periods and that successional change is a consequence of interactions within the community alone.

These early facilitation models were heavily criticised for overgeneralizations by numerous authors and gave rise to individualistic or stochastic models of succession (McCook 1994). Tansley in 1935, argued against the assumption that a climax state would always have the same species composition, as differences in local geology; topography etc. should result in different communities (Glenn-Lewin *et al.* 1992). Similarly, Gleason (1926) emphasised the individualistic behaviour of species that would result in an overlap of community distributions based on common environmental tolerances (McCook 1994).

In 1954, Egler expanded on Gleason's model (Glenn-Lewin *et al.* 1992). The philosophy was adopted that the appearance of a successional sequence is a result of differences in growth rate of species that allows certain species to eclipse the growth of other species that dominate later (McCook 1994). Similar to Egler's argument, Drury and Nisbet showed that vegetation abundance patterns included not only successional replacements but also cycles and divergences (McCook 1994). Connell & Slatyer (1977) proposed three alternative models of succession based on these findings, namely the facilitation, tolerance and inhibition pathways (Figure 4.1). As with early concepts, these pathways were heavily criticised and described as "essentially empirical descriptions or classifications without explicit mechanistic bases". Contemporary theories regarding succession reject concepts of species replacement and embrace the view that succession is the result of interactions of species with each other and their abiotic environment (McCook 1994).

Conceptual trends include a shift from holistic explanations toward mechanistic approaches that emphasise the role of local system dynamics in causing vegetation change. Modern succession theorists describe succession as 'dynamic' and refrain from assuming long-term site stability or the existence of an 'end point' to the process. The importance of disturbance and patterns in the physical environment over a temporal scale as well as life-histories and population dynamics of species are strongly emphasised (Glenn-Lewin *et al.* 1992, McCook 1994). This introduces the concept of multiple successional pathways for any one situation. Pathways can be progressive, moving from pioneer community to a climax stable community (Avis 1992). Retrogressive pathways are usually reflected by decreases in species diversity and biomass in comparison to pre-existing community (Woodwell & Whittaker 1968). Even cyclic pathways have been discovered where regular disturbance re-initiates a sequence of processes (Ranwell 1960).

Despite the controversy in the attempts to quantify and describe the patterns of processes observed from changes in vegetation communities, one pertinent factor is highlighted. Natural communities exist in a dynamic state of continuous change in response to varying environmental and biological conditions (McCook 1994). The patterns observed are multifaceted and highly complex especially in ecosystems subject to persistent and dynamic formative processes as the coastal dune environment.

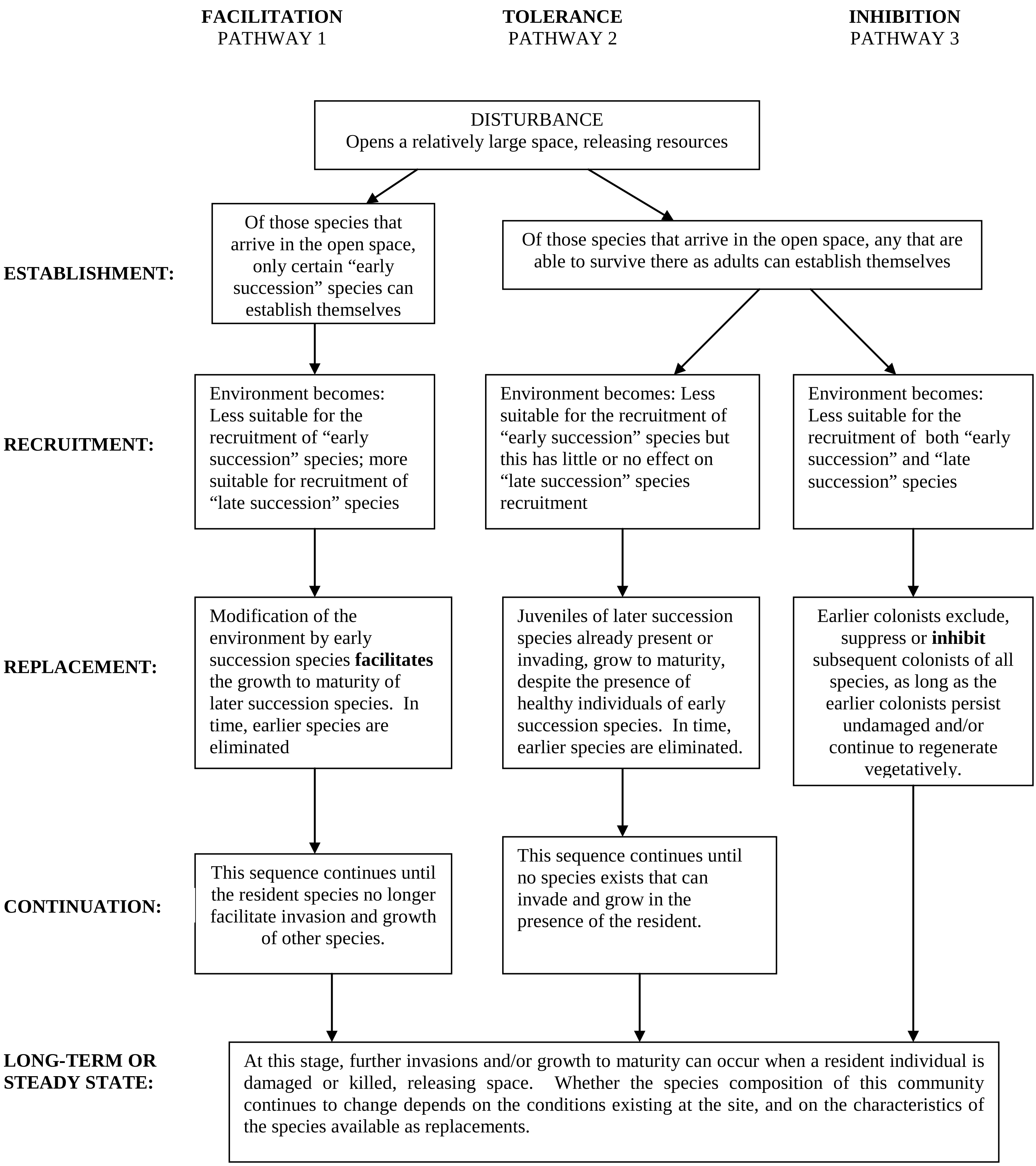


Figure 4.1. Alternative pathways of succession proposed by Connell & Slatyer (1977).

Specific aspects of the vegetation dynamics of the study site were examined in this study. A quantitative overview of the dune vegetation of the WRCP dunefield was conducted to compare and record changes between past and present vegetation communities. Spatial and temporal changes in the structure of these communities were also examined to describe succession as well as identify successional pathways that result in the community structure observed at the site.

4.2. Methods:

Data processing;

To investigate changes in vegetation structure and composition, each metre of the transect was sampled. All the species were recorded and the species richness, number of individuals per m^2 (density) and percentage cover was noted. These parameters were then used to calculate percentage frequency, species importance values, Simpson's diversity, Shannon's diversity, Simpson's dominance and equitability.

The importance values (I.V.) of each species per sample interval were calculated for each transect as the sum of the relative density, cover and frequency of that species:

$$\text{I.V.} = Rd + Rc + Rf$$

Where: Rd = Relative density

Rc = Relative cover

Rf = Relative frequency

Relative density is defined as the number of individuals of a species within the sample as a proportion of the total density of the sample. Relative cover is the percentage cover of a species as a proportion of the total cover within each sample. Relative frequency is the probability/chance of finding a species in a given sample area relative to the total percentage frequency of all the species of a given sample.

Simpson's diversity index (*D*) takes into account both species abundance and species richness. It was calculated by determining the inverse of the sum of proportions that individual species contribute to the total sample. The equation for these indices is as follows:

$$D = \frac{1}{\sum_{i=x}^{s} Pi^2}$$

Where: s = Total number of species present in the sample

Pi = Proportion of individual or biomass that an individual species contributes to the whole sample.

Simpson's dominance index was obtained as the reciprocal of the Simpson's diversity index. As a comparison, Shannon's diversity index (*H*) was also calculated as per below:

$$H = -\sum_{i=1}^{s} Pi \ln Pi$$

Where: s = Total number of species present in the sample

Pi = Proportion of individual or biomass that an individual species contributes to the whole sample.

This index assumes that an infinitely large population is randomly sampled and that all the species from the community are present in the sample. It also assumes that the complete species composition of the study site is known which may not be valid in every case (Kent & Coker 1992). In addition to the species richness of an area, the "evenness" with which the individuals are distributed among the species present in a community or area is also important. Equitability is a measure of this evenness and was calculated using the following equation (Begon *et al*. 1996):

$$E = \frac{D}{D_{max}} = \frac{1}{\sum_{i=x}^{s} Pi^2} \times \frac{1}{S}$$

Where: D = Simpson's diversity

D_{max} = S = maximum possible value D would assume if all individuals were evenly distributed among the species present.

s = Total number of species present in the sample

Pi = Proportion of individual /biomass that an individual species contributes to the whole sample.

Data analysis:

Two Way Indicator Species Analysis (Twinspan) was carried out to classify the vegetation data into plant communities using the software, Community Analysis Package (CAP,© Pices Ltd., 1999 ver 1.42). This technique makes use of reciprocal averaging to produce a dichotomy of samples and /or species. This dichotomy is refined through iterative process until the user-defined minimum group size is achieved (CAP 2001). Groups of samples / species are placed near one another based on their floristic similarities. The resultant outputs of Twinspan were species and sample dendograms that illustrate the grouping of species and samples. An indirect gradient analysis of the vegetation data was performed by means of Detrended Correspondence Analysis (DCA), using the DECORANA option in CAP. Vegetation data from March 1989 and July 2001 were analysed to determine the community structure for both periods.

The Sørenson's coefficient of similarity was used to calculate the similarity in species composition between communities identified by Twinspan analysis based on species presence/absence data (Kent & Coker 1992; Avis 1992). Analysis was performed using the Community Analysis Package (CAP, © Pices Ltd., 1999 ver 1.42).

Analysis of each transect incorporating all time intervals were also conducted to identify successional pathways for the site. A chronological sequence of community change was produced by DCA analysis to describe the mechanism or pathway by which this change occurs. Samples were categorised by distance along the transect and the chronological sequence tracked for each distance category. The sequence of samples which best described the change exhibited by all samples in that distance category was highlighted on DCA plots. Samples from each distance category are distinguished by colour on the plots as follows:

Table 4.1: Colour key for DCA sample plots (distances dependent on length of transect).

COLOUR CODE	DISTANCE ALONG TRANSECT
RED (Upper section)	5 – 10m
GREEN (mid-section)	20 – 60m
YELLOW (mid-section)	70m
BLUE (lower section)	80-200m

4.3. Results:

4.3.1: Vegetation description:

Community classification and distribution:

In 1989, the eastern bank of the river mouth supported five communities as identified by TWINSPAN species classification. These were pioneer, enriched pioneer, open scrub, closed scrub and saltmarsh communities (after Avis 1992, Fig. 4.2.). The total species richness for the study site at this time was 31 species.

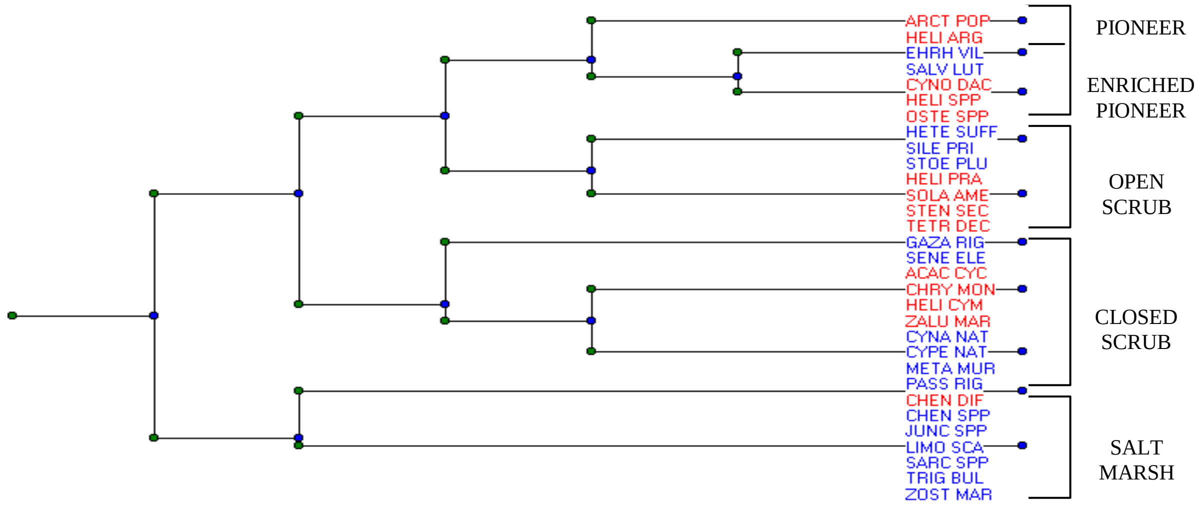


Figure 4.2. Species dendogram showing communities present in March 1989. See Appendix 1 for species abbreviations.

The saltmarsh community existed at the northern edge of the study site indicating that tidal inundation of the WRSB still occurred at least up to this section of the bank in 1989 (Figure 4.3.). Species present included *Triglochin bulbosa*, *Sarcocornia spp*., *Spartina maritima* and *Juncus spp* (Figure 4.2). Species diversity and equitability was high while species dominance was low (Table 4.2.).

Table 4.2. A comparison of community types revealed by Twinspan classification in 1989.

	SALT MARSH	PIONEER	ENRICHED PIONEER	OPEN SCRUB	CLOSED SCRUB
Total mean % cover	55.07 ±4.87	12.20 ±9.22	7.57 ±8.15	12.83 ±19.49	46.5 ±27.80
Species richness	7	5	6	22	16
Mean no. of species	4.33 ±1.53	1.70 ±0.57	1.04 ±0.21	5.15 ±1.46	5.40 ±1.64
Simpson's diversity	3.20	1.84	1.06	5.23	5.98
Simpson's dominance	0.31	0.54	0.95	0.19	0.17
Equitability	0.46	0.37	0.18	0.23	0.37

The pioneer community consisted of the herbaceous dicots and grasses dominated by *Arctotheca populifolia* and *Ehrharta villosa.* Other species present in this community type were *Syncarpha argentea* (previously known as *Helichrysum argentum*) and *Daispermum suffructicosum.* This community was found closed to the high water mark as vegetated hummock dunes at the southern, and most exposed, end of the study site (Plate 4.1, Figures 4.2 & 4.3). Species diversity and equitability was low while species dominance was high.

Plate 4.1. Pioneer hummocks at Bushman's River Mouth.

The sparsely vegetated, enriched pioneer community occurred along foredunes that ran parallel to the river, north and east of the pioneer community (Plate 4.2, Figure 4.3.). The grass, *Erharta villosa* dominated this community but was interspersed with other species such as *Cynodon dactylon*, *Helichrysum spp.* and *Osteospermum fructicosum* (Figure 4.2). Species diversity, percentage cover and equitability were lower than that of the pioneer community while species dominance as high (Table 4.2.).

Plate 4.2. *E. villosa* dominated enriched pioneer community forming a low foredune ridge.

The open scrub community was located east of both the pioneer and enriched pioneer communities behind the foredunes in 1989 (Figure 4.3.). The foredunes protected this region from harsh environmental conditions and allowed for the colonisation and establishment of species less tolerant to mobile sands. Prominent species include grasses such as *Stenotaphrum secundatum*, the herbs, *Daispermum. suffructicosum, Tetragonia decumbens* and *Helichrysum praecinctum* as well as shrubs such as *Stoebe plumosa* (Figure 4.2.). Species richness was high in this community type and reflected as a high species diversity and equitability at the site. Species dominance was low and percentage cover was moderate but variable (Table 4.2.).

Plate 4.3. Open scrub situated behind the foredune ridge (from De Villers 1987).

Located along the foot of the Westbourne road embankment and adjacent to the entrance of DBV was the closed scrub community (Figure 4.2. & 4.3.). This community differed from open scrub due to the presence of the woody shrubs, *Passerina rigida* and *Metalasia muricata.* These two shrubs are indicators of closed scrub at the site. This community had a greater cover and density than open scrub (Plate 4.4). Other shrubs present included *Chrysanthemoides monolifera*, as well as the herbs *Gazania rigens*, *Senecio elegans*, and the sedge, *Cyperus natalensis* (Figure 4.2.). The closed scrub had the highest percentage cover and species diversity of all the community types identified during this period. Species dominance was also low with a high equitability of species (Table 4.2.).

Plate 4.4. Closed scrub community at DBV. Consists of a variety of herbs, grasses and woody shrubs such as *C. monilifera* (from De Villers 1987).

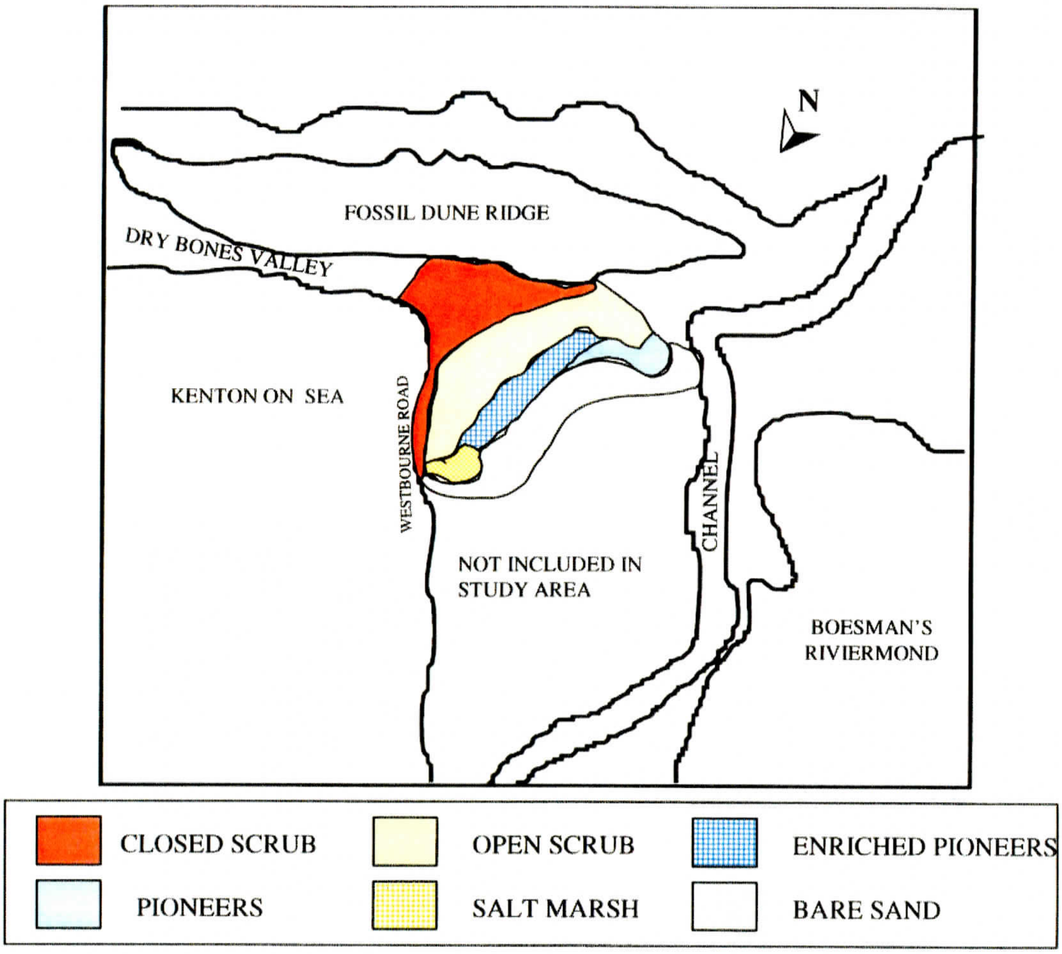


Figure 4.3. Schematic representation of the distribution of communities at Bushman's River Estuary in March 1989. Based on sample ordination.

TWINSPAN species classification of 2001 vegetation data revealed five communities along the eastern bank. The saltmarsh community of 1989 was no longer present while a scrub-thicket community developed in addition to pioneer, enriched pioneer, open scrub and closed scrub communities (Figure 4.4.). Although only two species made up the pioneer community of 2001 namely *E. villosa* and *S. virginicus*, the high equitability of these species was reflected by the species diversity and low species dominance (Table 4.3.).

The dense enriched pioneer community present at this time consisted of a mixture of grasses and herbaceous species that was situated along the foredunes further west than the other communities (Figure 4.4. & 4.5). Similar to the enriched pioneer community of 1989, a low species diversity and high dominance were recorded (Table 4.3). *E. villosa* has remained the dominant species of this community and an increase in both cover and abundance resulted in the formation of a foredune ridge. Other species present in this community included *Ipomoea pes-caprae,* a small, prostrate creeper that build characteristic dune hummocks as well as the grass *Sporobolus virginicus* (Figure 4.4. & Plate 4.5).

Plate 4.5. Enriched pioneer community in 2001 situated along a foredune ridge.

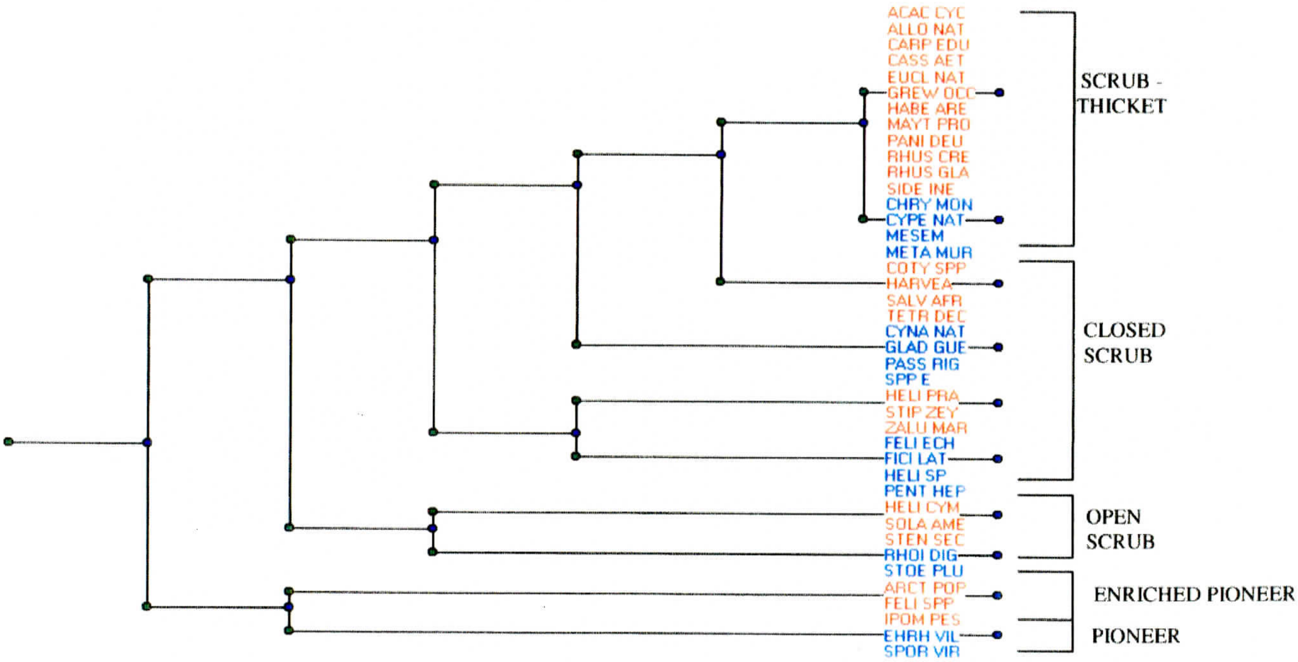


Figure 4.4. Species dendogram showing communities present in July 2001.

Table 4.3. A comparison of community types revealed by Twinspan classification in 2001.

	PIONEER	ENRICHED PIONEER	OPEN SCRUB	CLOSED SCRUB	SCRUB THICKET
Total mean % cover	3.63 ±3.7	16.01 ±17.28	27.74 ±17.46	40.26±25.60	46.5±12.07
Species richness	2	12	15	20	19
Mean no. of species	1.29 ±0.5	2.15 ±1.12	4.76 ±1.58	4.47 ±1.93	7.86±1.07
Simpson's diversity	1.98	1.08	3.34	1.90	9.48
Simpson's dominance	0.51	0.93	0.30	0.53	0.11
Equitability	0.99	0.09	0.22	0.11	0.5

The open scrub community of 2001, situated behind the foredunes, was comprised of a mixture of herbs, shrubs and grasses that included the following species, *Helichrysum cymosum, Solanum americanum, S. secundatum, S. plumosa* and *Rhoicissus digitata* (Figure 4.4 & 4.5.). Although a certain amount of species overlap occurred between the open scrub of 1989 and 2001, the latter community had a greater species diversity and cover (Table 4.3. & Plate 4.6).

Plate 4.6. Open scrub community situated behind foredunes.

The remnant of a closed scrub community was situated at the foot of the Westbourne Road embankment and directly west of the scrub-thicket community at DBV (Figure 4.5). It was a transitional community with components of both the open scrub and scrub-thicket. Open scrub species included the grasses *Stipagrostis zeyhrii* and *Pentachustis heptamera* while woody, scrub-thicket species were *P. rigida* and *Salvia africana-lutea* (Plate 4.7 & Figures 4.4 & 4.5). Uncharacteristically, species diversity was low and dominance was high for this community type.

Plate 4.7. Closed scrub community in the foreground with a dense canopy formed by woody shrubs.

The scrub-thicket community occupied the area adjacent to the entrance of DBV (Figure 4.5). Tree and woody shrub species such as *Sideroxylon inerme* (milkwood), *Allophyllis natalensis, Grewia occidentalis, Cassine aethiopica, C.monilifera, M. muricata* as well as the invasive wattle, *Acacia cyclops* (Rooikrans), occurred in this community (Figure 4.4). The scrub-thicket was the oldest and most complex of the communities present at Bushman's River Mouth (Plate 4.8). This community exhibited the highest species diversity and equitability of all communities previously classified for the site in both 1989 and 2001.

Plate 4.8. Scrub-thicket community comprised of a closed canopy of trees and shrubs.

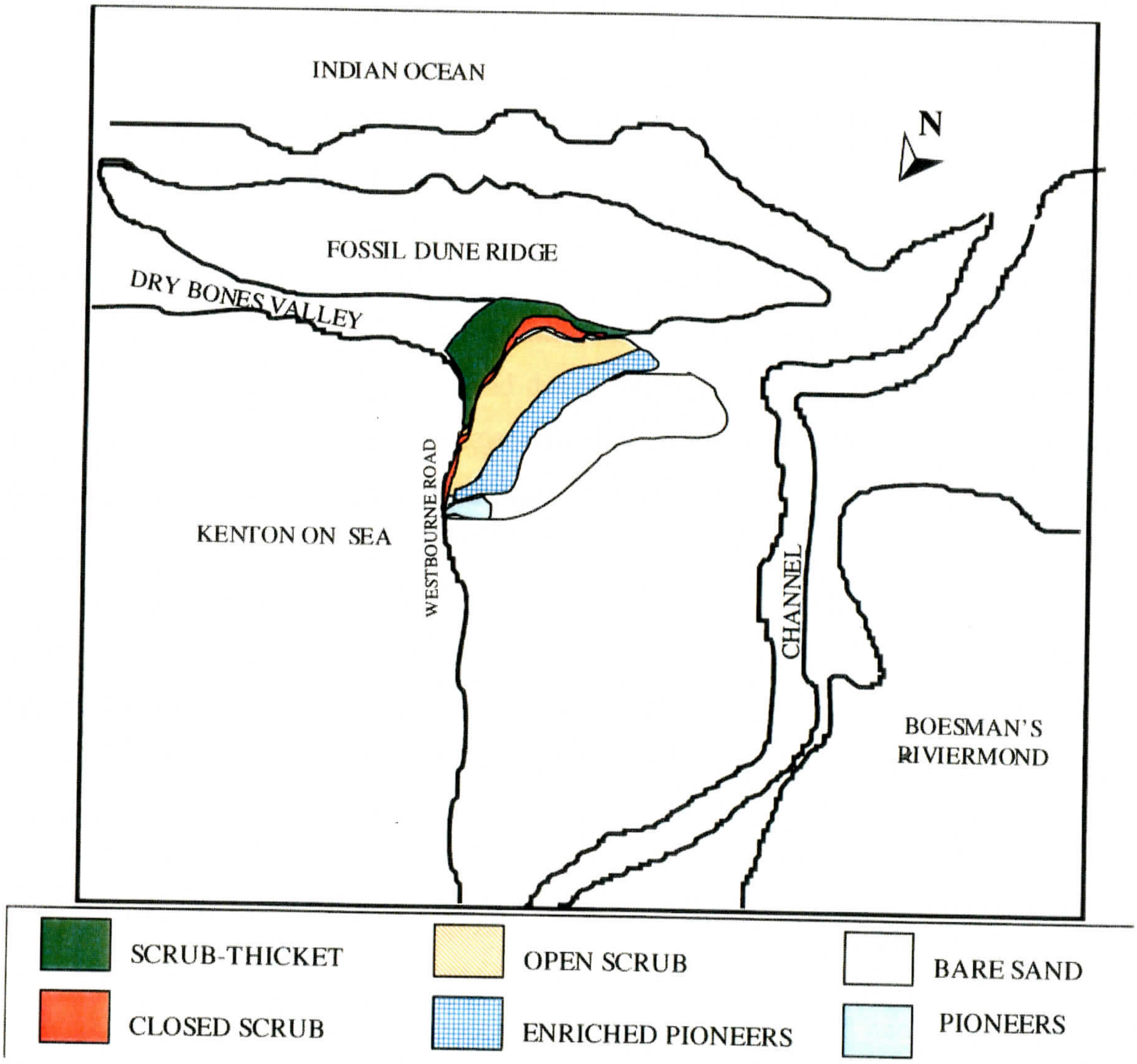


Figure 4.5. Schematic representation of the distribution of communities at the Bushman's River Estuary in July 2001. Based on sample ordination.

As seen from the schematic representation of community distribution at the site, the transects sampled transversed successive vegetation communities from the foot of the Westbourne Road embankment to the high water mark. Figure 4.6 and 4.7 illustrate species distributions along a representative transect, in this case, transect 4. In 1989, the upper reaches of the transect spanned the oldest and most species rich of the communities namely the closed scrub community and later in 2001, the scrub-thicket community. Vegetation cover was also greatest in this section of the transects. The mid-section (30-60 m) was less well vegetated with only a few species of grass and herbs present. In contrast, the mid-section in 2001 showed a greater species richness and cover than in the past with grasses, herbs and shrubs well established. During both time intervals the mid-section spanned the open scrub community. The lower section of both the 1989 and 2001 transects (60-90 m & 60-150 m) transversed enriched pioneer communities that were very low in species richness and cover. The main species present in the lower reaches is *E. villosa*, a grass species that is tolerant to highly mobile sands.

Examining these species distributions reveals that a change in community structure occurs from the high water mark to the embankment. These changes reflect a chronology in the establishment of vegetation as beach and dunes form in the prograding system. In order to understand these chronological changes or succession over time and space, a closer examination of the underlying processes was required.

4.3.2: Vegetation analysis:

A change in the vegetation structure at the site occurred from 1989 to 2001. The abundance, cover and species richness increased at the site. Thirty species were recorded in 1989 in comparison to fifty species in 2000/2001. The examination and comparison of diversity, dominance and species composition in 1989 and 2001 described the overall trend of vegetation change at the site.

Species diversity and dominance:

Calculations of diversity and dominance showed that transects 9, 8, 5 and 2 respectively had the highest diversity and lowest dominance in 1989 (Table 4.4). In 2001, the highest diversity was recorded at transects 9, 7 and 8 respectively. Although an increase in species richness occurred over the long-term, each transect showed a decrease in species diversity while species dominance increased over the same duration (Table 4.5).

This pattern of decreased diversity and increased dominance was also observed for all transects over a short-term monitoring period from May 2000 to July 2001 (Table 4.5).

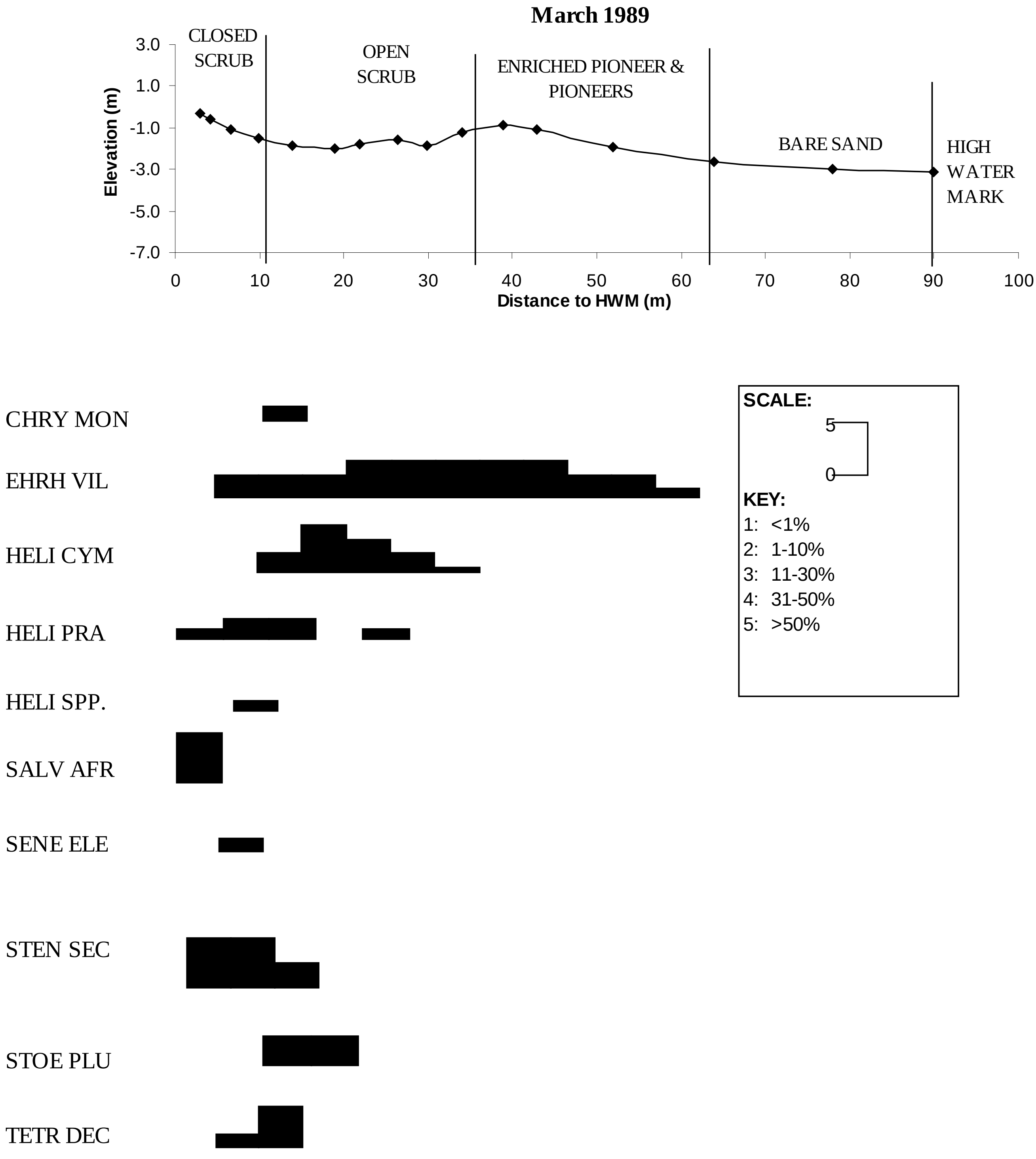


Figure 4.6. Species distribution along the eastern bank of the Bushman's River Mouth in 1989. Species abundance indicated as horizontal cover in 1m x 5m plots along the transect line.

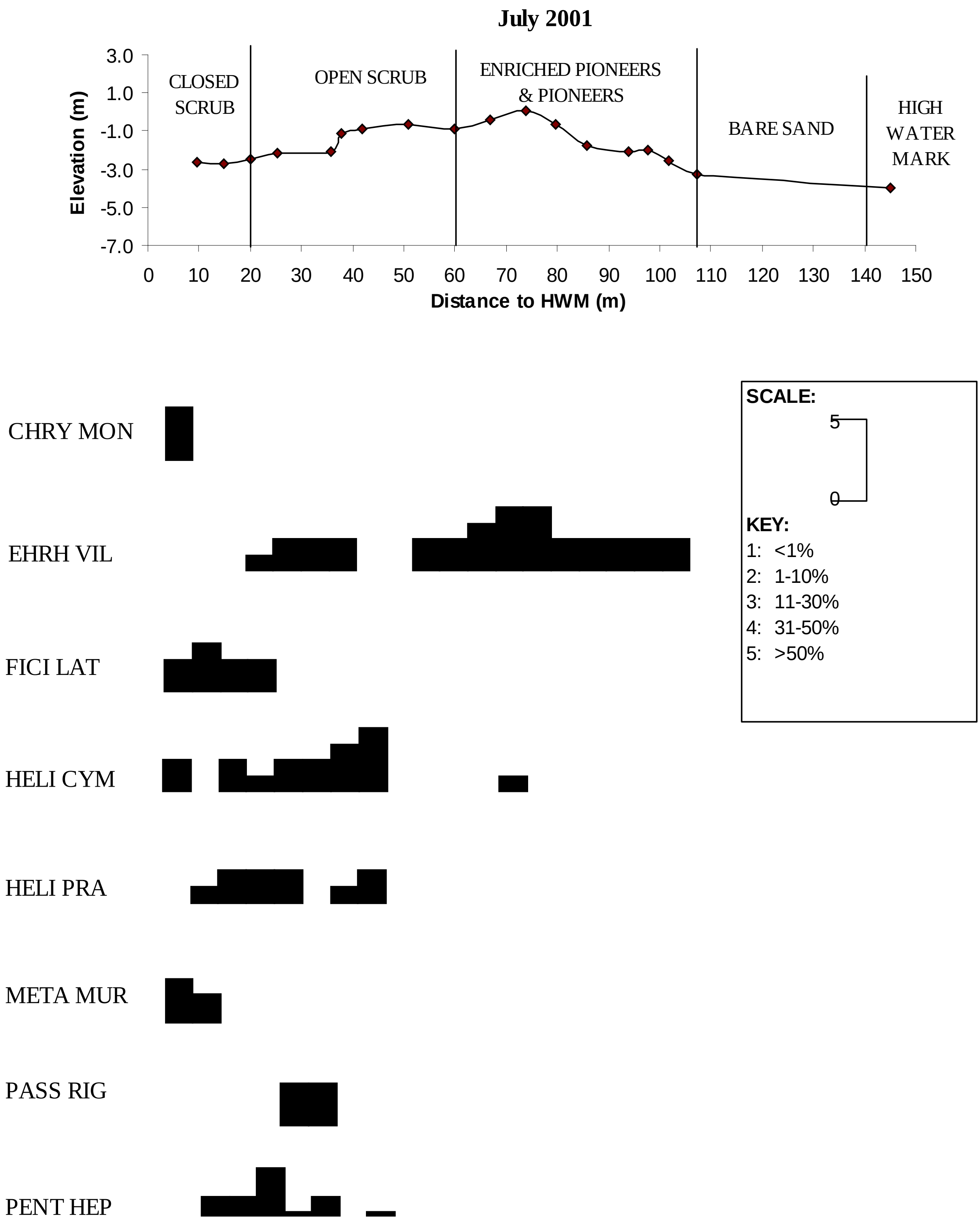


Figure 4.7. Species distribution along the eastern bank of the Bushman's River Mouth in 2001 Species abundance indicated as horizontal cover in 1m x 5m plots along the transect line.

Both diversity indices used provide an indication of species richness but also reflect the 'evenness' or equitability of the species present. An investigation of species composition and the relative contribution of each species within each sample area may therefore shed light on the above finding.

Table 4.4. Simpson's (Sd), Shannon's (H') diversity and Simpson's (SD) dominance indices for transects 1-9 for March 1989 to July 2001.

TRANSECT	Sd		H'		SD	
	MAR 89	JUL 01	MAR 89	JUL 01	MAR 89	JUL 01
1	-	1.44	-	0.60	-	0.69
2	2.93	1.18	1.47	0.41	0.34	0.85
3	2.00	1.20	0.95	0.47	0.50	0.84
4	1.90	1.21	1.08	0.47	0.53	0.83
5	2.96	1.15	1.37	0.38	0.34	0.87
6	1.69	1.20	1.06	0.44	0.59	0.83
7	-	1.77	-	1.21	-	0.57
8	3.79	1.74	1.64	1.14	0.26	0.58
9	4.15	3.46	1.60	1.74	0.24	0.29

Table 4.5. Simpson's (Sd), Shannon's (H') diversity and Simpson's (SD) dominance indices for transects 1-9 for May 2000 to July 2001.

TRANSECT	Sd		H'		SD	
	MAY 00	JUL 01	MAY 00	JUL 01	MAY 00	JUL 01
1	2.10	1.44	1.04	0.60	0.48	0.69
2	1.47	1.18	0.73	0.41	0.68	0.85
3	2.06	1.20	1.56	0.47	0.49	0.84
4	2.55	1.21	1.44	0.47	0.39	0.83
5	2.66	1.15	1.54	0.38	0.38	0.87
6	3.21	1.20	1.76	0.44	0.31	0.83
7	5.05	1.77	2.29	1.21	0.20	0.57
8	3.31	1.74	1.88	1.14	0.30	0.58
9	5.23	3.46	2.30	1.74	0.19	0.29

Species composition and equitability:

A change in the importance values of species at each transect was noted from 1989 to 2001 (Figure 4.8 - 4.9). The most profound change was observed at transect 1 (Figure 4.8). A complete change in species importance occurred from an area dominated by saltmarsh species that included *T. bulbosa* and *Juncus spp.*, to one dominated by grasses and herbs characteristic of dunefield vegetation (Figure 4.8). The only species present in both saltmarsh and dune vegetation to increase in importance value was *S. virginicus*.

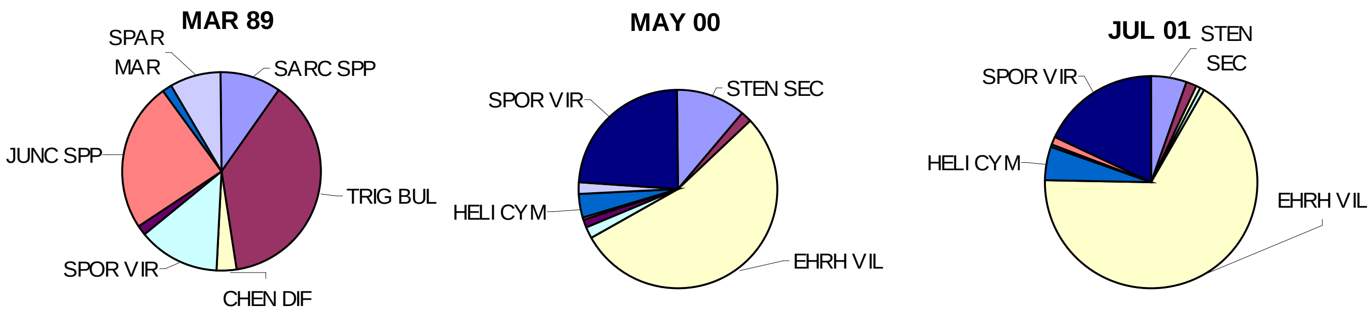


Figure 4.8. Species importance values for transect 1 for 1989, 2000 and 2001.

Although the species composition at transects 3-6 represented dunefield vegetation at all time intervals a noticeable trend of increasing importance values of woody shrubs and grasses was recorded. For example, a striking increase in the importance value of *E. villosa* occurred (Figure 4.9). This increase was observed for all transects from 1989 to 2001 even the recently established transect 7. A comparison of 2000 to 2001 data showed *E. villosa* to be the only species that increased significantly in importance value (Figure 4.9). Similarly albeit to a lesser extent, the importance of woody species such also increased at these transects (Figure 4.9). In 1989, the area transversed by transects 3 to 6 was mostly comprised of herbaceous dicots such as *A. populifolia, T. decumbens O. fructicosum, H. praecinctum, G. rigens.* The relative importance of these species gradually diminished as woody species such as *M. muricata* and *S. plumosa* became established and dominated the area (Figure 4.9).

The examination of importance values from 1989 to 2001 showed that certain species only have become more important in relation to all the species present at each transect. This decrease in the evenness of species was confirmed by a decrease in equitability indices based on Simpson’s and Shannon’s diversity indices. Equitability decreased from March 1989 to July 2001 at all transects (Table 4.6). This suggested that although an overall increase in species richness occurred at the site, certain species were at a competitive advantage and became more abundant or productive in comparison to others. A similar pattern occurred for the short-term study period from May 2000 to July 2001 with a decrease in equitability at all transects (Table 4.7).

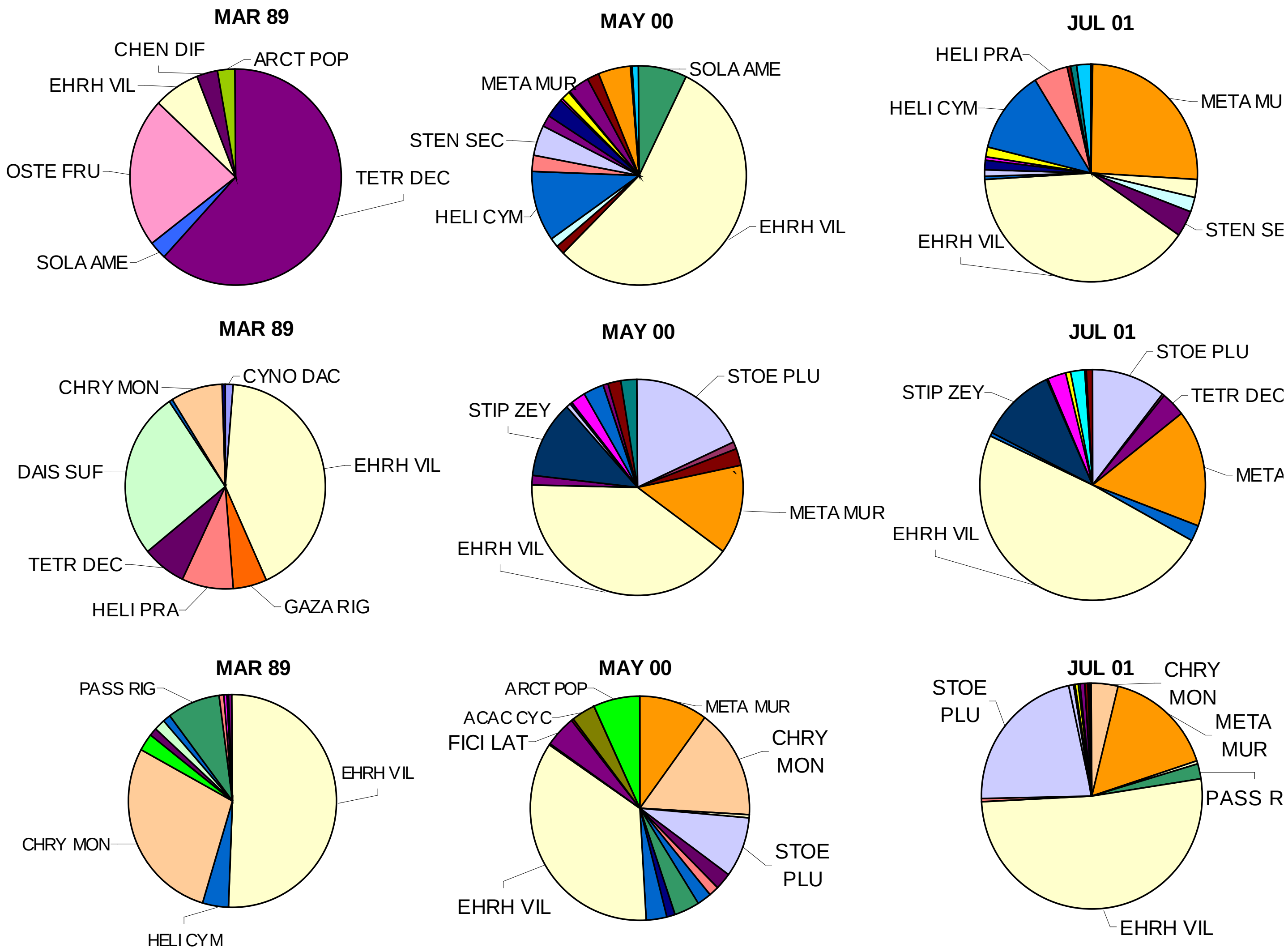


Figure 4.9. Species importance values for (A) transect 3, (B) transect 5, (C) transect 6 & (D) transect 7 for 1989, 2000 and 2001 illustrating a change in species composition.

Table 4.6. Equitability based on Simpson's *(E)* and Shannon's *(J)* diversity indices for long-term study period (1989-2001).

TRANSECT	E		J	
	MAR 89	JUL 01	MAR 89	JUL 01
1	-	0.16	-	0.27
2	0.29	0.09	0.64	0.16
3	0.33	0.07	0.53	0.17
4	0.19	0.09	0.47	0.18
5	0.33	0.08	0.62	0.14
6	0.13	0.07	0.41	0.16
7	-	0.06	-	0.36
8	0.32	0.07	0.66	0.35
9	0.32	0.18	0.62	0.59

Table 4.7. Equitability based on Simpson's *(E)* and Shannon's *(J)* diversity indices for short-term study period (2000-2001).

TRANSECT	E		J	
	MAY 00	JUL 01	MAY 00	JUL 01
1	0.23	0.16	0.47	0.27
2	0.12	0.09	0.29	0.16
3	0.12	0.07	0.55	0.17
4	0.17	0.09	0.53	0.18
5	0.18	0.08	0.57	0.14
6	0.17	0.07	0.60	0.16
7	0.13	0.06	0.62	0.36
8	0.11	0.07	0.56	0.35
9	0.19	0.18	0.69	0.59

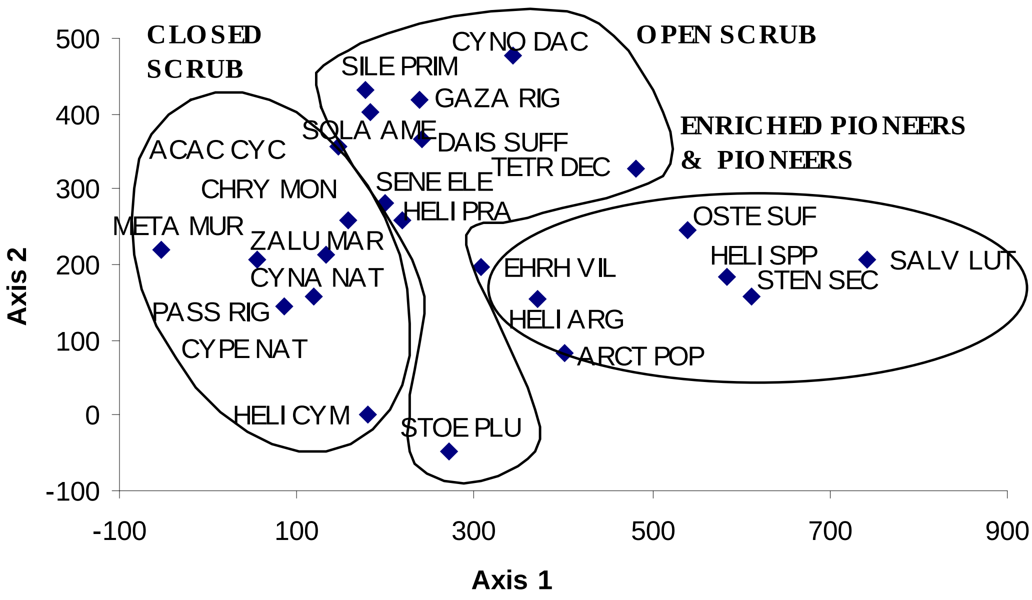
The change in species composition, diversity and equitability from 1989 to 2001 as well as changes evident from the vegetation description indicated that a temporal continuum of vegetation occurred at the site. This suggested that a successional gradient was present along the eastern bank of the river mouth.

Floristic changes along successional gradient:

The distribution of the dunefield plant communities in 1989 along both sample and species ordination axes reflected floristic change along a successional gradient. The distribution of communities along ordination axis 1 corresponded to decreasing distance from the shoreline that related to the age, diversity and complexity of the communities (Figure 4.10). Older, more diverse and complex communities such as the open and closed dune scrub communities preceded younger and less diverse communities namely the pioneer communities from right to left along Axis 1 (Figure 4.10). The saltmarsh community was ecologically distinct from the dunefield and occurred to the extreme right of the ordination plot although not plotted in Figures 4.10. Samples and species of this community type were removed as outliers in further analyses as they masked the distribution of dunefield communities along Axis 1.

Differences in the species composition within sample groups resulted in a gradient along Axis 2. For example, within the pioneer and enriched pioneer grouping, consecutive samples along certain transects differed only in species composition and richness that reflected as almost 'linear trend' along Axis 2 (Figure 4.10. B). Dispersion on axis 2 within community groups on the species ordination was related to the diversity of life forms present in each community. The open scrub community showed the greatest dispersion along axis 2 with grasses and herbs separated furthermost from shrubs while the enriched pioneer and pioneer groups had the least differentiation along axis 2 (Figure 4.10 A).

(A)



(B)

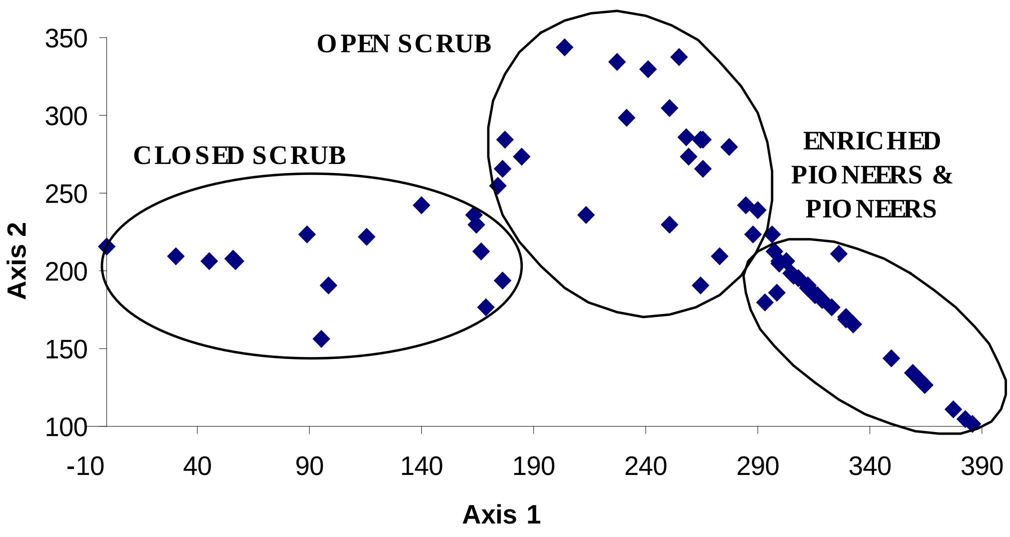


Figure 4.10. DCA ordination of (A) species and (B) samples for March 1989 communities. Communities were identified by Twinspan classification. For species abbreviations see Appendix 1.

The successional gradient along ordination axis 1 persisted in July 2001. The continuum of communities was illustrated by species and sample ordination plots in that the enriched pioneer community, the right of the plot, proceeded to a scrub-thicket community via open and closed scrub on the left (Figure 4.11). Ordination of both 1989 and 2001 vegetation data did not show discrete community groupings and possibly suggested that the communities intergraded continuously along the successional gradient.

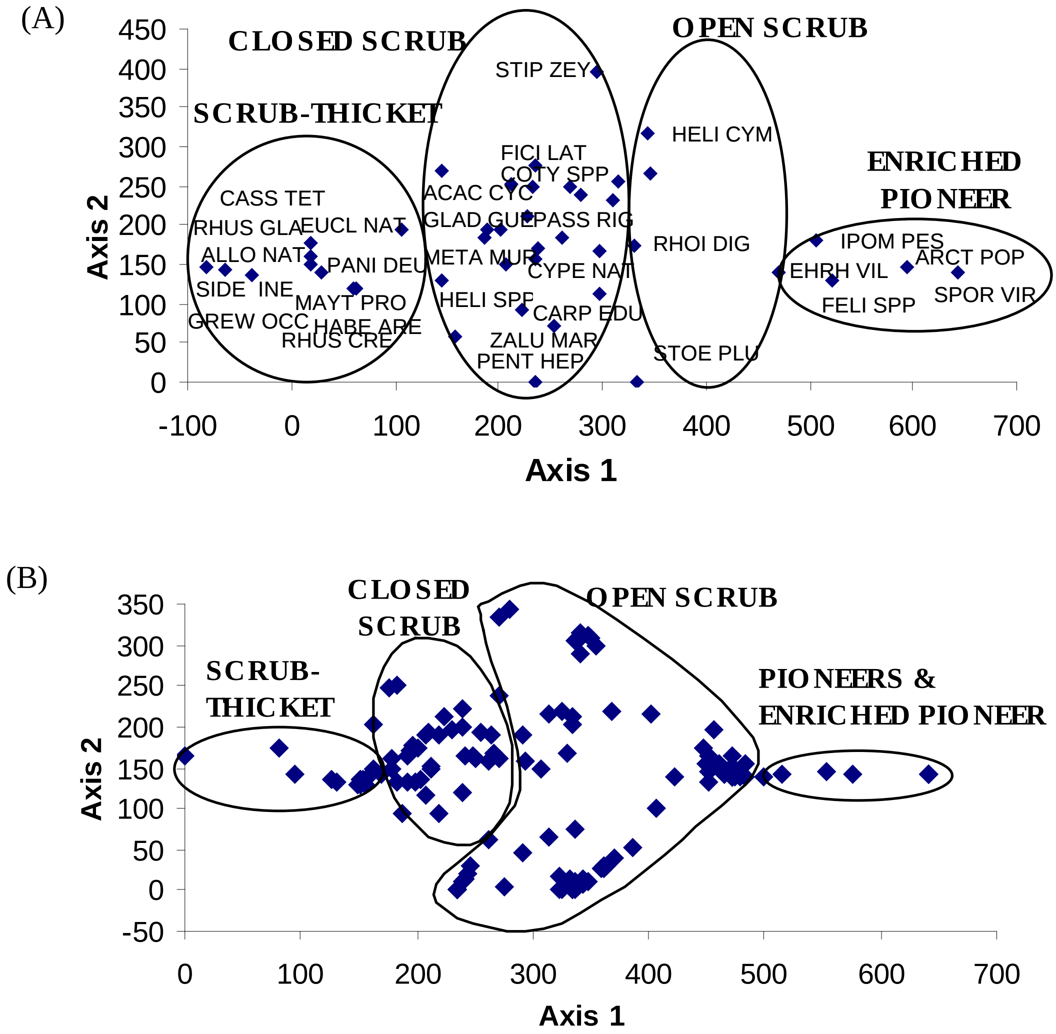


Figure 4.11. DCA ordination of (A) species and (B) samples for July 2001 communities. Communities were identified by Twinspan classification. For species abbreviations see Appendix 1.

Sørenson's co-efficient (S_s) measured the similarity in species composition between the plant communities. The lowest S_s values were expected to correspond to communities that shared the fewest species and were spatially the furthest apart. This trend was noted for the dunefield communities with S_s values decreasing with increasing distance between the communities (Table 4.8).

The number of species shared appeared to remain fairly constant between the communities suggesting that a complete species turnover did not occur and that early pioneer species persist in late successional communities along the gradient in 1989. The saltmarsh again proved to be ecologically distinct with no similarity with the dunefield communities and no shared species.

Table 4.8. Similarity between 1989 communities denoted by the number of species shared (shaded) the species richness (bold) and the Sørenson's co-efficient similarity index (S_s).

COMMUNITY	SALTMARSH	PIONEER	ENRICHED PIONEER	OPEN SCRUB	CLOSED SCRUB
SALTMARSH	**7**	0.00	0.00	0.00	0.00
PIONEER	0	**3**	0.36	0.30	0.29
ENRICHED PIONEER	0	2	**6**	0.46	0.36
OPEN SCRUB	0	3	5	**22**	0.74
CLOSED SCRUB	0	3	5	12	**16**

A more distinct trend of decreasing S_s values and the number of shared species with seral communities was evident from the 2001 data (Table 4.9). Early successional species persisted in late successional communities but steadily decreased in number to the low values along the successional gradient. Again, this indicated that a complete turnover of species with succession did not occur at the study site.

Table 4.9. Similarity between 2001 communities denoted by the number of species shared (shaded), the species richness (bold) and the Sørenson's co-efficient similarity index (S_s).

	PIONEER	ENRICHED PIONEER	OPEN SCRUB	CLOSED SCRUB	SCRUB-THICKET
PIONEER	**2**	0.29	0.13	0.11	0.10
ENRICHED PIONEER	2	**12**	0.56	0.41	0.33
OPEN SCRUB	1	7	**13**	0.53	0.32
CLOSED SCRUB	1	6	8	**17**	0.57
SCRUB-THICKET	1	5	5	9	**19**

A closer examination of the distribution of nine dominant species at the site showed that *E. villosa* remained an important species in all the communities identified but exhibited a marked decrease in later successional communities. Other species importance peaked in certain communities such as *S. virginicus* in the pioneer community and *S. plumosa* in the open scrub community. Some species showed a gradual increase in importance from low values in early successional communities to relatively high values in late successional communities, for instance, *M. muricata* and *C. monilifera* (Figure 4.12).

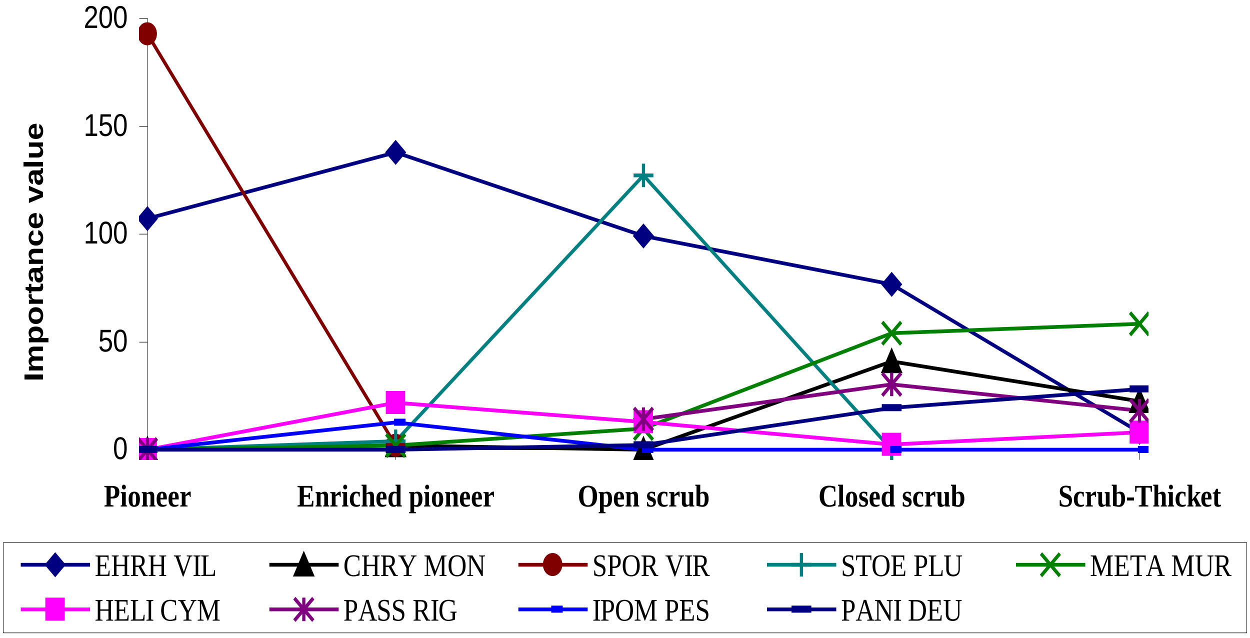


Figure 4.12. Variation in importance value of nine dominant species across five successional stages.

Successional trends:

Spatial studies of succession do not always reveal multiple pathway succession and a further temporal study of vegetation change was required to investigate the possibility of multiple pathways at the study site (Avis 1992). The following results corresponded to temporal vegetation change at the site that spanned a 12-year period from March 1989 to July 2001.

In order compensate for the progradation of the dunefield during the examination of successional trends at the site, the transects were divided into upper, mid and lower sections. Each transect is examined in detail to incorporate the effect of the spatial distribution of communities and spatial pattern in the sediment dynamics at the site (see Figure 4.3 & 4.5 and Chapter 3).

In general, a pattern of change typical of succession was observed for the transects situated further northward along the bank (Transects 1, 2 and 3). As seen in the previous section, transect 1 was dominated by a saltmarsh community in December 1989 (See Figure 4.8). After 12 years, the saltmarsh community disappeared as a result of a steady accretion of sand. At transect 1, the upper and mid-sections spanned the saltmarsh community which was subsequently replaced by an enriched pioneer community. The lower sections of this transect date from May 2000 onwards as the vegetation in this section was only recently established as the dune system prograded (Figure 4.13).

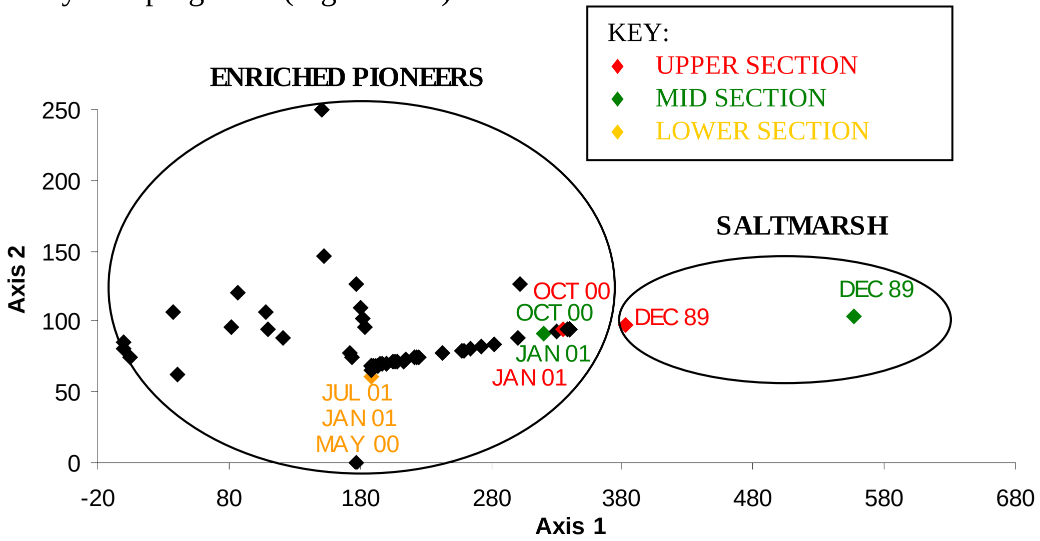


Figure 4.13. Chronological sequence of sample trajectories for transect 1 for the intervals; March 1989, December 1989, May 2000, January 2001 and July 2001.

In 1989, transect 2 transversed an area comprised of both saltmarsh and dune vegetation. Four communities were identified for the period beginning March 1989 to July 2001 namely saltmarsh, pioneer, open scrub and closed scrub communities (Figure 4.14). As with transect 1, the saltmarsh community was replaced by dune vegetation but in this case, the upper section proceeded to closed dune scrub.

This indicated that the northern margin of the saltmarsh situated at transect 2 perhaps experienced an inundation by sand as early as 1989 that led to the presence of a more advanced community in the upper sections by 2001. The mid-section of the transect spanned a portion of the saltmarsh in 1989 which advanced to open dune scrub by 2001. A distinct pioneer community was present at the lower section of the transect but as with transect 1, only samples dating from 2000 onwards were found within this community. This is attributed, again, to progradation of the dune system (Figure 4.14).

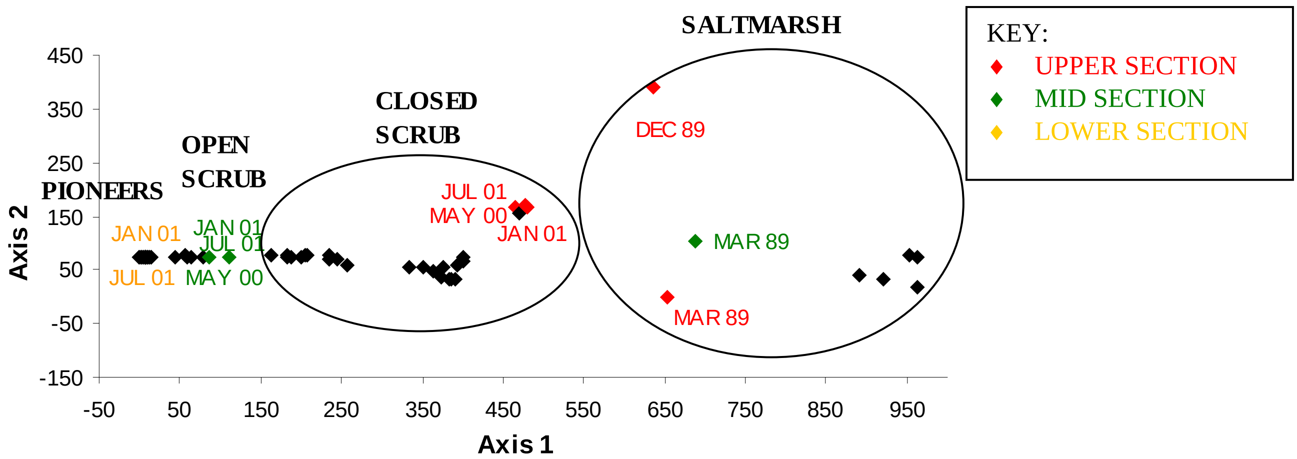


Figure 4.14. Chronological sequence of sample trajectories for transect 2 for the intervals March 1989, December 1989, May 2000, January 2001 and July 2001.

Over 12 years, three communities were identified for transect 3. In 1989, an open scrub system existed with the dominant species *T. decumbens* and *O. fructicosum* (Figure 4.15). In 2001, the upper section of the transect was comprised mainly of open scrub but showed an increase in species richness from the open scrub of 1989. This section also encompassed a closed scrub community situated at the margin of the transect where it met the foot of the Westbourne Road embankment. Whether this community was derived as a result of an 'edge effect' as a result of the vegetation established along the embankment or whether it was a true part of the dunefield vegetation is not certain. The mid-section of transect 3 was not well represented by 1989 data but spanned an *E. villosa*-dominated enriched pioneer community in 2001 as did samples situated at the lower section of the transect during the same time.

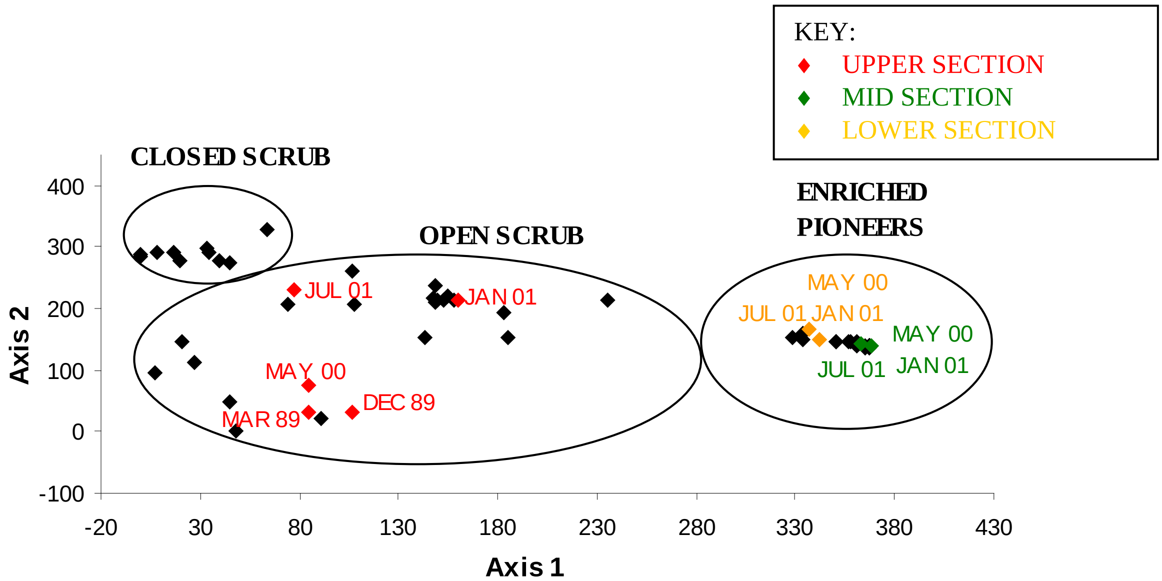


Figure 4.15. Chronological sequence of sample trajectories for transect 3 for the intervals March 1989, December 1989, May 2000, January 2001 and July 2001.

For transect 4, three communities were defined, the enriched pioneer community, a late open scrub and an early open scrub community during the study period (Figure 4.16). In 1989, the upper section of the transect spanned an early open scrub community. Subsequently, species richness and cover increased and resulted in a more complex community that was classified as late open scrub. The vegetation of both the mid- and lower sections of the transect fell into the enriched pioneer community grouping. The lower section of the transect had recently developed as with previous transects. The mid-section showed little progression from the enriched pioneer community since 1989 that suggested that a continuous supply of sand, which led to progradation of the bank, stalled the succession of this community.

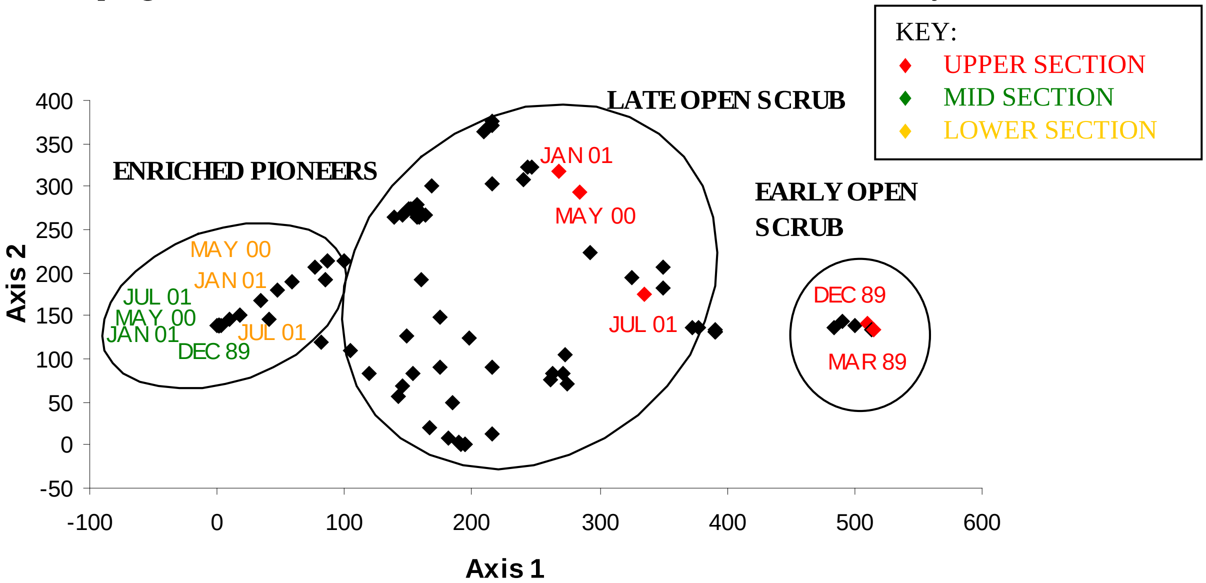


Figure 4.16. Chronological sequence of sample trajectories for transect 4 for the intervals; March 1989, December 1989, May 2000, January 2001 and July 2001.

The vegetation of transect 5 was divided into three communities, the pioneer, enriched pioneer and open scrub communities (Figure 4.17). In 1989, the area largely consisted of an enriched pioneer community. The upper and mid-sections of the transect since developed into open scrub and included species such as *T. decumbens*, *C. dactylon*, *S. africana-lutea* and *C. monilifera*. The lower section dated only from May 2000 onward and consisted of enriched pioneer species typically present on the foredunes of the site e.g. *A. populifolia* and *E. villosa*.

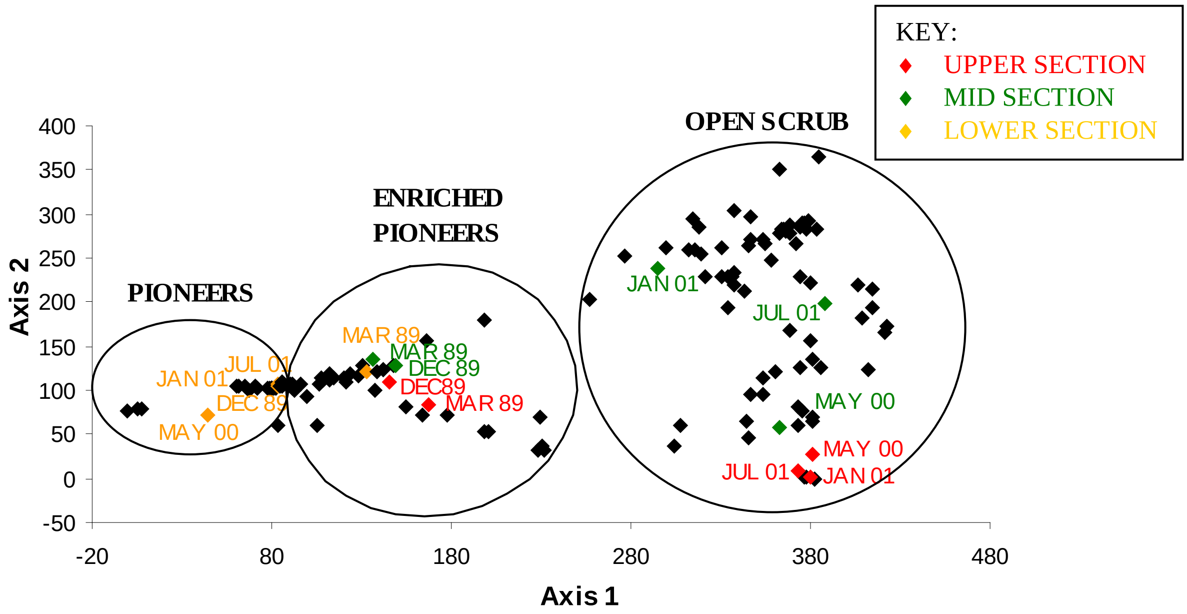


Figure 4.17. Chronological sequence of sample trajectories for transect 5 for the intervals March 1989, December 1989, May 2000, January 2001 and July 2001.

The upper section of transect 6 remained as closed scrub since 1989 although the number of woody species such as *P. rigida* and *M. muricata* increased in 2001. In 1989, the mid-section of the transect spanned an enriched pioneer community that included species such as *E. villosa, A. populifolia, S. argenteum* and *D. suffructicosum*. Over 12 years, an increase in the occurrence of grasses and herbs led to the development of an open dune scrub community in the mid-section of transect 6. The lower section remained as an enriched pioneer community since 1989 and indicated that a steady supply of sand effectively halted succession at this community (Figure 4.18).

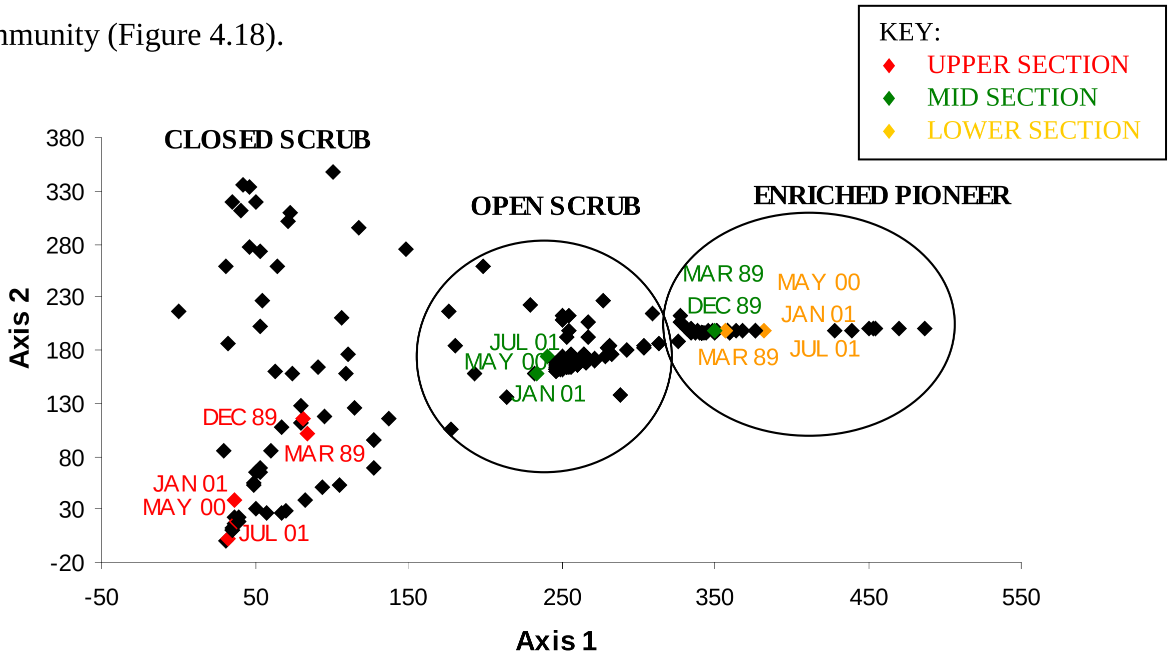


Figure 4.18. Chronological sequence of sample trajectories for transect 6 for the intervals March 1989, December 1989, May 2000, January 2001 and July 2001.

Transect 7 was the only transect to span a scrub-thicket community. This community was situated at the upper section of the transect and indicator species of this community included, *R. crenata*, *R. glauca*, *S. inerme* and *A. natalensis*. The mid-sections of the transect lay within a closed dune scrub community comprised of woody shrubs such as *P. rigida*, *M. muricata* and herbs such as *S. primuliflora* and *C. edulis*. Open scrub existed in the lee of a transverse dune at the western (lower) end of the transect. This section was previously cleared as part of an experimental destabilisation plan to address sediment build-up. The lower section consisted of a plateau dominated by *E. villosa* interspersed with *I. pes-caprae*, *G. guenzii*, *F. lateralis* and *S. zeyhrii* (Figure 4.19).

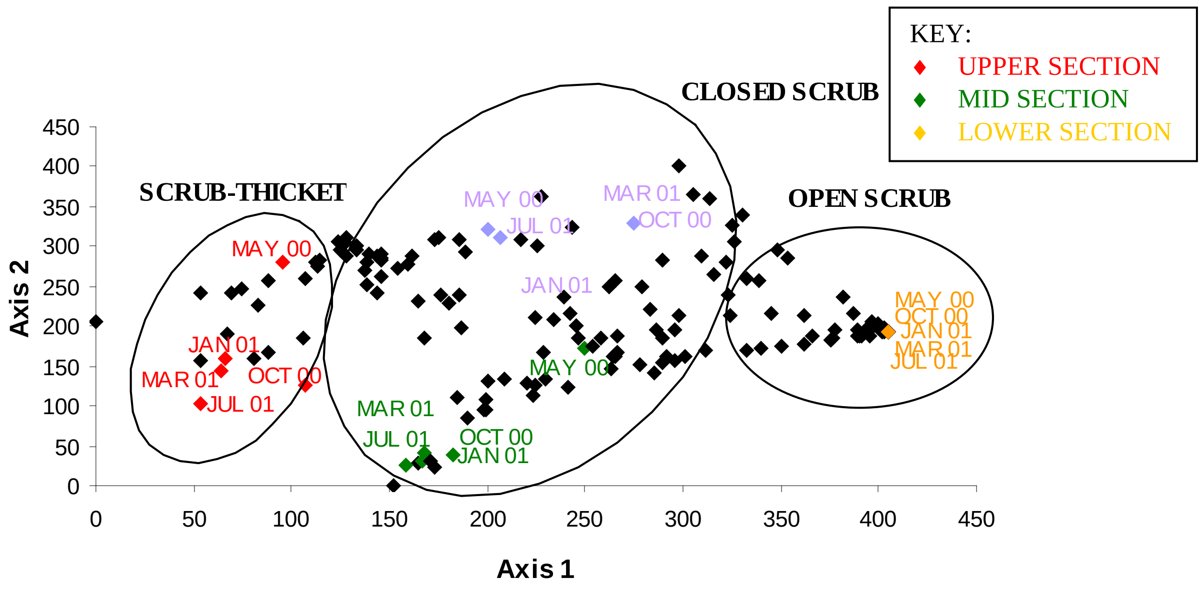


Figure 4.19. Chronological sequence of sample trajectories for transect 7 for the intervals; March 1989, December 1989, May 2000, January 2001 and July 2001.

A similar trend in succession was seen for both transect 8 and 9. The upper sections of transect 8 transversed a closed scrub community in 1989 that subsequently developed into a scrub-thicket community with a greater occurrence of trees such as *S. inerme* and *G. occidentalis*. The mid-sections of this transect encompassed open dune scrub in 1989 and grew into closed dune scrub over the study period as had the lower section. The lower section transversed ridges of alternating pockets of bare sand and closed dune scrub (Figure 4.20). Transect 9 consisted of three plant communities namely enriched pioneer, open scrub and scrub-thicket. The scrub-thicket was situated at the foot of the fossil dune ridge located in the south of the site. The mid-section of transect 9 showed a transition from an enriched pioneer community in 1989 to an open scrub community in 2001.

More recently an enriched pioneer community developed as the lower reaches of the transect due to progradation of the eastern bank of the river mouth that extended parallel to the Bushman's River Mouth. The lack of a closed scrub community in the successional sequence was a result of clearing that took place in the upper reaches of the transect. A dune slack community was also present along the line that changed to open scrub due to an increase of sand that resulted from the advent of the transverse dune (Figure 4.21).

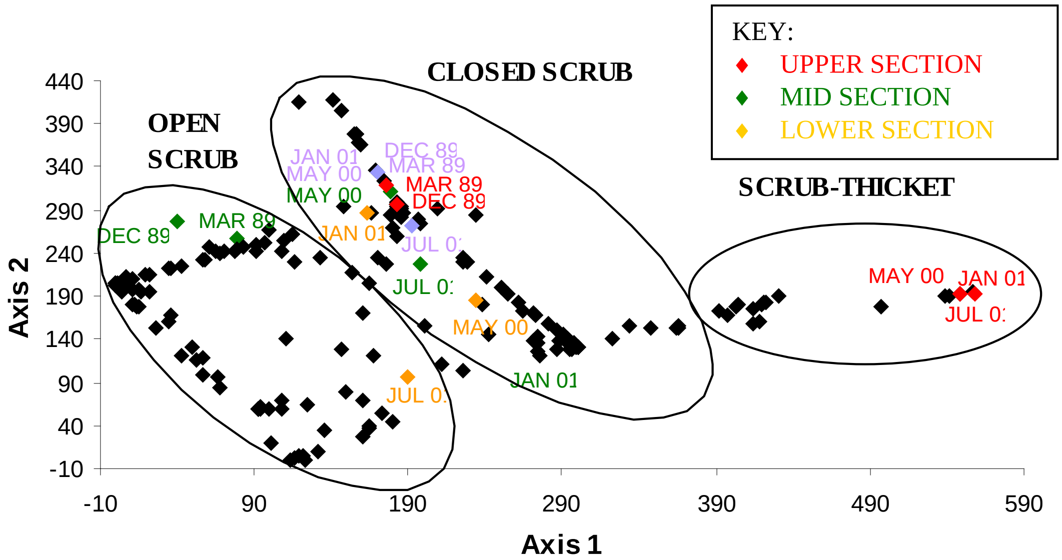


Figure 4.20. Chronological sequence of sample trajectories for transect 8 for the intervals; March 1989, December 1989, May 2000, January 2001 and July 2001.

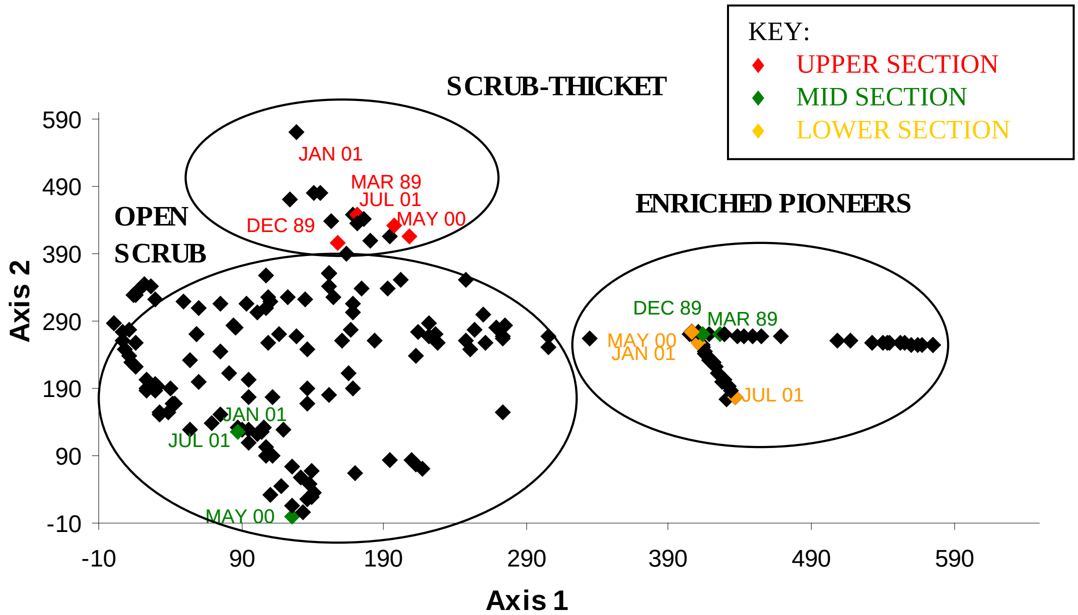


Figure 4.21. Chronological sequence of sample trajectories for transect 9 for the intervals; March 1989, December 1989, May 2000, January 2001 and July 2001.

4.4. Discussion:

The analysis of aerial photos by Jacob (1993) showed that the initial colonisation of the Westbourne Road Car Park (WRCP) dunefield by vegetation occurred as early as 1955 and that the sandbank was fully colonised by 1973. Booysen (1995a) suspected that this early establishment of vegetation resulted from the stabilisation of a well point at the western entrance and a car park at the eastern entrance of DBV (Chapter 3). The continuous accumulation of sand along the bank provided a site for colonisation by dune species that originated from the stabilisation of these structures within DBV. At the initiation of this study in 1989, vegetation had formed a retentive dune system along the eastern bank of the river mouth.

Vegetation description:

This study provided a site-specific quantitative overview of the dune vegetation at the Bushman's River Mouth. The community types determined by multivariate analysis were similar to those defined by Doing (1985), Tinley (1985), Young (1987), Lubke & De Villiers (1991), Avis (1992), McLachlan *et al*. (1996), Whitfield & Lubke (1998) and Lubke & van Wijk (1998). Five communities were discerned from 1989 data, namely the pioneer, enriched pioneer, open scrub, closed scrub and saltmarsh communities while 2001 data revealed the absence of the saltmarsh community but the addition of a scrub-thicket community.

Saltmarsh community

Saline-tolerant halophytes comprised the saltmarsh community of 1989. Although no study of the zonation within this saltmarsh was conducted in 1989, species that typified each zone, as describe by Whitfield & Lubke (1998) were present. *Triglochin bulbosa* and the rush, *Juncus krausii* dominated this community and typically occurred in the uppermost reaches and along the riverbank. *Sarcornia sp., C. diffusa* and *L. scabrum* colonised mid to upper portions while the aquatic, *Z. capensis* (eelgrass) occurred in the lower portions of the saltmarsh. The latter species was completely submerged except for short periods during low tides (Whitfield & Lubke 1998). This community exhibited moderately high species diversity, equitability, and low species dominance that are usually indicative of a mature and well-developed community.

Pioneer community

Avis (1992) distinguished three main pioneer communities at Kleinemonde (~40 km east of the study site) based on species composition, topography and location namely the embryonic foredune, hummock foredune and incipient foredune communities. The pioneer community at the study site accorded well with the embryonic foredune community of Avis's study. The community composed of *A. populifolia, E.villosa* and *S. argentea,* colonised small hummock dunes that occurred along the flat and level shore of the river mouth. It had characteristically low species diversity but a moderately low dominance due to the high equitability amongst the few species present in the community. The pioneer community also corresponded with Tinley's (1985) strand plant community described as being "composed of low creeping plants that are colonisers of bare shifting sand on the backbeach and on berms at the highest reach of wave swash". Similar communities were described as the perennial tidemark community in Doing (1985) and Henriques & Hay's (1997) pioneer vegetation of Group I.

Enriched pioneer community

The enriched pioneer community present was synonymous with the enriched pioneer community (Avis 1992) and the central foredune ridge community (Doing 1985). Species diversity and equitability of this community was the lowest recorded for all the communities described at the site. The perennial grass, *E. villosa*, dominated the community with its great abundance and exceptional ability to tolerate high rates of sand accumulation. Other species present included vestigial elements of the pioneer community such as *A. populifolia*, in addition to *C. dactylon, Helichrysum spp., O. fructicosum* and *I. pes-caprae.* The rhizome-stolon colonisation of the immediate backshore zone by *E. villosa* formed a foredune ridge referred to as Type 2A incipient foredunes by Hesp (1989) (Plate 4.2. & 4.5).

Open scrub community

The open scrub community was, as the nomenclature suggests, a woody plant community with an open canopy of shrubs and an understorey of herbs and grasses. Avis (1992) described the community as transitional to dune thicket and postulated that its occurrence was linked to limited rainfall patterns. At the Bushman's River Mouth, open dune scrub occurred in the lee of a foredune ridge and was protected from sand inundation and strong westerly winds. Indicator species of this community were *S plumosa, S. secundatum* and *Helichrysum* species.

This community differed singularly from the shrub community (Tinley 1985) and the open dune scrub (Avis 1992) in the absence of P. *rigida.* The woody shrub, *S. plumosa*, appeared to assume the ecological role of *P. rigida* i.e. as one of the first woody species to appear in seral communities at the study site. Differences in life-history traits or environmental tolerances, in particular tolerance to sand burial, could explain this difference since *P. rigida* was present at the site but only in later successional communities.

Closed scrub community

The closed dune scrub community at Bushman's River Mouth consisted of a closed canopy of woody shrubs as well as a number of herbs and graminoids. Species diversity and equitability were high and dominance low indicating a relatively mature community. Woody shrub species included *C. monilifera, P. rigida, H. cymosum* and *M. muricata.* Some herbaceous species present were *Z. maritima, C. natalitium,* and *G. rigens* while graminoids included *C. natalensis, S. zeyherii* and *P. heptamera.* This community has a larger proportion of woody species than the open scrub community but could also be considered transitional to dune thicket. Similar communities described in the literature were dune scrub or thicket (Lubke & van Wijk 1998), Coastal thicket (Lubke & De Villiers 1991), dune scrub community and closed dune scrub (Avis 1992).

Scrub-thicket community

Tinley (1985) describes the scrub-thicket community as a "community of mulitple-stemmed dwarf trees and shrubs with a compact canopy". The presence of tree species is distinctive of scrub-thicket communities and separates transitional scrub communities from true thicket communities (Tinley 1985, Avis 1992, Lubke & van Wijk 1998). At Bushman's River Mouth, *S. inerme* (milkwood), *P. tricuspidatus* (cherrywood) and *A. natalensis* were all identified as the predominant tree species (Lubke & van Wijk 1998). The dense canopy of the scrub-thicket was composed of numerous shrubs in addition to these trees. Shrub species included *M. procambens, R. crenata, E. natalensis, E. capensis, C. monilifera* and *C. aethiopica*. Grasses and herbs grew beneath the canopy and included species such as *C. edulis, P. deustrum, C. natalensis, R. digitata, A. racemosus,* and *C. cirrhosum*. Scrub-thicket is also referred to as coastal forest (Lubke & De Villiers 1991), Forest Margin community (Avis 1992), Shrub-thicket (Tinley 1985) and dune scrub or thicket (Lubke & van Wijk 1998).

Distribution and zonation:

Schematic diagrams of the spatial distribution of the dune vegetation communities were produced by matching the TWINSPAN classification of each sample to its location in the dunefield (Figures 4.2 & 4.4). It was apparent that the distribution of the vegetation communities corresponded to the direction of the progradation, and thus the chronological development of the WRCP dunefield as discussed in Chapter 3. The dunefield communities developed sequentially as sand accumulated at the eastern bank of the river mouth, first in a north-westerly and later in an easterly direction (Jacobs 1993; Booysen 1995a; Burkinshaw 1999).

The oldest and most diverse of the dunefield communities, the closed scrub and scrub-thicket, were situated in the south-eastern corner of the study site where sand first began to accumulate some thirty years before (Jacobs 1993; Burkinshaw 1999). Consecutively younger communities, ranging from open scrub to pioneer communities, occurred between these mature communities and the high water mark of the Bushman's River (Figures 4.5 & 4.6). Transects of high species richness and diversity coincided with the oldest portions of the WRCP dunefield i.e. the south-eastern corner while the younger portions, further north and west were areas of lower diversity and higher dominance (Table 4.2).

The zonation of vegetation communities at the study site was typical for prograding shorelines (Avis 1992). It was evident from the spatial distribution of communities and vegetation analyses that the species richness, cover, size and type of life forms (complexity) of vegetation communities increased with increasing distance from the prograding shoreline in both 1989 and 2001. This pattern of zonation on coastal dunes is typically derived from species-specific physiological tolerances to environmental gradients (Doing 1985; Tinley 1985; Lubke & van Wijk 1998). Numerous studies have identified and discussed the influence of environmental gradients on the zonation of coastal dune vegetation. Important factors identified from these studies were: soil moisture; soil salinity; nutrient availability; salt spray and sand movement (Oosting & Billing 1942; Parrish & Bazzaz 1982; Donnelly & Pammenter 1983; Moreno-Casasola 1986; Avis 1992; Avis & Lubke 1996; Henriques & Hay 1997).

It is widely accepted that the interactions between vegetation and the above-mentioned abiotic factors produce a "cause and effect" relationship that ultimately results in the mosaic patterns of coastal dune vegetation (Donnelly & Pammenter 1983; Tinley 1985; Doing 1985; Moreno-Casasola 1986; Lubke & van Wijk 1998). The relative importance of each factor in determining zonation patterns is site-specific as environmental conditions vary between dune systems (Donnelly & Pammenter 1983). In this study, sand movement was a composite factor and was particularly important at the site in light of the persistent accumulation of sand. Besides the physical effects of burial and erosion, an influx of sand increases the quantity and availability of nutrients and modifies the aeration and moisture content of the surface soil layers. Sand movement thus influences the competitive ability of species by inhibiting or promoting plant growth through the modification of the above mentioned environmental factors (Moreno-Casasola 1986). The striking increase in relative importance of *E. villosa* as well as the inundation and subsequent demise of the saltmarsh by enriched pioneer species bore witness to the importance of sand movement in zonation at the study site.

The perennial grass, *E. villosa*, is usually described as a dune scrub species that is "common on rear dunes, blowouts and the margin of coastal bush" (Lubke & van Wijk 1998). At the Bushman's River Mouth, however, it functions as a pioneer species by inhabiting and creating a prominent foredune ridge (Lubke *pers. comm*. in: Burkinshaw 1999). The species' ability to tolerate high rates of sand movement contributed to the competitive advantage it apparently had over other pioneer and enriched pioneer species such as *A. populifolia* and *I. pes-caprae.* In this case, *E. villosa* can be likened to the Australasian grass, *Spinifex sericeus* and the European grass, *Ammophila arenaria* (Hesp 1989; Heyligers 1993; Hertling 1998). The latter species was documented as having the ability to withstand sand burial of one metre per year (Hertling 1998). *A. arenaria* was also described as a obligate psammophyte that declines as the sand is progressively stabilised. *E. villosa* exhibited a similar growth pattern as a decline in the vigour and density of older and more stable, stands was observed during the study. It did, however, persist and had the highest importance value in each transect (Figures 4.8 & 4.9) as well as occurring in open and closed scrub communities (Figure 4.12). This is indicative of the success of *E. villosa* as both a pioneer and rear dune species.

The effect of salt-spray on vegetation zonation was somewhat mitigated since the WRCP dunefield was not sea facing. The configuration of the river mouth and the presence of a fossil dune ridge protected the study site from salt-laden winds in comparison to the sea facing beaches of previous studies. Although not measured in this study, inferences on other abiotic factors can be made for the study site based on previous studies (Avis & Lubke 1996). The progressive establishment of vegetation results in increasing gradients of soil moisture content, organic matter and nitrogen in addition to decreasing gradients of soil pH, sand movement, temperature extremes, salinity and moisture variability (Avis 1992).

A change in community structure was evident from 1989 to 2001 at the study site. More diverse and complex communities replaced early colonisers such as pioneer and saltmarsh species present in 1989 (Figure 4.3 & 4.5). Secondary colonisers of dune scrub vegetation increased in abundance and species richness. The sequence of plant communities evident at both time intervals was related to the development of the sandbank. Complex and mature communities were situated at the oldest sections of the dunefield where sand was initially deposited at the south-west corner of the site. Young, less diverse communities colonised the most newly deposited and active zones of the dunefield close to the high water mark of the river. A more detailed discussion of succession at the study site follows.

Succession:

The zonation of coastal dune vegetation forms part of a single plant succession (Tinley 1985). In order to discuss and understand plant succession, Avis (1992) outlined some important questions: do species associations replace each other as groups; whether early and late successional species are present from the onset to the tentative conclusion of succession? Also, do early seral stages facilitate, inhibit or have no effect on late seral stages, is succession unidirectional and lastly, what is the climax state, if any. This study attempted to answer these questions and identify the pathway of succession within the time constraints of the study (1989 – 2001).

Distinct changes in the physiognomy and species composition of communities were discerned both spatially and temporally at the study site. Species diversity, richness and equitability increased while species dominance decreased spatially with increasing distance from the prograding shoreline (Tables 4.2 & 4.3). However, species diversity and equitability did not increase over time. This finding as well as increases in the dominance of pioneer species such as *E. villosa*, are linked to sand accumulation and the constant formation of a new foredune zone. By monitoring the entire length of the transects over time, the increased area of the foredunes exaggerates the relative abundance of pioneer species and do not reflect successional trends accurately. By comparison, ordination of the temporal sequences of the coastal dune vegetation communities indicated that the trend in community change was from pioneer communities to dune scrub and finally to scrub-thicket along a gradient of increasing complexity and age.

These trends accord well with the facilitation pathway described by Connell & Slatyer (1977) and advocated by Avis (1992), del Moral & Wood (1993), Lubke *et al.* (1996), Avis & Lubke (1996) and Olson & Fletcher (2000). The development of the WRCP dunefield created a new site for the colonisation of vegetation. The species composition of vegetation that initially colonised the bank was specific to the prevailing, harsh environmental conditions i.e. high sand-movement rates. These early colonisers then had an autogenic effect on succession by reducing sand movement, stabilising the leading edge of the shoreline thus initiating foredune development (Hesp 1983 & 1989; Nickling & Davidson-Arnott 1990; Avis 1992 & Arens 1994). This created a more suitable environment that affected further species recruitment facilitating the establishment of species otherwise unable to survive in the extremely dynamic foredune zone (Connell & Slayer 1977). The development and colonisation of a foredune zone was therefore crucial for the initiation of succession at the study site.

The continuation of succession along the facilitation pathway indicates that the environment is altered to such an extent that it becomes unsuitable for the perpetuation of early successional species (Connell & Slatyer 1977). It is expected, under this model, that species associations or communities be replaced as groups with a low similarity in species composition between early and late seral stages. Findings appeared to deviate from this concept in that species overlap occurred between communities (Tables 4.8 & 4.9).

Earlier successional species persisted into later seral stages although seral stages were decreasingly similar in species composition (Figure 4.12, Table 4.8 & 4.9). The results suggested that species associations were possibly not replaced as groups but rather that, a more gradual change in community structure occurred.

The relative importance or dominance of individual species varied over time presumably in response to autogenic effects, resource utilisation, environmental gradients, competition, predation and time (Figure 4.12, Avis & Lubke 1996; Warren & Topping 1999; van der Veen 2000; Jochimsen 2001; Shuwen *et al.* 2001). These changes in dominance ultimately resulted in different community structures without a complete species turnover. This notion appeared particularly applicable to consecutive communities that were spatially and temporally close together such as the enriched pioneer and dune scrub communities.

In addition, ordination of both 1989 and 2001 vegetation data did not show discrete community groupings and suggested that the communities intergraded continuously along the successional gradient (Figures 4.10 & 4.11). This implied that after initial colonisation and facilitation of further species recruitment, community structure depended on allogenic factors rather than the facilitative role of secondary colonisers. Some of these factors included species availability, competition for resources and the ability to tolerate changes in environmental conditions

This idea conforms to a more modern, individualistic approach to succession that describes vegetation change as the result of interactions with other individuals, species and abiotic factors (Gleason 1926; Everson & Tainton 1984; Halpern *et al. 19*97; Houle 1997; Dahl & Steenberg 1999; Warren & Topping 1999, Jochimsen 2001, Shuwen *et al.* 2001). However, the decreasing level of similarity between communities and the presence of late successional species e.g. *S. inerme* exclusively in late seral stages indicated that the potential for complete species replacement existed. It is possible that the time span of the study was a limiting factor and that the pathway of succession was indeed facilitation. Avis (1992) found that species intergraded along a successional gradient for only short distances of approximately 100m. The spatial relationship of communities at Mtunzini, related to temporal succession, therefore indicated that species intergradation may only occur in the early stages of succession. The vegetated length of the transects in this study seldom exceeded 100m and represented perhaps, only a short, early portion of vegetation succession at the site.

A temporal survey of vegetation spanning 12 years also offered evidentiary support for the facilitation pathway. Vegetation change for the most part showed an orderly and unidirectional progression. As with ordination of the spatial sequence of communities, the overall successional trend was from pioneer and enriched pioneer communities to dune scrub and scrub-thicket. Transects 4 and 6 were unique in that the vegetation of mid- and lower sections of these transects did not progress during the study period. Succession appeared arrested or stalled in these instances with little community change from the enriched pioneer community over the 12 years. This was attributed to two factors that alluded to the presence of pathways other than that of facilitation.

Firstly, high sand movement rates possibly prevented species other than the most specialised from becoming established. It must be assumed, however, that the autogenic effects of these specialised species were mitigated by sediment influx preventing the facilitative role of the early colonisers. The influence of environmental factors on dominance and ultimately community structure was demonstrated by Shuwen *et al.* (2001). This study showed how transient climax communities could be altered based species abilities to tolerate the manipulation of environmental factors. In this case, a reed wetland was created from Lalang grassland by the careful management of water supply.

Secondly, the inhibition of species recruitment could have occurred due to the opportunistic and aggressive dominance of *E. villosa*. This species may inhibit other pioneer and enriched pioneer species recruitment and survival by its superior ability to capitalise on foredune resources, in particular, high sediment influxes. A similar inhibition pathway was recognised by Jochimsen (2001) where high productive biennial legumes “took advantage of full resources” and out competed other species. However, it was stated that this did not constitute an actual loss as some species persisted in the seed bank and regenerated naturally with further disturbance. Zahawi & Augsperger (1999) identified arrested succession in sites that were dominated by *Baccharis trinervis*, an aggressive shrub species that restricted species diversity in their study of abandoned pastures in Ecuador.

Recent studies of succession acknowledge that to adopt a single framework for succession is simplistic and have introduced the concept of multiple successional pathways for any one site. Avis (1992) in a study on the prograding shoreline at Mtunzini found species overlap and community intergradation denoted an individualistic successional pathway while discrete community groupings and low level of similarity between communities suggested a facilitation pathway. Avis stated that neither pathway was proved or disproved and that multiple working hypotheses of community structure could be adopted.

Warren & Topping (1999) found from succession simulations that life-history strategies were initially important in determining early dominants. Annual species with the potential for rapid growth and large-scale seed production quickly colonised and dominated bare sites. These species, however, were often short-lived and allowed for their ‘space’ to be occupied by other species. Which species dominated as secondary colonisers was related to their ability to tolerate and compete under particular management treatments such as grazing and mowing.

Fastie (1995) found that differing seed sources and species life-histories resulted in multiple succession pathways at ten sites in an attempt to determine successional stages after glacial retreat. In a study of environmental and disturbance influences on forest patterns, Wimberly (2001) stated that “no single theoretical framework was sufficient to explain the vegetation patterns observed in these forested watersheds”. Finegan (1984) summarised the need for multiple successional pathways by stating that “the relative importance of the various mechanism (of succession) is likely to vary widely between environments, but attempts to classify succession on the basis of a single underlying mechanism only obscure understanding and inhibit progress”

Although the trend of community change identified from pioneer to scrub-thicket indicated a progression toward communities of greater maturity, the existence of a single end point or climax community was not noted. The convergence of vegetation toward a single climax state at the site is feasible in light of the trend of community change and given enough ‘disturbance-free’ time and favourable climatic conditions as recorded by Avis (1992) at Mtunzini. Divergence from the coastal forest climax is however, more likely when considering the possibility of multiple successional pathways and the period of drought the area is experiencing presently (Fastie 1995, Avis 1992).

The importance of disturbance in succession must not be under estimated especially if future management strategies are based on the manipulation of vegetation. A change in any of the formative processes, dependent on wind regimes, hydrology, tides and sediment supplies, would produce a corresponding change in the successional pathway. For example, more frequent or stronger winds could initiate a retrogressional pathway as sand inundation would suppress the survival of secondary colonisers and effectively stall succession in a single seral stage. A major flood would scour out most of the bank leaving perhaps only the oldest communities by virtue of their location high above the high water mark. The entire process of colonisation and establishment would re-initiate should conditions return to their previous state. It is also necessary to take into consideration the facilitative role of the early pioneers as it greatly influences the stabilisation of the entire eastern bank of the river mouth. The development of foredunes by pioneer vegetation is essential for the initiation of succession, but evidence of multiple pathways was discovered and reflects the complex nature of ecosystem development and dune stabilisation at the study site.

CHAPTER 5
PUBLIC PERCEPTION

5.1. Introduction:

It is estimated that approximately 60% of the world's population live within 60 km of the coastline, which results in enormous pressure on global coastal resources (La Cock & Burkinshaw 1996). The South African coastline is no different - as a fast developing nation, an increased demand for recreational prospects is inevitable. The coastal zone, with its landscapes, beaches, estuaries and oceans, offers an enticing diversity of recreational activities that translates into an ever-increasing demand on South Africa's coastal resources (Avis 1992).

In an attempt to keep up with the demands, coastal zone managers are obliged to seek ways to increase access to these resources whilst protecting the resource itself to promote its sustainable use. Therein lies a paradox, as often, increased access may be detrimental to the resource itself. This is particularly true of coastal dune systems as they are widely accepted as highly sensitive and vulnerable ecosystems (Bate & Ferguson 1996; Rust & Illenberger 1996; Watson *et al.* 1996). Quantitative data regarding utilisation and perception of any site is therefore imperative to the coastal zone manager, in addition to ecological information, to maintain the balance between utilisation and conservation that is essential for sustainability (Avis 1992).

The authorities have traditionally defined these functions but trends in ecosystem management emphasise the role of community involvement in the decision-making process (Eagles 1984; van der Zande 1989; van der Meulen & Jungerius 1989; Wanders 1989; Hellström 1994). This philosophy is adopted and reflected in current legislation. The White paper for the Sustainable Coastal Development of South Africa recognises this 'profoundly new approach' and states that 'maintaining functional coastal ecosystems must be the achievement of people-centred coastal management' (Smith & Cullinan 2000). Other similar legislation are the National Environmental Management Act, the Environment Conservation Act and the Marine Living Resources Act (Smith & Cullinan 2000).

In accordance with this trend, numerous studies have been undertaken to quantify and assess the demands human utilisation places on coastal resources as well as public perception regarding these resources. Avis (1992) conducted a study to determine beach utilisation, perceptual carrying capacity and recreational preferences of beach users in East London, South Africa. Hertling (1998) used questionnaires to determine public perception regarding sites stabilised by *Ammophila arenaria* along the West Coast. Watson *et al.* (1996) carried out a study regarding the potential impacts of human activity on dune breeding birds in the Alexandria Coastal dunefield while Pendleton *et al.* (2001) assessed public perceptions of Environmental Quality in Los Angeles County.

This study serves a similar purpose as those described above. The objective was to acquaint decision-makers with the public's perception of the environment as well as its functions as defined by the utilisation of the beach and its facilities. To achieve this objective, a survey study of public opinion regarding the use, facilities, ecology and management study site was conducted. Renn *et al.* (1992) stated socio-economic status; cultural ties and experiences influence a person's perception of the environment (environmental quality). Considering this statement, the survey aimed to distinguish between the standing of respondents i.e. holidaymakers, holiday-home owners and permanent residents and assessed whether their perceptions differed significantly and how, or whether, this would influence management decisions. An assessment of awareness and knowledge was also necessary in order to validate their responses with regard in particular, to management strategy.

5.2. Methods:

A public survey was conducted in Kenton-on–Sea during the December 1999 and 2000 summer holiday season. The questionnaire was divided into five sections namely, general questions, facilities, beach usage, and management (see Appendix 2). A number of sites were surveyed on these days, which include Kenton central business district; Westbourne Road properties; Lands End properties; the east bank of the Bushman's river; Kariega river mouth and Kenton Middle Beach and Boesmansriviermond beach (Figure 2.2). Surveying was undertaken at random on the beaches and in the central business district.

At Westbourne Road and Land's End, all the properties that were open for the holiday season were surveyed as having been identified previously as affected parties. Seventy participants were interviewed over the two holiday seasons. A public meeting was held in the Kenton Town Hall on 30 December 1999 and was advertised by means of posters in the Kenton central business district and flyers handed out at random on the beaches and in the town. Questionnaires were also completed at this meeting.

Data analysis:

Cross tabulations of the survey data were produced and statistically compared using Pearson's Chi-squared values. This statistic determined whether the responses of holidaymakers, holiday-home owners and permanent residents differed significantly (Dunn 1977). All analyses were performed by STATISTICA (StaSoft ver. 6) at a 95% confidence interval.

5.3. Results:

The most important findings of this study were presented as a series of tables that show the responses of holidaymakers, holiday-home owners and permanent residents under separate headings. Pearson's chi squared values and associated probability values, included with the tables, indicated whether responses were significantly different. A copy of the questionnaire was included in Appendix 2.

5.3.1. Respondents profile (Questions 1-6):

The object of these questions was to determine the origin of visitors in Kenton during the December holiday season as well as the frequency and duration of their visits. The population during the holiday season was divided into three categories namely holidaymakers, holiday-home owners and residents. Seventy surveys were conducted and 11% of the respondents were permanent residents of Kenton-on-Sea, 51 % were holidaymakers and 37% owned a holiday home in the Kenton area. The majority of respondents were from Gauteng Province and Eastern Cape Province (44% and 32% respectively). The largest proportion of the holidaymakers resided in Gauteng province (61%) followed by the Eastern Cape province (19%). Most visitors that owned holiday-home in Kenton were from Gauteng (33%). The Eastern Cape (30%) and Free State (19%) provinces were also represented amongst holiday-home owners (Table 5.1.). No visitors were recorded from Kwazulu-Natal, the Northern Cape or from the Northwest Province. Holidaymakers visited Kenton annually with the majority spending two (27%) to three (32%) weeks in the town. Holiday-home owners visited more frequently than holidaymakers. They visited twice a year and stayed for three weeks to a month (35% & 27%). Twenty five percent of holidaymakers were first-time visitors in Kenton. All interviewed visitors responded that they would visit again (Table 5.2. & 5.3; *pers. comm*).

Although people of all ages were represented in the survey, findings showed that the majority of people in Kenton during the holidays are aged between 35 and 50 years. Family groups of holidaymakers and holiday-home owners mostly consisted of parents in this age group and children aged 15 years and younger. The majority of permanent residents were aged 50 years or older but family groups also consisted of people aged 15-20 years and younger than 15 years. The differences in age distribution between categories were not significant (Table 5.4).

Table 5.1. Cross-tabulations to compare the place of residence of visitors during December holiday season (Pearson's $\chi^2 = 31.26$; $p<0.05$).

PROVINCE	HOLIDAYMAKERS	HOLIDAY HOME	RESIDENTS	ROW
Eastern Cape Column % Row %	7 19% 30%	8 30% 35%	8 100% 35%	23 32%
Gauteng Column % Row %	22 61% 71%	9 33% 29%	0 0% 0%	31 44%
Free State Column % Row %	1 3% 17%	5 19% 83%	0 0% 0%	6 8%
Limpopo Column % Row %	1 3% 100%	0 0% 0%	0 0% 0%	1 1%
Western Cape Column % Row %	4 11% 57%	3 11% 43%	0 0% 0%	7 10%
Mpumalanga Column % Row %	0 0% 0%	2 7% 100%	0 0% 0%	2 3%
Foreign visitors Column % Row %	1 3% 100%	0 0% 0%	0 0% 0%	1 1%
Totals **Total %**	36 51%	27 38%	8 11%	70 100%

Table 5.2. Cross tabulation to compare category of respondent and frequency of visits (Pearson's $\chi^2=22.98$; $p<0.05$).

FREQUENCY OF VISIT	HOLIDAYMAKERS	HOLIDAY HOMES	ROW
1st visit Column % Row %	9 25% 100%	0 0% 0%	9 15%
12 x per year Column % Row %	1 3% 50%	1 4% 50%	2 3%
6x per year Column % Row %	2 6% 33%	4 16% 67%	6 10%
4x per year Column % Row %	1 3% 13%	7 28% 88%	8 13%

2x per year Column % Row %	5 14% 36%	9 36% 64%	14 23%
1x per year Column % Row %	18 50% 82%	4 16% 18%	22 36%
Totals **Total %**	36 59%	25 41%	61 100%

Table 5.3. Cross tabulation to compare category of respondent and duration of visit (Pearson's χ^2=10.08, p=N.S).

DURATION	HOLIDAYMAKERS	HOLIDAY HOMES	ROW
Day trip Column % Row %	1 3% 100%	0 0% 0%	1 2%
7 days Column % Row %	6 16% 75%	2 8% 25%	8 13%
10 days Column % Row %	4 11% 100%	0 0% 0%	4 6%
14 days Column % Row %	10 27% 67%	5 19% 33%	15 24%
21 days Column % Row %	12 32% 57%	9 35% 43%	21 33%
Month Column % Row %	3 8% 30%	7 27% 70%	10 16%
> Month Column % Row %	1 3% 25%	3 12% 75%	4 6%
Totals **Totals**	37 59%	26 41%	63 100%

Table 5.4. Cross tabulation to compare the age distribution and category of respondents (Pearson's χ^2 = 13.59 p= N.S.).

AGE DISTRIBUTION	HOLIDAYMAKERS	HOLIDAY HOMES	RESIDENTS	ROW
<15 years	53	58	2	113
Column %	25%	29%	20%	
Row %	47%	51%	2%	27%
15-20 years	34	23	3	60
Column %	16%	11%	30%	
Row %	57%	38%	5%	14%
20-35 years	32	33	1	66
Column %	15%	16%	10%	
Row %	48%	50%	2%	16%
35-50 years	69	59	0	128
Column %	32%	29%	0%	
Row %	54%	46%	0%	30%
>50 years	25	29	4	58
Column %	12%	14%	40%	
Row %	43%	50%	7%	14%
Totals	213	202	10	425
Total %	50%	48%	2%	100%

5.3.2. Beach utilization and general activities (Questions 7-11):

The Kariega (28%) and Bushman's (27%) river mouths were the most popular beaches visited followed by Middle beach. This sentiment was consistent for holidaymakers, holiday-home owners and residents alike and no significant differences in the preference of beach were found among these categories (Table 5.5). Respondents commented that choice of beach was often related to wind direction, as Kenton main beach is sheltered from the westerly winds and Bushman's River Mouth from the easterly winds. Approximately 84% of people felt that the number of visitors using the beach was "about right" and that it was neither under or overcrowded. The response from each category, however, was significantly different (Table 5.6). 11% of holidaymakers stated that the beach was sometimes overcrowded. Holiday-home owners differed in this sentiment and 11% expressed the view that the Bushman's River Mouth beach was under utilized. An equal number (13%) of permanent residents believed the beach to be overcrowded and under utilized although the greatest majority agreed with the consensus.

Respondents took part in numerous activities on the beach and no significant differences were found between the respondent categories (Table 5.7). Swimming, sunbathing and walking were the top three activities most often enjoyed at the Bushman's River Mouth beach (18%, 16% & 14% respectively). Holidaymakers and holiday-home owners took part in these three activities more often than other activities whilst in addition to those listed above, residents of Kenton included fishing, surfing, and snorkeling as activities done at the beach (Table 5.6). When asked whether people walked over the vegetated dunes or in the coastal thicket, the majority of holidaymakers (39%), holiday-home owners (52%) and residents (63%) stated that they did walk over the dunes. Fewer people left pathways to explore coastal thicket whilst walking. 19% of holidaymakers, 15% of holiday-home owner and 25% of residents admitted to walking in the thicket. A large portion of the beach users has lunch at home (77%) or to a lesser extent, on the beach (17%).

Table 5.5. Cross tabulations of beach preference and category of respondent (Pearson's χ^2=3.98, p=N.S.).

BEACH PREFERENCE	HOLIDAYMAKERS	HOLIDAY HOMES	RESIDENTS	ROW
Kariega	28	21	7	56
Column %	32%	25%	25%	
Row %	50%	38%	13%	28%
Middle Beach	14	17	5	36
Column %	16%	20%	18%	
Row %	39%	47%	14%	18%
Shelley Bay	11	15	4	30
Column %	13%	18%	14%	
Row %	37%	50%	13%	15%
Boesmansriviermond	8	11	4	23
Column %	9%	13%	14%	
Row %	35%	48%	17%	12%
Bushman's Beach	27	19	8	54
Column %	31%	23%	29%	
Row %	50%	35%	15%	27%
Totals	88	83	28	199
Total %	44%	42%	14%	100%

Table 5.6. Cross tabulation comparing perceptual carrying capacity of beaches and category of respondent (Pearson's χ^2=16.92, $p<0.05$).

PERCEPTUAL CARRYING CAPACITY	HOLIDAYMAKERS	HOLIDAY HOMES	RESIDENTS	ROW
Far too many	0	0	1	1
Column %	0%	0%	13%	
Row %	0%	0%	100%	1%
Too many	3	2	0	5
Column %	11%	5%	0%	
Row %	60%	40%	0%	7%
About right	24	31	6	61
Column %	89%	82%	75%	
Row %	39%	51%	10%	84%
Too few	0	4	0	4
Column %	0%	11%	0%	
Row %	0%	100%	0%	5%
Far too few	0	1	1	2
Column %	0%	3%	13%	
Row %	0%	50%	50%	3%
Totals	27	38	8	70
Total %	37%	52%	11%	100%

Table 5.7. Cross tabulations comparing beach activities and category of respondent (Pearson's χ^2=44.96, p=N.S.).

ACTIVITIES	HOLIDAYMAKERS	HOLIDAY HOMES	RESIDENTS	ROW
Games	15	10	1	26
Column %	10%	6%	4%	
Row %	58%	38%	4%	8%
Sunbathing	27	24	2	53
Column %	19%	14%	7%	
Row %	51%	45%	4%	16%
Surf	8	10	2	20
Column %	6%	6%	7%	
Row %	40%	50%	10%	6%
Swim	30	26	6	62
Column %	21%	15%	22%	
Row %	48%	42%	10%	18%
Braai	6	9	1	16
Column %	4%	5%	4%	
Row %	38%	56%	6%	5%
Powerboat	9	10	0	19
Column %	6%	6%	0%	
Row %	47%	53%	0%	6%
Fish	10	15	2	27
Column %	7%	9%	7%	
Row %	37%	56%	7%	8%
Snorkle	4	7	2	13
Column %	3%	4%	7%	
Row %	30%	54%	15%	4%

Windsurf	1	2	1	4
Column %	1%	1%	4%	
Row %	25%	50%	25%	1%
Canoe	2	8	1	11
Column %	1%	5%	4%	
Row %	18%	73%	9%	3%
Walk	22	18	7	47
Column %	15%	11%	26%	
Row %	47%	38%	15%	14%
Paddleski	3	8	1	12
Column %	2%	5%	4%	
Row %	25%	67%	8%	4%
Sandski	3	5	1	9
Column %	2%	3%	4%	
Row %	33%	56%	11%	3%
Sail	0	2	0	2
Column %	0%	1%	0%	
Row %	0%	100%	0%	1%
Waterski	0	13	0	13
Column %	0%	8%	0%	
Row %	0%	100%	0%	4%
Other	0	2	0	2
Column %	0%	1%	0%	
Row %	0%	100%	0%	1%
Totals	145	169	27	341
Totals %	43%	50%	8%	100%

5.3.3. Modes of Transport and facilities (Questions 12-16):

The majority of people either drove (47%) or walked (48%) to the beach and when asked whether they found the parking facilities at the Westbourne Road Car Park adequate most visitors agreed that the facilities were adequate (Table 5.8). Holidaymakers and residents (52% & 50%) deemed the parking facilities but holiday-home owners felt that parking at this site is inadequate (40%). The majority of respondents (45%) were willing to walk more than 200m from a distant parking facility if necessary although 21% were not willing to use a more distant car park at all.

Suggestions regarding improvements to general facilities at the Bushman's River Mouth beach were solicited from the respondents (Table 5.9). The most popular recreational facility improvements were picnic spots (27%) followed by a beach café (36%) and boardwalks (21%). Holidaymakers voted most often for a beach café (34%) whilst residents felt that both picnic spots and a café (24%) would improve the area.

Many holiday-home owners were indifferent to potential recreational improvements (34%) but also expressed a desire to see picnic spots provided (25%). All three categories listed boardwalks as another potential improvement. Most people questioned felt that it was not necessary to implement any changes regarding information provisions (28%). It was suggested that if changes were to be made, that nature trails and information boards were potential educational improvements (25% & 22%). All three categories of respondents were of this opinion and differences between their responses were not statistically significant (Table 5.9).

Table 5.8. Cross tabulation comparing the response of the categories of respondents and adequacy of parking facilities (Pearson's χ^2=1.93, p=N.S.).

PARKING	HOLIDAYMAKERS	HOLIDAY HOMES	RESIDENTS	ROW
Adequate	19	9	4	32
Column %	53%	36%	50%	
Row %	59%	28%	13%	46%
Inadequate	11	10	3	24
Column %	31%	40%	38%	
Row %	46%	42%	13%	35%
Indifferent	6	6	1	13
Column %	17%	24%	13%	
Row %	46%	46%	8%	19%
Totals	36	25	8	69
Total %	52%	36%	12%	100%

Table 5.9. Cross tabulation of desired improvements in recreation (Pearson's χ^2=16.48, p<0.05) and information (Pearson's χ^2=3.00, p=N.S.) facilities at the study site.

FACILITIES		HOLIDAY MAKERS	HOLIDAY HOMES	RESIDENTS	ROW
Recreation	**Indifferent**	1	11	3	15
	Column %	2%	34%	18%	
	Row %	7%	73%	20%	17%
	Picnic spots	12	8	4	24
	Column %	29%	25%	24%	
	Row %	50%	33%	17%	27%
	Restaurants	5	1	3	9
	Column %	12%	3%	18%	
	Row %	56%	11%	33%	10%
	Beach café	14	5	4	23
	Column %	34%	16%	24%	
	Row %	61%	22%	17%	26%

	Boardwalk	9	7	3	19
	Column %	22%	22%	18%	
	Row %	47%	37%	16%	21%
	Totals	41	32	17	90
	Total %	46%	36%	19%	100%
Information	**No need**	13	12	4	29
	Column %	25%	31%	29%	
	Row %	45%	41%	14%	28%
	Nature trails	13	11	2	26
	Column %	25%	28%	14%	
	Row %	50%	42%	8%	25%
	Info boards	13	7	3	23
	Column %	25%	18%	21%	
	Row %	57%	30%	13%	22%
	Tours	7	5	2	14
	Column %	14%	13%	14%	
	Row %	50%	36%	14%	14%
	Education centre	5	4	3	12
	Column %	10%	10%	21%	
	Row %	42%	33%	25%	12%
	Totals	51	39	14	104
	Total %	49%	38%	13%	100%

5.3.4. Perception of the environment (Questions 17-20):

In general, the vegetated dunes at Bushman's River Mouth are perceived to be attractive (61%) or very attractive (27%) by holidaymakers, holiday-home owners and residents alike (Table 5.10). Whether the public perceived the dunes to be an asset to the area was unclear. 40% agreed that the vegetated dunes were an asset but an equal percentage was indifferent to the question. Holidaymakers and holiday-home owners were divided in their opinion. Most holidaymakers were indifferent (43%) while 35% are of the opinion that the dunes were an asset. The sentiment of holiday-home owners was similar with 44% indifferent and 48% believed that the dunes were an asset. Half of the residents interviewed did not see the dunes as an asset but 38% disagreed with this opinion (Table 5.11). All three categories of respondents expressed no desire to have a greater beach or water area at the river mouth (53%) and commented that they enjoyed the area as is. A slightly larger proportion of residents preferred more beach area to water frontage but both holidaymakers and holiday-home owners preferred slightly more water frontage to beach area (Table 5.12).

Table 5.10. Cross tabulation comparing respondents perception of the aesthetic appeal of the vegetated dunes (Pearson's χ^2=14.16, p=N.S).

AESTHETIC APPEAL	HOLIDAYMAKERS	HOLIDAY HOMES	RESIDENTS	ROW
Indifferent	0	1	1	2
Column %	0%	4%	13%	
Row %	0%	50%	50%	3%
Very attractive	7	10	2	19
Column %	18%	40%	25%	
Row %	37%	53%	11%	27%
Attractive	29	10	4	43
Column %	76%	40%	50%	
Row %	67%	23%	9%	61%
Not attractive	2	2	1	5
Column %	5%	8%	13%	
Row %	40%	40%	20%	7%
Eyesore	0	2	0	2
Column %	0%	8%	0%	
Row %	0%	100%	0%	3%
Totals	38	25	8	70
Total %	54%	35%	11%	100%

Table 5.11. Cross tabulation comparing respondents opinion on whether the vegetated dunes are an asset to Bushman's River Mouth beach (Pearson's χ^2=7.79, p=N.S.).

ASSET	HOLIDAYMAKERS	HOLIDAY HOMES	RESIDENTS	ROW
Indifferent	16	11	1	28
Column %	43%	44%	13%	
Row %	57%	39%	4%	40%
Yes	13	12	3	28
Column %	35%	48%	38%	
Row %	46%	43%	11%	40%
No	8	2	4	14
Column %	22%	8%	50%	
Row %	57%	14%	29%	20%
Totals	37	25	8	70
Total %	53%	36%	11%	100%

Table 5.12. Cross tabulation comparing respondents preference for beach or water frontage at the river mouth (Pearson's χ^2=2.54, p=N.S.).

RIVER MOUTH	HOLIDAYMAKERS	HOLIDAY HOMES	RESIDENTS	ROW
Indifferent	0	1	0	1
Column %	0%	4%	0%	
Row %	0%	100%	0%	1%
More beach area	9	6	2	17
Column %	23%	24%	25%	
Row %	53%	35%	12%	24%
More water area	9	6	1	16
Column %	23%	24%	13%	
Row %	56%	38%	6%	22%
Neither	21	12	5	38
Column %	54%	48%	63%	
Row %	55%	32%	13%	53%
Totals	39	25	8	70
Total %	54%	35%	11%	100%

5.3.5. Public awareness and management (Questions 21-28):

Public awareness of present and future management issues was low with 65% of respondents expressing a lack of information regarding management program for the river mouth and its surrounding beaches (Table 5.13). No statistical differences were found between categories. Since no statistical differences were also found between holiday-home owners and permanent residents for all the questions relating to management strategies and issues at the site, the results of these questions were summarized into a single table, Table 5.14.

The majority of respondents believed that neither the silting (79%) of the river or mobile drift sand (80%) would affect their properties. When questioned whether the "council" should restore the main river channel to the eastern bank, 47% chose the affirmative answer. A high percentage of respondents, 32% answered that they were indifferent or "did not know what to answer" (Table 5.14). 68% of ratepayers were aware of the dredging program in the river mouth in attempt to curb silting. 41% of ratepayers were of the opinion that the program was successful while 32% disagreed.

A sizable number of respondents were indifferent or had no opinion (26%). Opinion regarding the most recent management proposal of destabilizing the vegetated dunes was ambivalent. While 50% were in favour of destabilizing, again a high percentage of people, 35% were indifferent or did not know what to answer. The eradication of the alien, *Acacia cyclops* (Rooikrans) from the area received the majority of respondent's support (82%).

Table 5.13. Cross tabulation of whether information on environmental issues or management was received by ratepayers (Pearson's χ^2=1.10, p=N.S.).

MANAGEMENT INFORMATION	HOLIDAY HOMES	RESIDENTS	ROW
Indifferent	3	0	3
Column %	12%	0%	
Row %	100%	0%	9%
Yes	7	2	9
Column %	27%	25%	
Row %	78%	22%	26%
No	16	6	22
Column %	62%	75%	
Row %	73%	27%	65%
Totals	26	8	34
Total %	76%	24%	100%

Table 5.14. Summary of cross tabulation for ratepayers' perception of management strategies and environmental issues and (Pearson's χ^2 values were not significant for any of the listed questions).

MANAGEMENT STRATEGY	YES	NO	DON'T KNOW / INDIFFERENT
Does the silting of the river affect you?	12%	79%	9%
Would mobile sand affect your property?	17%	80%	3%
Should the river be restored to the Eastern Bank?	47%	21%	32%
Are you familiar with the dredging programme?	68%	26%	6%
Did you think that dredging was worthwhile?	41%	32%	26%
Are you in favour of destabilization?	50%	15%	35%
Are you in favour of Rooikrans eradication?	82%	6%	12%

5.4. Discussion

Kenton–on-Sea is a popular holiday destination and it is estimated that the population increases by some 5000 residents during the holiday season, approximately ten times the size of the permanent population (De Villiers 1987). The enormous demand on the river mouths as well as the economic input of these visitors during the season cannot be overlooked. The development of a sound management plan under a holistic framework required information regarding this demand as well as the utilisation of Kenton-on-Sea's coastal resources. The survey conducted in this study provided such information.

Utilisation and activities:

The large influx of people into Kenton-on-Sea during the Christmas peak season translated into an increased demand for recreational outlets. Findings showed that the Kariega and Bushman's River Mouths and their associated beaches were the most popular recreational areas. Their popularity resulted from the wide range of attractions these beaches had to offer. Kariega River Mouth has an extensive lagoon area as well as a sea-facing beach that were well utilised by sunbathers and swimmers. A beach café and restaurant served beach users during the holiday season. Beach users had access to basic amenities such as clean, modern ablutions and freshwater taps associated with these facilities. A municipal toilet block also existed at Kariega River Mouth but was in very poor condition during the study period. A car park situated above the main sea-facing beach as well as a smaller car park that belongs to the restaurant and café supplied the necessary parking facilities. The Bushman's River Mouth also offered an extensive lagoon and beach area for sunbathing and swimming although no sea-facing beach existed. A basic but functional municipal toilet block was provided and a single freshwater tap. A small car park known as the Westbourne Road Car Park was situated adjacent the lagoon beach area.

Kariega River Mouth beach was presumably more popular than Bushman's River Mouth beach because of the superior facilities available and the sea-facing beach. Respondents commented that the choice of beach depended on the facilities available and the proximity of the beach to residences or accommodation. The weather also played an important role in the choice of beach, as the Kariega beach is sheltered from the westerly winds and Bushman's River Mouth from the easterly winds. Kenton Middle beach, the third most popular beach, is the only beach that has rock pools and a safe 'paddling' area for young children.

Avis (1992) discussed the concept of carrying capacity in terms of physical, ecological and perceptual carrying capacities. This study investigated perceptual carrying capacity defined as “the visitors perception of others present at the same time and the effect of crowding on their enjoyment and appreciation of the site” (Avis 1992). Perceptual carrying capacity provided information on the extent of the utilisation of the beaches as defined by resource users. The survey showed that visitors and residents alike agreed that numbers at the Bushman’s River Mouth beach (study site) were at a comfortable level. Holidaymakers expressed the sentiment that the beaches were overcrowded at times while holiday-home owners and residents felt that the beach was sometimes under-utilised. This indicated that during the peak holiday season in December especially during public holidays that the full physical capacity of the most popular beaches was reached. Glassom & McLachlan (1989) suggested that people considered a beach crowded at densities of 6-9 m^2/person but for natural areas, such densities were considered unacceptable as in the case on Kenton beaches. It was expected that holiday-home owners and residents were more likely to consider the beaches under utilised as they were present in Kenton-on-Sea not only in peak season but also during the off-peak season. Far, fewer people spent time on the beaches during this time, which gave holiday-home owners and residents a different perspective of beach utilisation.

Beach users participated in many activities at the Bushman’s River beach. The most avidly enjoyed were swimming, sunbathing, walking, fishing and beach games. Besides swimming, few respondents took part in water sports such as windsurfing, sailing and water-skiing at the river mouth, possibly because the appropriate facilities for these sports do not exist on the eastern bank of the river mouth. Although swimming, sunbathing and fishing were confined to the sandy beach, river mouth and rocks, many people walk along the sandy beach and into a portion of the Joan Muirhead Nature Reserve. This stretch connects Bushman’s River Mouth beach and Middle beach. A number of respondents walked over the vegetated dunes, mainly to access the sandy beach and river from the car park. Some included walks through the coastal thicket for the scenic view and as a route over a vegetated fossil dune ridge to Shelley Bay.

Facilities:

The majority of beach users drove or walked to the river mouth and for the most part, parking facilities were considered adequate. Holiday-home owners commented that in season, many holidaymakers park directly adjacent to their homes on the Westbourne Road embankment when the car park is full. This caused congestion along the narrow Westbourne Road and occasionally restricted access to their properties. Although this was a valid concern, it was quite rare that the car park was full and vehicles parked informally along the embankment. The migration of the transverse dune at the site as described in Chapter 3 poses a threat to the Westbourne Road car park and municipal toilet block. Both are located directly in the path of the dune and will probably be inundated by sand in ~15-20 years. A possible solution to this problem is the construction of a distant parking lot and ablution block, out of the path of the dune. The finding that beach users were willing to walk more than 200 m from such a parking lot indicated that this may indeed be a feasible option.

Suggestions for recreational improvements to the site included the addition of picnic spots and a beach café. Although many visitors to the beach chose to have lunch at home, many felt additional facilities such as the picnic spots and a café would increase utilisation of the Bushman's River Mouth beach. Interestingly, inspite of the restricted access to the beach from the car park as a result of the development of vegetated dunes, boardwalks were not a listed first as the most favoured improvement to the site. This suggested that addressing the problem of access to the sandy beach and river was less urgent than previously thought by interested and affected parties. The presence of two concrete stairways along the Westbourne Road embankment that lead directly from Westbourne Road to the beach and were not restricted by the newly developed dunes may have mitigated this problem. They are within 200m from the car park and respondents had already stated that they were willing to walk similar distances to the beach. Favoured information improvements to the facilities were listed as nature trails and information boards. This would benefit the area since the Joan Muirhead Nature Reserve borders the study site and information regarding the reserve and its fauna and flora. Such development would draw greater attention to the conservation role of the site by providing ecology related recreational activities.

Perceptions of the environment and ecology:

The environment around the Bushman's River Mouth beach consists of a sandy beach, vegetated dunes and the river mouth. Overall, the public found the area and its vegetated dunes attractive but whether they regarded the vegetated dunefield as an asset to the area remained unclear. Although many respondents felt the dunes were an asset, an equal portion was indifferent or of no opinion. This was possibly due to the nature of the question, as many people do not normally consider ecological features in this manner. In addition, many commented that they did not know since they considered the dunes simply as "part of the scenery" and were therefore indifferent to the question. The majority of permanent residents did not find the dunes an asset possibly because they were more aware of the ecological and aesthetic issues in contention surrounding the newly developed dunefield.

Along similar lines, the majority of respondents felt that neither more beach area nor more water area would improve the appeal of the site. Findings showed that most people were generally accepting in their perception of the area. Very few respondents appeared to have any knowledge regarding the ecology of the area at all except for a small number of long-time residents. It appeared that although the beach and surrounding environment is aesthetically pleasing to visitors, they are far more interested in recreational activities than in the surrounding environment.

Functions for society:

Within the immediate vicinity of the study site, a number of functions or land uses overlap namely recreation, conservation, education and residential. The assessment of the utilisation, facilities and perceptions of the Bushman's River Mouth beach by the resource users helped define the functions, or role of the beach in Kenton-on-Sea. The area primarily functions as a recreational site particularly during the December holiday season. The majority of beach users participated in numerous beach and water-related activities. Improvements to the facilities as those suggested would greatly benefit the recreational utilisation of the site and may also draw attention to some of the other, lesser functions of the site e.g. conservation.

The Joan Muirhead Nature Reserve located between the Bushman's and Kariega River Mouths, safeguards coastal flora and fauna that are indigenous to the area. A number of pathways exist that transverse the reserve that allows access to all except the most sensitive areas. The western can be accessed from the Bushman's river beach and adjacent car park. The relatively young vegetated dune system at the beach is unique, as it is one of the few examples of a prograding dune system in South Africa. In conjunction with the proximity of the Reserve, the area was an attractive site for educational purposes. It was often visited by students and has been the site for a number of research projects.

A well-developed residential area exists adjacent the site. Numerous houses are located along Westbourne Road and overlook the Bushman's River Mouth with its sandy beach and vegetated dune system. The aestheticism of beach as well as river access was important in terms of property value and desirability for potential buyers and current owners. Many of the concerns raised during meetings were voiced by property owners and were associated with restricted beach and river access as well as the aesthetics of the area.

Perceptions regarding management:

Most of the respondents have never received any information regarding past, present or future management plans for the study site. It is likely that the apparent lack of information has resulted from a number of shortcomings in management procedure. Prior to the development of the Estuarine Forum in 2001 facilitated by the Institute of Natural Resources, environmental issues were disjointedly debated at Ratepayers Association, Bushman's Kariega Trust and Joan Muirhead Nature Reserve Advisory Committee meetings. On occasion meetings were held in conjunction with the Department of Environmental Affairs and Tourism and the Transitional Local Council. Local NGO's committees consisted of some members of the community but little was done to contact or advise all affected parties. Interested parties were more likely to attend meetings but all the residents of Land's End, Westbourne Road and Boesmansriviermond should possibly be notified in writing of pending meetings regarding environmental issues or management proposals.

Although a number a management plans have been implemented at the Bushman's River beach, the majority of visitors and residents are unaware of any except the most visible of actions for example, dredging of the river mouth and invasive species eradication. Respondents also believed that neither sedimentation in the river mouth or mobile sands would affect their properties. This may be due to a lack of information regarding ecological issues at the site and it is very likely that the general opinion will change if these issues were better understood. Renn *et al.* (1992) stated that familiarity or exposure to information about the environment interacts with personal attributes and affected overall perceptions. Considering the findings, it would be prudent to offer public lectures, discussion groups or distribute information on environmental and management issues pertaining to the study site. The survey also failed to distinguish between affected respondents and other residents of Kenton-on-Sea thereby introducing a bias by virtue that most respondents were not affected since their properties were not located at the study site. In light of this fact, the best approach may be a focus group meeting with residences that are directly affected by management plans (Avis *pers comm* 2003).

Another objective of this survey was to determine whether holidaymakers, holiday-home owners and permanent residents of Kenton-on-Sea differed in their perceptions and utilisation of the study site. A conflict between these standings for example, in the utilisation of an area, would greatly influence management decisions considering the economic importance of the annual visitors and the inherent rights of property owners. Fortunately, such a conflict did not arise between people of different standings with respect to utilisation and perceptions at the Bushman's River Mouth beach. Statistical analysis of the responses showed that for the majority of questions, no significant relationship was found between the responses of each category or standing of respondents. The consensus found from the survey possibly resulted from a shared, common cultural background that influenced their leisure activities and perceptions of the environment (Pendleton *et al*. 2001). Although different socio-economic groups were surveyed, the majority of respondents (and beachgoers) were caucasian, English or Afrikaans-speaking South Africans.

CHAPTER 6
GENERAL DISCUSSION

The main objective of this thesis was to provide an insight into the ecological functioning of the dunes at Bushman's River Mouth in order to provide decision-makers with a holistic platform on which to develop future management strategies. This objective was achieved through the strategic analysis of important ecosystem components namely the sediment and vegetation dynamics as well as public perceptions regarding the system as a whole. This chapter outlines ecosystem functioning at the study site and discusses how this information can best be put to use in developing a management plan for the area.

6.1. Management perspectives:

The lower reaches of the Bushman's river and the river mouth itself have had a history of poor management that resulted in a number of management issues. Prior management strategies were based on speculation and subjective assessments of the present and past "natural functioning" of the river mouth dune system and were implemented on a "trial-and-error" approach. Considering these failed attempts, the authorities and key role-players have since recognised the value of a ecosystem approach in the development of future management strategies for the area. Central to the formulation of such a management plan is setting clear objectives based on information regarding all aspects that influence the system (Davies *et al*. 1995). It is likely that a lack of a clear, definitive objective for the Bushman's River Mouth resulted in the bad management practices of the past.

Under an ecosystem approach, the present and future functions of the system are paramount in determining an appropriate, long-term goal and a successful dune management plan. Commonly, authorities and/or policy defined these objectives or 'end point' goals but more recently, the role of community involvement is emphasised as part of a holistic, ecosystem approach to dune management (Eagles 1984).

For the purposes of this discussion, the functions of the Bushman's River Mouth are defined by the community's response regarding the most popular utilisation and activities enjoyed at the study site. Within the immediate vicinity of the study site, a number of functions or land uses overlap namely recreation, conservation, education and residential. The area primarily functions as a recreational site particularly during the December holiday season. The majority of beach users participated in numerous beach and water-related activities. Best achievable ecosystem function within the framework of optimal recreational and aesthetic value could well serve as desired end points for the system.

6.2. Management Issues at Bushman's River Mouth:

The management issues identified for the site are primarily concerned with the alleged disruption of the natural ecological function of the river mouth. It was assumed that this occurred through the stabilisation of a headland bypass system and the subsequent development of at retentive vegetated dunefield (Booysen 1995a). Sedimentation in the river mouth, sand accumulation and the development of the WRCP dunefield are considered the product of human intervention for which remedial action is required.

In the past, the development of the WRCP dunefield was considered an ecological, aesthetic and recreational loss to Kenton-on-Sea (Booysen 1995a). From an ecological perspective the transformation from a transgressive to a retentive dune system reflects a shift in the dynamic equilibrium. This shift occurred in response to changing environmental variables that are beyond, but possibly exacerbated by human intervention.

Sand begun accumulating along the eastern bank of the Bushman's River Mouth approximately 60 years ago (Jacobs 1993). Marine-derived sediments entered the river mouth with the tides and were deposited along the bank forming a sandy beach referred to as the Westbourne Road Sandbank (WRSB). The development of the sandbank created a bare site for the establishment of vegetation and by 1973, the WRSB was fully colonised by coastal dune species. Once dry, subsequent accretions were transported by aeolian processes into the newly established vegetation resulting in the development of the Westbourne Road Car Park (WRCP) dunefield. This complex interaction between sediment, aerodynamics and vegetation forms the central nucleus of dune ecosystem dynamics.

Presently, the retentive vegetated dune system consists of a combination of dunes types namely hummock dunes, parallel beach ridge hummocks, retention/precipitation foredune ridge and a mobile transverse dune. The system acts as a sediment sink with an accretion rate of 12.03 m^3yr^{-1} (Figure 3.8). A prominent feature of the northern section of the dunefield is a foredune ridge that was colonised by the aggressive grass species, *E. villosa.* This section prograded in a north-westerly direction due to the ability of *E. villosa* to rapidly colonise bare sand deposited below the foredune ridge. The southern section of the dunefield is distinct as it supports a mobile transverse dune. This dune exhibited a westward migration at a net rate of 9.00 m yr^{-1} from May 2000 to July 2001.

A number of factors influence sedimentological processes at the WRCP dunefield such as wind regime, topography, coastal configuration, rainfall, presence of vegetation, long shore drift and wave action as well as the hydrology of the river mouth (Tinley 1985). The amount of sand deposited throughout the year depends on seasonal wind patterns. A greater accumulation of sand resulted during intervals when westerly winds dominated. An aeolianite cliff confines the eastern bank and in addition to the configuration of the river mouth exposes the study site to these sand-laden westerly winds whilst protecting it from the summer easterlies (Chapter 3.3.3).

Long-term spatial variations in processes reflected the temporal pattern of sand deposition and aeolian transport from north to south at the site while short-term variation represented the inherent dynamics of the dune types present. Although a spatial variation was evident from north to south along the dunefield, the data did not support the conjecture that two separate dune systems exist at the WRCP dunefield.

Sedimentation in the Bushman's River Mouth is part of the natural dynamics of this tide-dominated system. River mouths and estuaries function as natural sediment traps for both fluvial and marine sediments (Jacobs, 1993). The amount and pattern of sedimentation is influenced by a reduction in flow volume attributed to numerous small impoundments upriver and the restriction of the upper reaches of the mouth by the national road bridge (see Chapter 2 for details). However, changes in the same parameters could also be attributed to prevailing eustatic sea level conditions and alternating deposition and erosion cycles primarily influenced by the short-term dynamic cycle of flooding (Jacob 1993).

The colonisation of the study site by vegetation and the development of a retentive dune system through the interaction of aeolian and vegetation processes were also found to conform to accepted ecological principles coastal dunes (Chapter 4). The species present were typical of dunefield vegetation of the Eastern Cape coastline (Lubke & Van Wyk, 1998). Five communities were recorded at the site over the 12-year study period namely, the saltmarsh, pioneer, enriched pioneer, open and closed scrub as well as scrub-thicket communities. Distinct differences in the physiognomy and species composition existed between these communities. Species diversity, richness and equitability increased while species dominance decreased with increasing distance from the prograding shoreline.

As more sand accumulated along the bank, a greater area for colonisation was created and the vegetation continued to spread. The communities developed sequentially as sand accumulated first in a northwesterly and later in an easterly direction. The distribution of plant communities reflected this sequential establishment of vegetation. The oldest, most mature and diverse communities were situated in the south-eastern corner of the site whilst consecutively younger communities occurred with decreasing distance from the high water mark of the river mouth. The zonation of vegetation communities at the study site was typical for prograding shorelines and was derived from species-specific physiological tolerances to environmental gradients. The most important factor in determining vegetation zonation at the site was sand movement. The zonation of coastal dune vegetation forms part of a single plant succession (Tinley 1985).

The successional trend was from pioneer communities to dune scrub and finally to scrub-thicket. This trend was typical for prograding coastal dunes along the South African coastline (Avis & Lubke, 1996). The development of foredunes by pioneer vegetation is essential for the initiation of the process, which is unidirectional along a gradient of increasing diversity, age, complexity and decreasing species dominance. Initially succession follows the facilitation pathway with early reducing sand movement and stabilising aeolian accretions. This created a more suitable environment that facilitated the establishment of species otherwise unable to survive in the extremely dynamic foredune zone.

Findings showed that after primary colonisation further species recruitment, community structure depended on allogenic factors rather than the facilitative role of secondary colonisers. These findings suggested the existence of multiple successional pathways at the site. The convergence of vegetation toward a single climax state at the site was feasible but not observed while divergence from the coastal forest climax was more likely when considering the possibility of multiple successional pathways.

It can therefore be argued that sand accumulation; sedimentation and the establishment of vegetation at the Bushman's River Mouth are an equilibrium shift through natural processes in response to a number of changing environmental variables. It follows that since there in no fixed equilibrium for ecosystems, especially those that are subject to dynamic formative processes such as the coastal dune system, that no past or present features of that system should be used to define a 'natural state' for any given ecosystem (Jacob 1993). Does this change in the ecology of the area, not wholly due to human intervention then constitute an ecological loss solely because it differs from a previous state?

The second reputed 'loss of value' of the area resulting from this equilibrium change in the system is that concerned with aestheticism. A highly subjective issue such as this can only be quantitatively assessed by determining the opinion of those utilising and residing in the area. In general, the public found the site aesthetically pleasing while only respondents that were aware of the contention surrounding the area expressed a negative perception of the dunefield. This finding casts doubt on whether this issue is indeed a valid concern and whether it requires any consideration in a management plan for the site. Should decision-makers choose to take into account both opinions, they would have to prioritise or rank these perceptions in order to make a decision on a course of action to address this issue. They would then be faced with the question of, which is more important, the opinion of the general public utilising the area or the residents living in the immediate vicinity?

The third issue raised by interested and affected parties is that of recreational loss at the site. The WRCP dunes restrict access to the sandy beach and river frontage from the Westbourne Road Car Park. This problem appears to be mitigated for the moment by the existence of concrete stairways that allow access directly to the beach approximately 200m from the car park.

It was reported in Chapter 5, that the majority of beach users are prepared to walk 200m to access the beach from a distant parking lot. This indicates that visitors are probably comfortable walking the extra distance to these stairways in any case. It is, however, likely that the dunes adjacent to these stairways will increase in height and vegetation cover over time since this portion of the dunefield is relatively young and in an early successional stage. Should these dunes restrict the use of the stairways, access to the beach will become an important management priority. An additional problem at the site is the migration of the mobile transverse dune adjacent to DBV. The Westbourne Road car park and municipal toilet block are situated directly in the path of the migrating dune. A residential development at the entrance of DBV, adjacent to the car park is also at risk of sand inundation.

6.3. Recommendations:

A few management scenarios exist; some of which have already been proposed but the choice of appropriate solution requires the managers of the Bushman's River mouth to define a clear objective for the site. Considering the recreation and residential functions of the area, maintaining access to the river mouth, car park and toilet block is essential as is protecting new residential developments from sand inundation.

The ideal situation would be to manage the retentive vegetated system back to a mobile transgressive system, if conclusive evidence could be presented indicating that the system previously functioned as a headland bypass system. The Bushman's Kariega Trust proposed the destabilisation of DBV and the WRCP dunefield. Burkinshaw (1998) conducted a feasibility study on destabilisation and listed a number of recommendations regarding a destabilisation strategy and the monitoring thereof. Burkinshaw (1998) advocates the destabilisation of DBV as a potential tool to manage the migrating transverse dune but cautions that as a result of a change in environmental conditions and the volume of sand that has to be mobilised, that there is no guarantee that the bypass system will re-activate successfully. The destabilisation of the WRCP dunefield is not recommended in her report.

The findings of this thesis support Burkinshaw's (1998) recommendations. The spatial variation of sedimentological processes indicate that the northern and southern portions of the dunefield differ and that the inherent properties of the dune types should be taken into account in that the mobile transverse dune should be managed separately from the vegetated ridges and hummocks. The influence of the seasonal wind regime cannot be ignored either and that management efforts pertaining to the transverse dune in particular should be co-ordinated with the wind regime.

Vegetation succession is an important process in the development of vegetated ridges and hummock dunes. However, under existing environmental conditions, it is unlikely that the entire dunefield could be effectively managed through the eradication and manipulation of plant communities. Avis & Lubke (1996) found that low and erratic rainfall, coupled with strong winds were responsible for the paucity of vegetation and the maintenance of mobile, transgressive dunefields along the Eastern Cape coastline. Therefore, periods of higher rainfall or a change in the wind regime may allow the establishment of vegetation at sites otherwise unsuitable (Chapter 3.4). Destabilisation would be extremely costly and potentially unsustainable as conditions are conducive to vegetation establishment and colonisation of the accretions would probably recur systematically as seen at the Robberg Nature Reserve (Lubke 1990).

Options that are more feasible would be to remove the sand as it encroaches on the Westbourne Road Car Park and toilet block or relocate these facilities altogether. However, there is not a suitable site to relocate to within 200m of the existing facilities as per public survey results. Another potential management option involves tidal flooding. As discussed in Chapter 2 and earlier in this chapter, sediment accumulation in the river mouth is influenced by a short-term cycle of flooding. A major flood would scour the eastern channel and remove much of the WRSB and WRCP dunefield. Tidal flooding involving the utilisation of an inflatable dam wall upriver from the mouth and the periodic, artificial flooding of the river mouth could be an ecologically feasible option. The financial implications of such a venture would have to be investigated.

6.4. Future research

This thesis is by no means a definitive study into the ecology and dynamics of the dunefield at the Bushman's River Mouth. It does, however, allow for the recognition of additional avenues of research to further aid the formulation of a management programme. In light of the destabilisation proposal, a study of the local wind regime is necessary. An investigation of wind speed along the bank (north to south) and down Dry Bones Valley assess the viability of the re-activation of the headland bypass dune system. A study similar to one presented in this thesis would also be necessary to assess the impact of the re-activation of the bypass system on the ecology and sediment dynamics of Middle beach, Kenton-on-Sea. Continuous monitoring to assess the success and impact of any management strategy implemented at the site is always required.

6.5. Conclusions

The Bushman's River Mouth has undergone numerous changes over the last 50 years as a result of shifting environmental conditions exacerbated by human intervention. In an attempt to reach a new equilibrium, this ecosystem has altered from a transgressive, mobile dune system to a retentive, vegetated sediment sink. The successful management of this system is imperative considering the inherent ecological value and functions of the river mouth to Kenton-on-Sea. The effectiveness of a management strategy depends on the compilation and analysis of quantitative information regarding the ecological and social components specific to this ecosystem. Different management scenarios are possible but each must be evaluated and prioritised within the context of defined objectives that ultimately serve the best interests of ecosystem functioning and human utilisation.

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APPENDIX 1

Species list and abbreviations:

Species name	**Abbreviation**
Acacia cyclops	ACAC CYC
Acalypha species	ACAL SPP
Albuca species	ALBU SPP
Allophylus natalensis	ALLO NAT
Anthospermum species	ANTH SPP
Arctotheca populifolia	ARCT POP
Asclepias physocarpa	ASCL PHY
Asparagus densifloris	ASPA DEN
Asparagus racemosus	ASPA RAC
Asparagus species	ASPA SPP
Capparis sepiaria	CAPP SEP
Cariophilaceae	Cariophilaceae
Carpobrotus edulis	CARP EDU
Cassine aethiopica	CASS TET
Chasmathe aethiopica	CHAS AET
Chenolea diffusa	CHEN DIF
Chrysanthemoides monilifera	CHRY M0N
Cotyledon species	COTY SPP
Crassula nudicaulis	CRASS NUD
Cynanchum natalitium	CYNA NAT
Cynodon dactylon	CYNO DAC
Cyperus natalensis	CYPE NAT
Cyphostemma cirrhosum	CYPH CIR
Daispermum suffructicosum	DASI SUF
Ehrharta vilosa	EHRH VIL
Epilobium species	EPIL SPP
Euclea natalensis	EUCL NAT
Eugenia capensis	EUGE CAP
Fagara capensis	FAGA CAP
Felicia aethiopica	FELI AET
Felicia echinata	FELI ECH
Felicia ??	FELI FIL
Ficinia lateralis	FICI LAT
Gazania rigens	GAZA RIG
Gladiolus guenzii	GLAD GUE
Grewia occidentalis	GREW OCC
Habenaria arenaria	HABE ARE

Species name	**Abbreviation**
Harveya speciosa	HARV SPP
Helichrysum argenteum	HELI ARG
Helichrysum asperum	HELI ASP
Helichrysum cymosum	HELI CYM
Helichrysum praecinctum	HELI PRA
Helichrysum teretifolium	HELI TER
Heteroptilis suffruciticosum (Daispermum suffructicosum)	HETE SUF
Hypoestes aristata	HYPO ARI
Ipomea ficifolia	IPOM FIC
Ipomea pes-caprae	IPOM PES
Isolepis cernua	ISOL CER
Juncus kraussii	JUNC SPP
Leonotis lenora	LEON LEN
Limonium scabrum	LIMO SCA
Maytenus procambens	MAYT PRO
Metalasia muricata	META MUR
Myrisphyllum asparagoides	MYRS ASP
Osteospermum fructicosum	OSTE FRU
Oxalis species	OXAL SPP
Panicum deustrum	PANI DEU
Passerina rigida	PASS RIG
Pentaschistis heptamera	PENT HEP
Phylica litoralis	PHYL LIT
Pterocelastrus tricuspidatus	PTER TRI
Rhoicissus digitata	RHOI DIG
Rhus crenata	RHUS CRE
Rhus glauca	RHUS GLA
Salvia africana-lutea	SALV AFR
Sarcocornia species	SARC SPP
Satyrium species	SATY SPP
Scirpus nodusus	SCIR NOD
Senecio elegans	SENE ELE
Senecio litorosus	SENE LIT
Senecio species	SENE SPP
Sideoxylon inerme	SIDE INE
Silene primuliflora	SILE PRI
Solanum americanum	SOLA AME
Spartina maritima	SPAR MAR
Sporobolus virginicus	SPOR VIR
Stenotaphrum secundatum	STEN SEC

Stipagrostis zeyheri	STIP ZEY
Stoebe plumosa	STOE PLU
Tetragonia decumbens	TETR DEC
Triglochin bulbosa	TRIG BUL
Xathoxylum capensis	XANT CAP
Zalusianskya maritima	ZALU MAR
Zostera capensis	ZOST CAP

APPENDIX 2

BUSHMAN'S RIVER MOUTH

BACKGROUND REGARDING THE STUDY:

Funding from the Marine Living Resources Fund has made it possible to carry out a research programme on the management of the dune system at the mouth of the Bushman's river, Kenton-on-Sea.

The lower reaches and mouth of the Bushman's River between Kenton-On-Sea and Boesmansriviermond has had a history of poor management. Consequently sand has accumulated on the Kenton (east-bank) side of the river that has been stabilized by grasses, herbs and shrubs.

This has resulted in the loss of open water and boat channels on the east bank. A sound research programme on the mobility of the sand in this dune system is therefore to be undertaken in the next two years.

Address enquiries and returns to:
Professor R.A. Lubke/Miss Claire Fraser
Department of Botany
Rhodes University
GRAHAMSTOWN,6140
Phone (046) 603 8592 Fax (046) 622 5524 e-mail fraser@rhobot.ru.ac.za

QUESTIONNAIRE ON KENTON/BUSHMAN'S RIVER MOUTH BEACH AND ADJACENT MUIRHEAD NATURE RESERVE

A. <u>GENERAL QUESTIONS (Please tick the relevant box</u>)

1. Are you :
Full time resident ☐ Holiday-maker ☐ Holiday home owner ☐

2. If you are on holiday, where are you from?

E. Cape		Mpumalanga		Western Cape	
Kwazulu-Natal		Free State		Northern Cape	
Gauteng		Northern Province		North western Province	

3. How often do you visit Kenton-on-Sea?

Weekly		4 x per year	
Monthly		2 x per year	
6 x per year		1 x per year	
First visit			

4. How long are you staying for?

Day trip		2 weeks		Longer than one month	
Week		3 weeks			
10 days		month			

5. How many in your group are:

Younger than 15 yrs	
15-20 yrs	
20-35 yrs	
35-50 yrs	
Older than 50 yrs	

6. Will you visit Kenton again?

YES ☐ NO ☐

Why?____

____

B. UTILIZATION AND ACTIVITIES

7. Which of Kenton's beaches do you visit?

Kenton Main Beach (Kariega river)	
Kenton Middle Beach	
Bushman's river mouth	
Shelley Bay	
Boesmansriviermond	

8. Generally, do you think that the number of people on the beach is:

Far too many	
Too many	
About right	
Too few	
Far too few	

9. What do you usually do at the beach?

Sunbathe		Powerboat		Waterski		Walk	
Surf		Sail		Snorkeling		Paddleski	
Swim		Beach games		Windsurfing		Sandski	
Picnic/braai		Fish		Canoeing		Other(specify)	

10. Where do you usually have lunch?

On the beach	
In the dunes	
Restaurant / take away	
Home	

11. Do you walk or climb over the vegetated dunes?

YES ☐ NO ☐

Reason for your answer:

____

____

12. Do you enter the coastal thicket/forest in areas with no pathways?

YES ☐ NO ☐

Reason for your answer:

____

____

C. TRANSPORT AND FACILITIES

13. How did you travel to the beach?

Motor vehicle		Cycle	
Walk		Motor bike	

14. Do you think that the parking facilities at the Westbourne Road Car Park are adequate?

YES ☐ NO ☐

15. Would you be prepared to walk to the beach/river from a more distant parking lot, along an established pathway?

YES ☐ NO ☐

16. If yes, how far:

50m	
100m	
150m	
200m	
More than 200m	

If no, why not?

____

____

17. Do you think that the following should be provided:

Picnic spots		Boardwalk / gang plank (improved access)	
Restaurants		Other (specify)	
Beach café			

18. Would you like to see educational facilities such as these below added to the Joan Muirhead Nature Reserve?

Nature trails	
Information Boards	
Guided tours	
Educational centre	
Other (specify)	

D. PERCEPTION OF THE ENVIRONMENT

19. Do you consider the vegetated dunes along the riverfront beach:

Exceedingly attractive	
Attractive	
Not attractive	
An eyesore	

20. Do you find the new dunes an asset to the area?

YES ☐ NO ☐ INDIFFERENT ☐

Reason for your answer:

21. At the Bushman's river mouth, would you prefer more:

BEACH AREA ☐ WATER AREA ☐ NEITHER ☐

Reason for your answer:

____

____

E. PUBLIC AWARENESS AND MANAGEMENT – RATEPAYERS ONLY

22. Have you received any information on management programmes that have been implemented in this area?

YES ☐ NO ☐

If yes, details: ______________________________

23. Do you or your friends, family, etc have jetties into the river on the east bank affected by silting of this river?

YES ☐ NO ☐

24. Do you think the "council" should restore this river access to the jetties?

YES ☐ NO ☐

25. Are you familiar with the past dredging programme on the Bushman's River?

YES ☐ NO ☐

26. If yes, do you think it was worthwhile?

YES ☐ NO ☐

Reason for your answer:
____
____

27. A destabilization programme has been started on the dunes at the mouth and in Dry Bones Valley. Are you in favour of this programme?

YES ☐ NO ☐

28. Would the mobile sand affect you directly, for example, sand moving into your property, blocking path-ways, etc?

YES ☐ NO ☐

Explain:____
____

29. Are you happy with the removal of rooikrans (Acacia cyclops) and other alien plants in the Joan Muirhead Nature Reserve?

YES ☐ NO ☐

Reason for your answer: ____

THANK YOU FOR YOUR PARTICIPATION