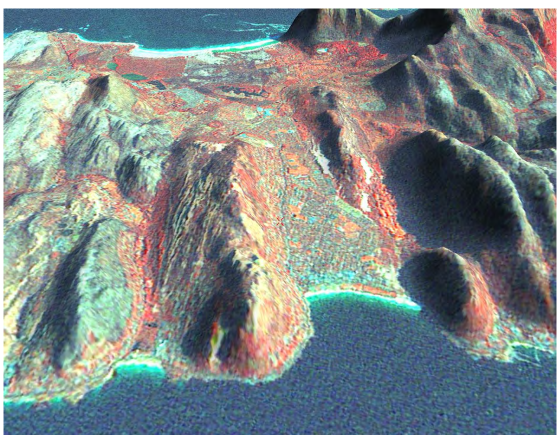
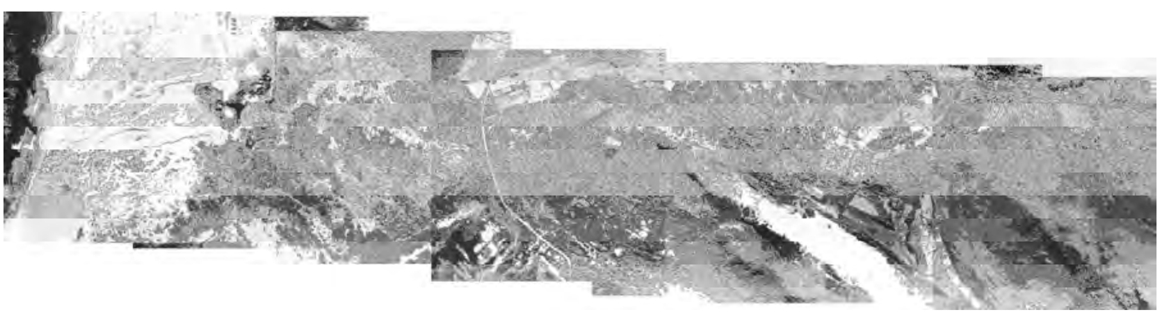
THE GEOMORPHIC CHANGES TO A DUNE SYSTEM IN THE CAPE PENINSULA: FISH HOEK – NOORDHOEK DUNE CORRIDOR





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THE GEOMORPHIC CHANGES TO A DUNE SYSTEM IN THE CAPE PENINSULA: FISH HOEK – NOORDHOEK DUNE CORRIDOR

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A thesis submitted in partial fulfillment of the requirements for a BSc Honours degree in the Department of Environmental and Geographical Science
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ABSTRACT

Sequential aerial photography was used to analyse the nature, extent and timing of the changes to the dune systems found within the Fish Hoek – Noordhoek Dune Corridor on the Cape Peninsula, Western Cape. The production of spatial overlays of the bare sand areas within the corridor representing the dune systems for the years 1945 to 2000 as well as the calculation of area estimates for the spatial extent of these systems, clearly identified the nature of the changes and quantified the rate of the spatial reduction of these systems over the time period of the study. The major factors that have led to these changes were identified. Alien vegetation encroachment coupled with urban growth has caused the increased stabilisation of the dune systems within the corridor. This combination has effectively changed the nature and functioning of these systems and the sediment dynamics of the entire corridor has been altered as a result of these changes.

ACKNOWLEDGEMENTS

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TABLE OF CONTENTS

CHAPTER 7: CONCLUSIONS

LIST OF APPENDICES

LIST OF FIGURES

LIST OF TABLES

LIST OF PLATES

CHAPTER 1: INTRODUCTION

1.1 BACKGROUND

"Coastal dune ecosystems of southern Africa are probably of greater importance and therefore of greater value per unit area, than any other biome or group of ecosystems in the region" (Tinley, 1985: iii).

The enormous value of coastal dune systems is not only as biodiversity assets but also due to their important role as dynamic buffer zones with the ability to absorb large amounts of energy and thus act as vital tools for the protection and stability of coastal areas (Tinley, 1985). Therefore coastal dune systems are intrinsically important on global, regional and local scales as unique, extremely valuable natural geomorphic systems.

However despite their great value, coastal dune areas are constantly and increasingly vulnerable to disturbance by humans. Disturbance by humans is considerable especially due to the fact that 60% of the world's population lives in coastal areas and therefore development occurs preferentially within these areas (Kurtiel, 2004). Coastal dune areas are impacted by development by humans primarily due to the nature of urban population expansion which predominantly manifests itself as chaotic and rapid growth of urban areas. This is then coupled with various other demands for coastal areas such as requirements for recreational and residential areas, access routes, informal settlements, development and industry.

Another process detrimental to coastal dune areas, indirectly initiated by human interference within these coastal areas, is the growth and principally invasive expansion of alien plant infestation. This heavily impacts on the nature of coastal dune areas, resulting in various changes to the biodiversity, ecology and geomorphology characteristics of these areas.

These types of pressures mean that coastal dune areas in southern Africa, and more specifically in the popular cosmopolitan region of the Cape Peninsula, are under threat. Studies such as the one carried out by Holmes and Luger (1994) of the coastal dune system found in Hout Bay, connecting Hout Bay harbour to Sand Bay via the Karbonkelberg dune corridor, is an example of the how coastal dune systems have been heavily impacted by human development initiatives and the combined spread of invasive alien plants within the dune area. Their study indicates how these processes have lead to the reduction of the spatial extent and mobility of the entire dune system. In addition their investigation also suggests that the change to this individual dune system could have far-reaching effects on the sediment budget further up the coast. Consequently their study alerts one to the fact that the remaining dune ecosystem pockets found within the Peninsula could possibly in the future be permanently and irreversibly consumed into the ever-expanding built environment without due attention being paid to the importance of their preservation and conservation.

Therefore comprehensive studies of these types of areas within the Peninsula need to be conducted from a geographical perspective, in order to evaluate and bring about further awareness to the nature of past changes that have occurred and the extent to which these natural geomorphic systems have already been impacted by humans.

The corridor of land connecting Fish Hoek on the False Bay (eastern) side to Noordhoek beach on the western side of the Cape Peninsula is such an area. This region consists of various developed areas ranging from well established residential towns and suburbs (including both Noordhoek and Fish Hoek) to recently developed housing developments through to more industrially-orientated areas. Therefore this corridor has been the focus of various different urban developments over an extended period of time. However insufficient attention has been paid to the environmental impacts of these developments in general, and more importantly the impacts to the coastal dune systems found within this corridor in particular. Therefore the exact nature and outcome of the interactions between the coastal dune systems and the expanding built environment is of particular concern and needs further investigation.

1.2 AIMS AND OBJECTIVES OF THE STUDY

The aim of this study is to establish the nature, extent and timing of changes to the dune systems within this Fish Hoek – Noordhoek corridor and to evaluate the impacts of these changes on the geomorphology of the area as a whole. By reviewing the study done by Holmes and Luger (1996) on the headland bypass dune system in Hout Bay, situated just to the north of Noordhoek, it was decided to use their work as a methodological framework for this project. Therefore, in accordance with their work, the aim of this study is achieved predominantly by analysis of sequential aerial photography of the study area over a time period of more than 50 years. This is done in order to trace the spatial change in the extent of the dune systems within the designated time frame. Special attention is not only given to identifying the growth of development in these coastal dune areas but also the encroachment of alien vegetation onto these dunes and the extent to which this has effected the degree of stabilization of these dune systems. Once the extent to which the dune areas within this dune corridor have been altered has been determined, this study then attempts to establish the reasons for the determined change and the environmental implications thereof. Finally by initially reviewing the effectiveness of various coastal dune management initiatives within South Africa and further a field, possible steps to restore to some degree the coastal dune areas within the study region to their natural state will be discussed.

The following objectives are identified in relation to the abovementioned aim:

- Review the literature on coastal dune systems found both within southern Africa as well as in other parts of the world.
- Obtain sequential aerial photographs of the study area for as long a time as possible from Department of Land Affairs Chief Directorate: Surveys and Mapping (CD:SM).
- Describe the environmental characteristics of the study area including geomorphology, climate and vegetation, in order to understand the context from which this study will be investigated and also to identify and describe the geomorphic systems encompassed within the study area.
- Input aerial photographs into a GIS programme, identify appropriate land uses and produce map overlays so that the land use changes can be clearly identified over the chosen time period.
- Derive quantitative information on the changes in spatial extent of the dune systems in the form of actual area estimates for each year under investigation.
- Describe the changes identified from the sequential aerial photographic analysis and explore possible reasons for the observed changes.

1.3 THESIS STRUCTURE

Chapter 2 provides an overview of the applicable literature pertaining to coastal dune systems and their morphodynamic characteristics. It elaborates on the sub-systems found within these dune systems and emphasizes the factors that produce, sustain and alter these types of systems. The importance and relevance of coastal dune systems in general will also be discussed.

Chapter 3 supplies the regional context of the study and provides an overview of the climate, geology and vegetation of the region and provides specific details of these factors that pertain to the coastal dune systems specifically. The latter part of the chapter will focus in detail on the individual dune systems and types found within the area

Chapter 4 outlines the methodological steps taken to achieve the targeted objectives mentioned above. Chapter 5 provides the results of the study in the form of images and tables with Chapter 6 providing an interpretation into what the results are illustrating and the possible reasons for the observed changes to the dune systems. Chapter 6 also discusses the results of the study in the context of the literature examined in Chapter 2.

Chapter 7 concludes the study by providing an overall summary of the work done and elaborates on to what extent the aims and objectives of the study were achieved.

CHAPTER 2: COASTAL DUNE SYSTEMS

2.1 THE IMPORTANCE OF COASTAL DUNE SYSTEMS

The fact that coastal dunes, on a global level, are scattered across a variety of regions ranging from polar to tropical latitudes, means that their great value is intrinsically tied to their broad distribution and ecological diversity – "in terms of their geomorphological dimensions, environmental heterogeneity and species variability" (Martinez *et al*., 2004: 5).

In addition, as briefly mentioned in chapter 1, coastal dunes are "extremely important coastal landforms as they often act as a coastal defence, protecting coastal lowlands from marine inundation" (Haslett, 2003: 64). As part of the broader coastal environment, they also serve as locations for groundwater recharge and assist in the retention of freshwater as a buffer against saltwater intrusions (Martinez *et al*., 2004). Therefore their presence as both physical buffer zones protecting coastlines and interiors and as important ecological assets, attests to the fact that these areas should never be overlooked as just tracts of inconsequential sand but rather regions of inherently high environmental importance (Psuty, 1992).

Apart from their environmental importance, coastal dunes are also highly valued by humans as an economic asset in terms of being of significance to sectors such as agriculture, mining, housing and tourism (Carter, 1992). Therefore in summary, coastal dunes are important in terms of their geomorphological (Psuty, 1992), biological and ecological (McLachlan, 1990) and resource values (Nordstrom, 1992).

According to Tinley (1985) the conflicts between the high ecological and economic importance of coastal dune areas have led to the declining conservation status of these parts of the coastline. The evidence of this is that many coastal dune systems have become severely degraded as a result of many factors, as mentioned in Chapter 1. Therefore these areas are under threat and consequently there needs to be assessments of individual dune systems in order to establish their current state and where at all possible provide a means for their rehabilitation to ensure their continued existence into the future.

To assess the state of the dune systems found within the study area as well as identify the components of these systems, an extensive review of previous work done on coastal dune systems in general as well as specifically in terms of southern African examples, is needed to achieve the objectives outlined in chapter 1.

2.2 GLOBAL DISTRIBUTION OF COASTAL DUNES

Coastal dunes are widely distributed across the globe and are coincident with the widespread occurrence of wave-dominated sandy beaches and with coastal barrier systems (Martinez *et al*., 2004).

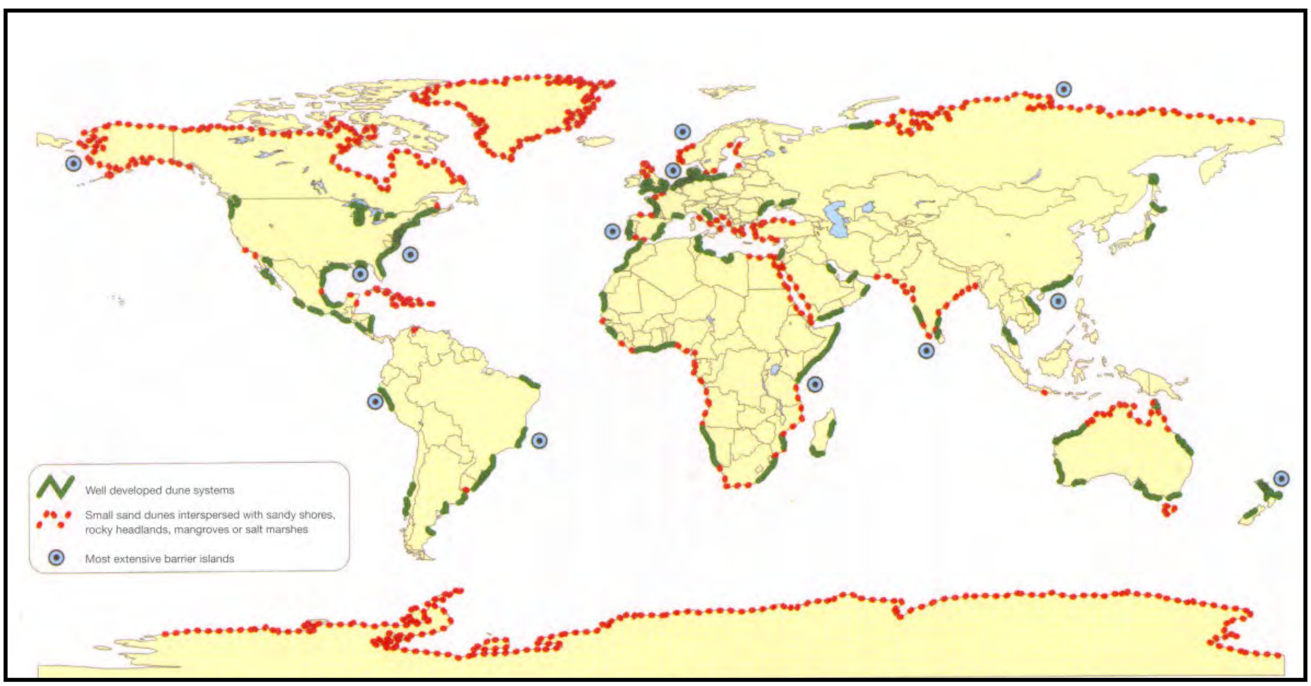


Figure 2.1: Global Distribution of Coastal Dunes (Martinez *et al*., 2004: 4)

2.3 BROAD CONDITIONS REQUIRED FOR THE FORMATION OF COASTAL DUNES

The following, after Haslett (2003), are the requirements for the formation of coastal dunes in general:

- An area landward of the beach that is suitable to accommodate blown sand.
- A strong on-shore wind for transporting sand from its source on the beach to the dune area.
- Suitably sized sand and an abundant supply of it. Sand supplied either by longshore drift from eroding headlands, cliffs and other dune systems, or by rivers or by the sea bottom (van Meurlen, 1996).
- Some degree of vegetation to stabilize blown sand (otherwise unvegetated dunes occur and are known as bare or free dunes).
- Low gradient of the source beach and a large tidal range. This means that large expanses of beach sand are exposed at low tide. Thus drying can occur and then transport to the dune area.

Thus coastal dunes form where sand deposited by the sea (or accumulated at rivers or exposed by lower sea levels) is able to dry out and is then blown landward by the wind (Tinley, 1985).

2.4 GENERAL MORPHOLOGICAL APPROACH

Coastal dunes have a variety of different spatial dimensions from small hummocks (less than a metre in length) to extensive ridges (more than a 100 m in elevation), from individual ridges to large fields of parabolic or linear dunes stretching many kilometres inland (Sherman, 1995 and Psuty, 2004). Despite the myriad of possible formations of coastal dunes, from a geomorphological perspective, coastal dune systems are distinct and unique geomorphic features that develop in coastal regions where an abundant supply of loose sand is available to be transported inland by the prevailing winds. They are perceived to mark the landward limit of marine influence on the coast (Haslett, 2003). They consist of different components which interact in response to variations in energy levels and to mobilization of sand from one component to another across the whole system (Psuty, 2004). According to Tinley (1985) in general the major components of a typical individual coastal dune system include the following:

- Dune: A hill, mound or ridge of sand which is composed of particles transported and heaped up into accumulations by the wind (from Moore, 1959 in Tinley, 1985)
- Dune trough: a linear depression between dunes
- Slack: a seasonally or perennially wet depression between dunes, oval, irregular or linear in shape
- Hollow: a dry depression between successive dunes

The fact that coastal dunes are diverse dynamic (i.e. they are constantly changing) systems that occur over such differing spatial scales means that there exists a wide range of classifications of the formational processes and configuration of coastal dune systems (Mabbutt, 1977; McKee, 1979; Tinley, 1985; Pye, 1990; Hesp, 2002 and Psuty, 2004). One approach that can be taken and which is the logical evolution of the methodology originally taken by Bagnold (1936 and 1940) is an evolutionary type of approach. This requires one to look at coastal foredunes as the initial geomorphological requirement for the establishment of coastal dune systems. There then exists a complex foredune development sequence related to changing sediment variability that ultimately shapes the specific type of dune systems that form. The primary phase of development is the establishment of the foredune (also known as the primary dune in Psuty, 2004).

Coastal foredunes have been called a variety of other names including 'embryo dunes', 'frontal dunes', 'retention ridges', 'beach ridges', 'parallel dune ridges', and 'transverse' dunes (Hesp, 2002). The foredune can be transgressing inland as the whole system moves inland or it can be stable and fixed in its geographical position or shift towards the sea. The foredune represents the most dynamic element of the system and is the only dune form that is completely dependent on a coastal location (Psuty, 2004). There exists an active exchange of sediment between the beach and the foredune and therefore foredune characteristics are intricately related to coastal morphodynamics such as the type of coastline, wave energy and type and inclination of the beach (Hellemaa, 2000). These processes not only shape the beach but add or remove sand from the foredune. From this point sand is transferred from the foredune inland to feed secondary dunes and therefore is lost to the beach-foredune sand sharing system. Secondary dunes can be active (active migration of dunes represented by deflation hollows and parabolic or crescentric morphologies) or stable (no longer in the active beach-foredune system but not migrating further inland) (Psuty, 2004: Table 2.1).

Psuty (2004) identifies the fact that the dynamics of this foredune development sequence related to "a continuum of morphological responses to ambient conditions" (Psuty 2004: 17). He indicates that the dominant variable that drives the development of this sequence both in terms of spatial and temporal variability is sediment availability (Figure 2.2). "The foredune stores and releases sediment as it waxes and wanes in concert with the erosional or accretional trends of the adjacent beach" (Psuty, 2004: 24). The variation in the sediment availability can create substantial complexity in coastal foredune development as well as in subsequent dune morphologies formed further inland (Psuty, 2004).

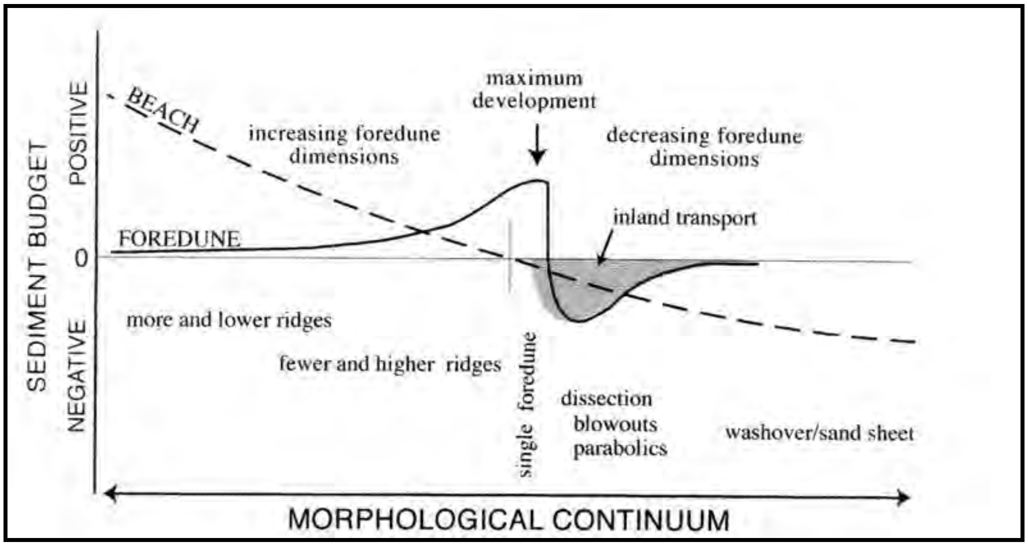
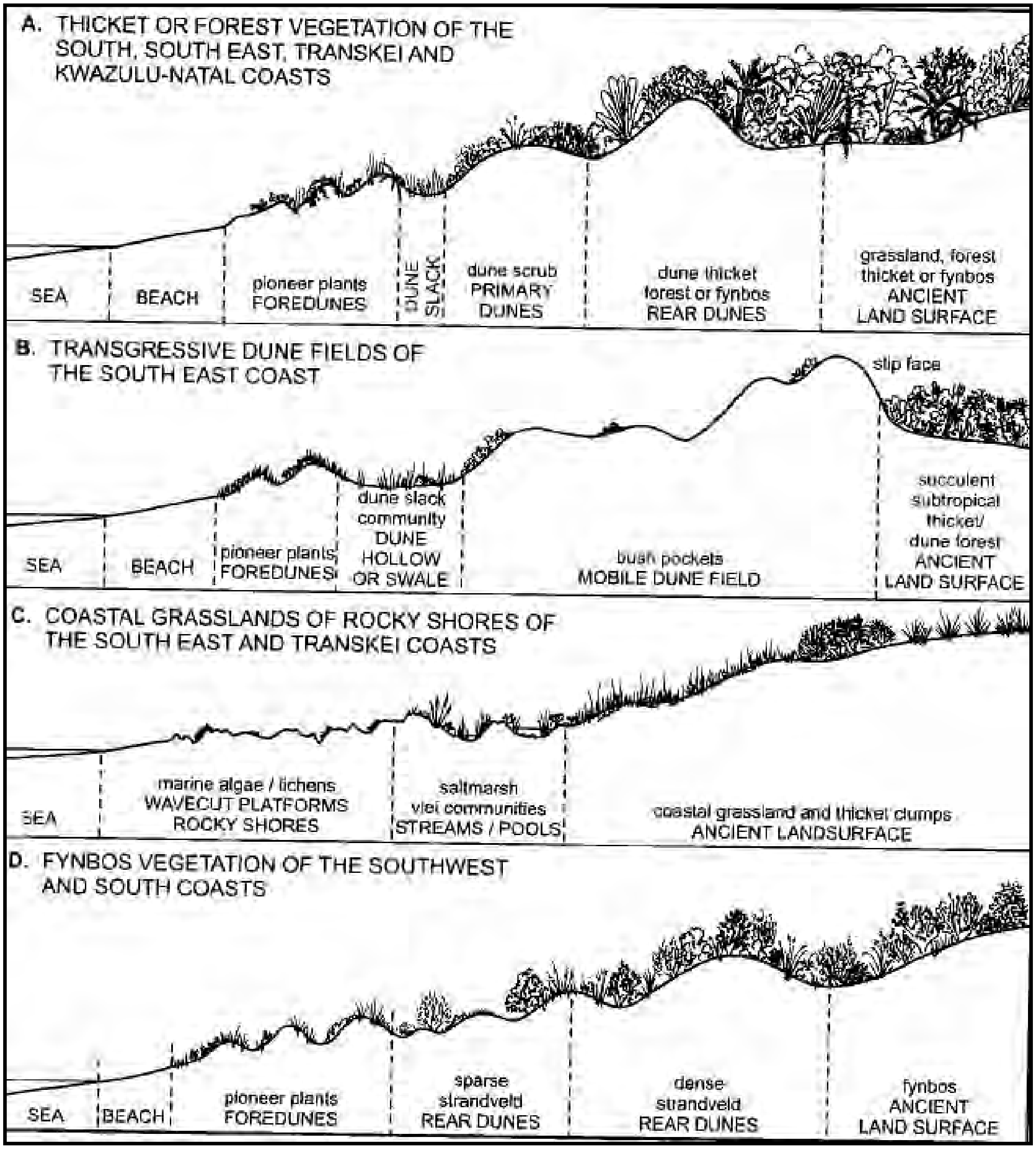


Figure 2.2: Morphological Continuum Model showing the morphological outcomes of foredune forms which is the result of the relationship between the sediment budget of the beach and the sediment budget of the foredune (Psuty, 2004: 69).

2.5 VEGETATION AS A VARIABLE

Hesp (1999) incorporates further complexity to the aforementioned foredune developmental approach with the addition of vegetation as a major factor that affects stability and mobility relative to foredune dynamics and sediment supply. An example of a thorough study on the ecological succession relating to vegetation community changes within a coastal dune system in the Eastern Cape, South Africa was conducted by Avis and Lubke (1996). Further evidence of the fact that vegetation community changes can have a dramatic effect on the state of coastal dunes is made apparent in the further South African case studies mentioned in the next section.



<u>Figure 2.3</u>: Vegetation dynamics and succession for different coastal regions of South Africa (Lubke, 2004: 69)

2.6 THE EFFECTS OF HUMANS ON COASTAL DUNE SYSTEMS

Apart from the natural variation in sediment variability that leads to a complex sequence of primary and secondary dune morphologies outlined above, there can be substantial manipulation of this sequence by humans (Psuty, 2004). Coastal dune systems can be affected by humans through both direct and indirect influences on processes and responses – both in terms of morphological and ecological alterations. Humans can impart a further variable in the foredune developmental model mentioned above (Figure 2.2) because humans can alter the sediment budget, mould or destroy dune morphologies and displace shorelines. These are all factors that have a considerable influence on the morphodynamics as well as the ecological value of the system. The influence of humans can accelerate the processes found within the model by causing jumps or steps in the model thus increasing the rates of transition between the processes. Or in contrast, humans can force the opposite reaction that is to create an artificial steady-state to allow a desired mode (e.g. stabilized dune systems) to be maintained.

A. Mobilization

Although the process of increased mobilization of stable vegetated dunes can result from climate change alone (Thomas *et al*., 2005), human activities can rapidly artificially reduce the sediment content maintained by dune systems thereby altering the natural vegetation and dynamics of the system and making the dunes favourable to intrusion from invasive and exotic species (Kim, 2004). The removal of the natural vegetation found on dunes as a result of over-grazing and cutting causes an increase in sediment movement rates in the system. Some researchers relate this process to the process of desertification (Kumar and Bhandary, 1993 and Barth, 1999 in Kutiel *et al*., 2004).

The reduction in vegetation on coastal dunes also increases erosional processes, promotes dune stabilization and effects groundwater supplies (Kim, 2004).

B. Stabilization

The opposite of the process of mobilization is that of stabilization. This is one of the most important phenomena in coastal dune systems and is controlled and governed by diverse factors such as climate change (e.g. Lancaster, 1997; Hugenholtz & Wolfe, 2005 and Arbogast *et al*., 2002) and over a shorter time span, human activities (Holmes and Luger, 1996; Kutiel *et al*., 1999 and 2004 and Levin and Ben-Dor, 2004).

The general coastal dune stabilization process takes the form of the following sequence: there is an increase in soil moisture content where the accumulation of sand is low (as in dune crests) which allows an increase in vegetation density. This results in a decrease in the area of bare sand which in turn leads to an increase in accumulation of fine particles which allows for the formation of a biogenic crust and a decrease in the sand saltation (movement) (Kutiel *et al*., 2004). This process threatens the endemic flora and fauna species that is specifically adapted to the habitat of exposed, moving sands.

The process of dune stabilization can be indirectly or inadvertently initiated by humans as a consequence of land use changes, or more likely the desired outcome of efforts to stabilize the shifting dunes (particularly foredunes) or expand the beach for recreational needs (Nordstrom and Lotstein, 1989). This has been done in various parts of the world predominantly through the introduction of alien plant species such as the Australian acacia (*Acacia saligna* and *A. cyclop*) and various species of perennial grasses, such as maritime grass (*Ammophilla arenaria*). These plants grow rapidly, have low demands on their habitats and are able to cope with strong winds and seawater spray close to the coast. Over certain periods of time, these plants expand their range and cover broad areas, thereby stabilizing bare sand dune systems and modifying the landscape by altering both the geomorphic and biological functions of the system (Kutiel et al., 2004).

2.7 IMPORTANCE OF BARE SAND AREAS

Sand movement is one of the most important factors in the distribution and functioning of natural communities in dunes. It buries and erodes the leaves of plants, alters the amount of nutrients and available moisture, modifies soil aeration in surface layers, changes competition among plant species (Nordstrom, 1989: 6-7).

When stabilisation occurs (either naturally or due to human influence) the quantity and variety of vegetation initially increases in the areas that are stabilised, but it does not necessarily mean that the character of the vegetation will be maintained if further sediment transfer is prevented (Nordstrom, 1989). The characteristics of the dune environment may change dramatically as a result of vegetation succession. Therefore important vegetation species can be eliminated with the establishment of a stable system (Nordstrom, 1989).

Sand movement to some degree is also necessary to create or maintain valuable habitats for dune fauna. Invertebrates use bare sand areas extensively and ‘snags’ (which form as a result of sand inundation of stands of trees) are important habitats (Nordstrom, 1989).

Many bare sand areas are stabilised to specifically protect valuable species from sand inundation, but inspection of the significance of the dune habitat to those species does not always justify stabilization, as was the case for the Pacific Northwest dunes near Oregon (USA) (Nordstrom, 1989). People’s misconceptions of what the ‘natural’ indigenous composition of the fauna and flora of the dune systems near Oregon added to the fact that these dunes were stabilised as managers of the region thought that species were indigenous and unique to the dune areas and therefore wanted to preserve them but they were actually not historically endemic to the region.

The factors mentioned above are often overlooked or not known and therefore the importance of bare sand areas is not made apparent leading to their artificial stabilization.

2.8 COASTAL DUNES OF SOUTHERN AFRICA

The fact that more than 80% of the southern African coastline comprises of sandy beaches and associated coastal dune systems indicates that these coastal dune areas should be considered extremely important geomorphological and ecological systems (Tinley, 1985). A fundamental study was carried out by Tinley in 1985 which comprehensively assessed the coastal dune systems along the entire southern African coastline. This descriptive overview despite being somewhat dated provides an excellent background into the distribution and specific type of coastal dunes found along the coast as well as the geomorphological and ecological characteristics of these dunes.

“Sand supply, wind strength and the density of the vegetation cover are usually the primary factors affecting dune topography, these factors are said to together determine the type of dunes (Hack 1941 in Hellemaa, 2000: 13). The great variety of the possible combinations of the nature of the factors mentioned in the above quote stand testament to the existence of many different types of dunes and different classifications of them. The following table provides a summary of Tinley (1985)’s classification of southern African dunes (also refer to Figures 2.3 2.4 and 2.5 for the geographical location and general characteristics of these types of dunes).

	Bare or Free Dunes (wind formed)
A. B. C. D.	Mobile sand sheets and mounds Cresentric or Transverse dune types: 1. Barchan 2. Barchanoid 3. Transverse 4. Reversing 5. Butress barchanoid Linear Star
	Vegetated Dunes (wind and plant formed)
A. B. C.	Strand plant hummock dunes 1. Driftline embryo dune 2. Hummock or hillock dunes 3. Parallel beach ridge hummocks Precipitation dune or retention ridge Parabolic Dune Types 1. Blowout 2. Accretion ascending parabolic 3. Deflation hairpin parabolic 4. Parallel wind-rift ridges
	Dunes related to topographic barriers
A. B. C.	Climbing-falling dune Headland bypass dune Windward diverging dunes
	Dunes related to wetlands
A. B. C.	Hummock dunes of slacks, washes or river flats Playa lunette dunes Lagoon-shore dunes

Table 2.1 Classification of dune types according to Tinley (1985)

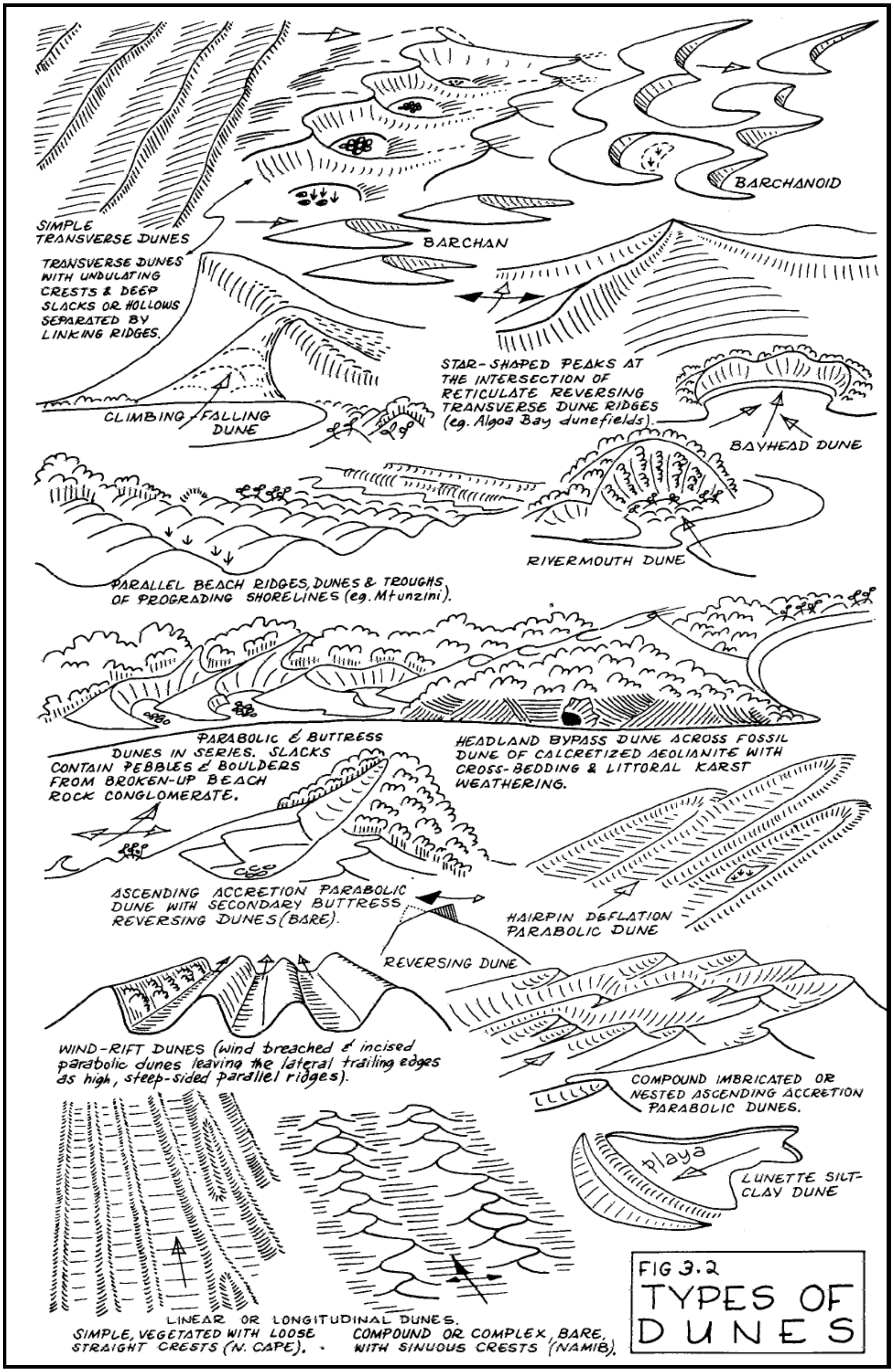


Figure 2.4: A graphic representation of the various different types of dunes identified and classified by Tinley (1985: 14)

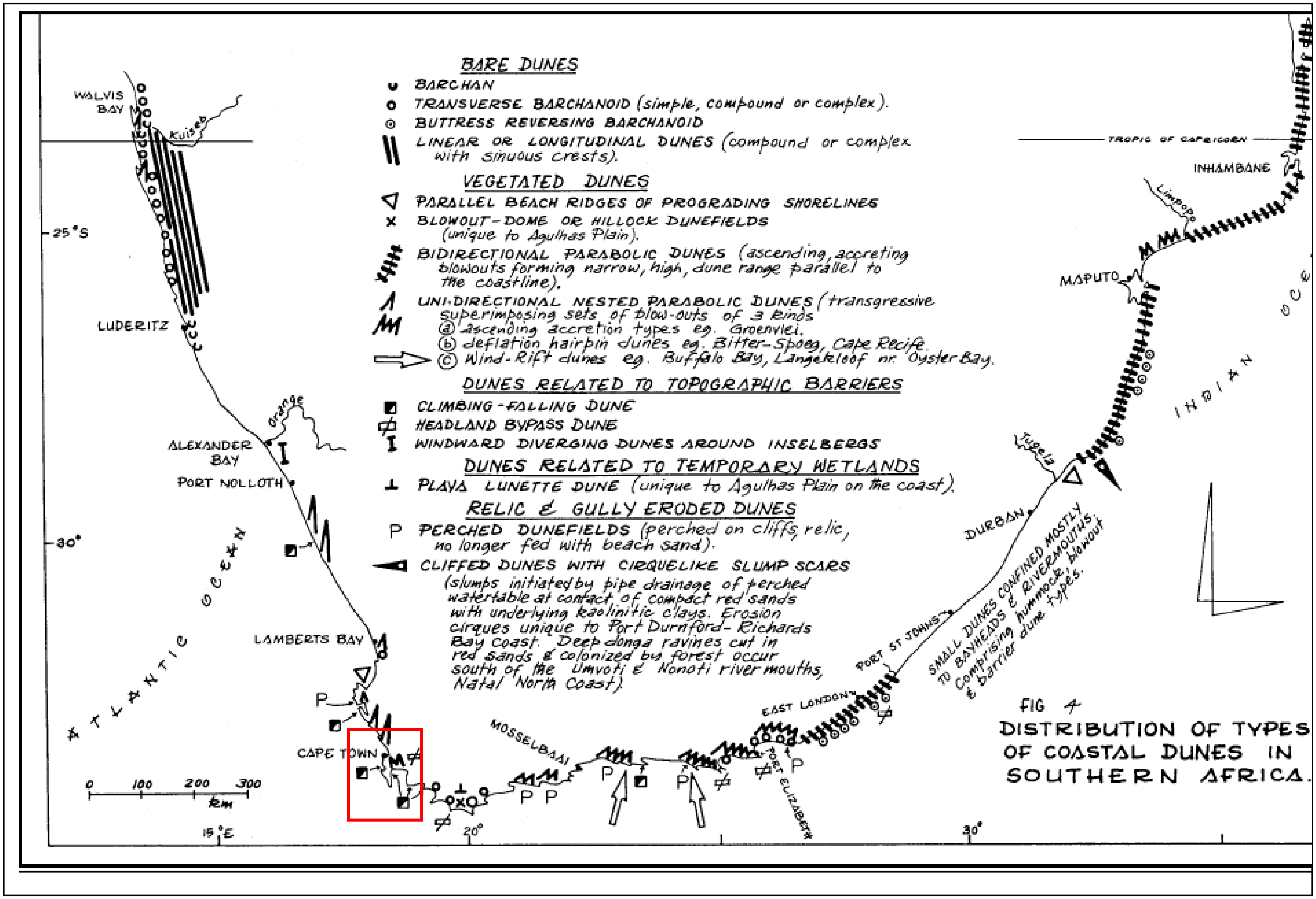


Figure 2.5: Tinley (1985: 33)'s map of the southern Africa coastline identifying the locations of the different types of coastal dune systems found within his classification (red box identifies the location of the study area)

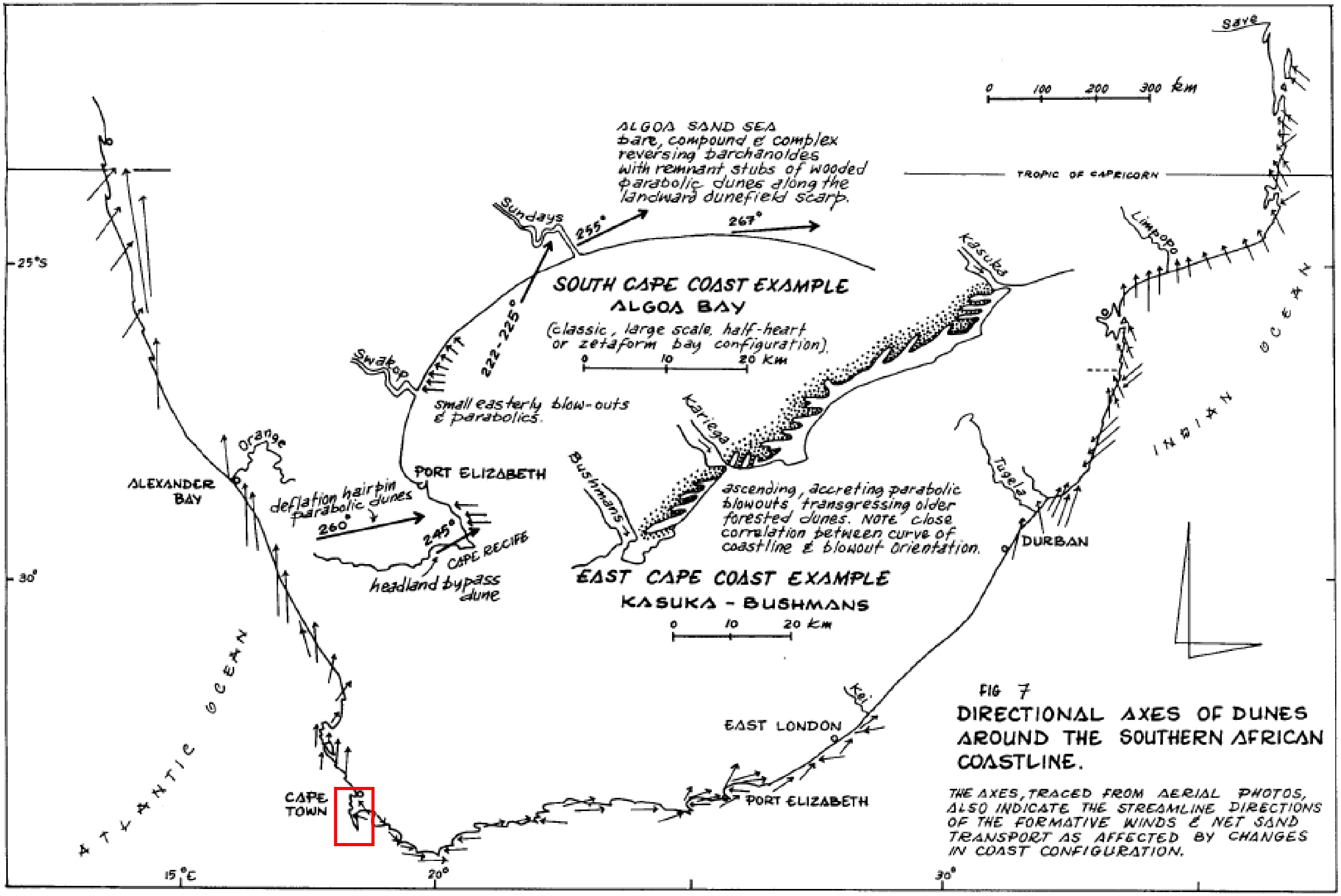


Figure 2.6: Tinley (1985: 35)'s map of the directional axis of dunes situated along the southern African coastline (red box identifies the location of the study area)

Tinley (1985)'s extensive study on the dune systems situated along the coast of southern Africa is complimented by more recent research into individual dune systems, their ecology, geomorphology and particularly their stabilization (Avis and Lubke, 1996; Hellstrom, 1996; Holmes and Luger, 1996; La Cock and Burkinshaw, 1996; Kerley *et al*, 1996 McLachlan *et al*.,1996; van Aarde *et al*, 1996 and Lubke, 2004) . These various studies build on the understanding of the processes which govern these systems and focuses on the dynamic nature of these systems and provided valuable background information to this study on the dunes in the Fish Hoek – Noordhoek corridor. They also focussed on the need for conservation/management initiatives that specifically take into account the importance of retaining the natural states of these systems.

The study that most closely relates to the Fish Hoek – Noordhoek dune corridor is that of the Holmes and Luger (1996), who examined the recent development of the Hout Bay – Sandy bay headland bypass dune system. Where sandy beaches occur upwind of headlands, onshore winds can transport sand overland to the downwind bay in strips of migrating dunes known as a headland bypass dune system (Tinley, 1985). These systems are important to the overall sediment budget of the coastline as they maintain sand supply to beaches cut off by the headlands that precede them (La Cock and Burkinshaw, 1996). The Holmes and Luger (1996) study indicated how the Hout Bay – Sandy Bay headland bypass system had been severely impacted by human activities involving the stabilization of the system: the foredunes on the Hout Bay side were degraded and sediment input to the Sandy Bay side had become impaired. These alterations in the dynamics of this system could potentially, as indicated above, have far-reaching effects on the sediment budget and nature of the entire coastline to the north of the system.

La Cock and Burkinshaw (1996) studied one of the largest remaining, still active headland bypass dune systems in South Africa that crosses the Cape St Francis headland, on the southern Cape coast. Their study showed that poorly planned development disrupted the natural functioning of the dune system as well as the associated river. Construction of a road across the dune system and river restricted the natural water and sediment flow. They urge that coastal sediment transport systems such as dune systems need to be managed as a whole and their dynamic nature needs to be taken into account where further development is concerned (La Cock and Burkinshaw, 1996).

More recently Lubke (2004) investigated the effect of *Ammophila arenaria* as a dune pioneer on the dunes at the mouth of the Heuningnes River at De Mond Nature Reserve on the southern Cape Coast. *Ammophila arenaria* or 'Marram grass' became well established as a pioneer grass on foredunes along the coast, such as the southern Cape Coast, where rainfall is high and where there are few extended periods of droughts. However, Lubke (2004) found that, unlike other invasive species, marram did not show traits of an outwardly aggressive behaviour in the dune ecosystems. Stands stabilized by *Ammophila arenaria* in the 1980s now have dense shrub vegetation. The study showed how the grass provides temporary stability of the dune sands until indigenous dune plants takes over (Lubke, 2004).

Lubke (2004) contrasts the above behaviour of Marram grass as a less aggressive invader to that of the Australian acacias such as *Acacia cyclops* and *A. saligna*. Originally *Acacia cyclops* and *A. saligna* were introduced to stabilize the Cape Flats of the Western Cape. These species have however, invaded regions far beyond this. These species have a high invasive potential (Lubke, 2004) and are very successful in stabilizing mobile dune fields causing a lack of supply of sand to the beaches in the bays upwind from the dune systems (Lubke 1985 and Holmes and Luger 1996). They are not foredune pioneers (like Marram grass) but are nodule-forming legumes that are very successful in low-nutrient sands and may fill a niche that is vacant on open dunes.

2.9 SUMMARY AND CONCLUSIONS

The literature outlined above on coastal dunes both within South Africa and around the world describes the processes behind their formation and their present conditions. From this review it is evident that the three most important controlling factors of coastal dune systems are the sediment budget and the type, amount of vegetation and the strength and direction of prevailing winds. The dynamics of the first two factors are of particular significance due to the fact that they can be substantially influenced by human activities. The case studies outlined within this chapter indicate how the changes to the nature of these two factors as a result of human activities can have critical consequences to both the morphological and ecological functioning of coastal dunes.

Reviewing the research done on individual dune systems enriches the overall understanding of the dynamic interactions inherent within these systems and the specific responses these systems have to certain perturbations. The literature provides both a broad contextual background to the study in terms of the functioning of dune systems from around the world as well as specific details on the behaviour of coastal dunes found within South Africa and even adjacent to the study area (Hout Bay – Sandy Bay dune system, Holmes and Luger, 1996).

The next chapter makes use of this rich contextual base to elaborate on how the specific characteristics of the regional setting of the study area relates to the formation, distribution and type of coastal dunes found within this region.

CHAPTER 3: FISH HOEK – NOORDHOEK DUNE CORRIDOR

3.1 GEOGRAPHICAL LOCATION

The southern Cape Peninsula is located at the south-western tip of Africa. The Fish Hoek – Noordhoek Corridor is situated on the Cape Peninsula within the greater Cape Metropolitan Area, 35 km south of Cape Town. It encompasses approximately a 22 km^2 area of land stretching across the Peninsula, with Noordhoek (34^0 07′ S; 18^0 21′ E) on the Table Bay side and Fish Hoek (34^0 08′ S; 18^0 26′) on the False Bay side. Fish Hoek is bounded on either side by steep headlands (Trappieskop to the north and Elsepiek to the south). Noordhoek beach's northern end is bordering on Chapman's Peak, 550 m above sea level, and its southern region ends at Klein Slangkop (see Figure 3.1 and Map 3.1).

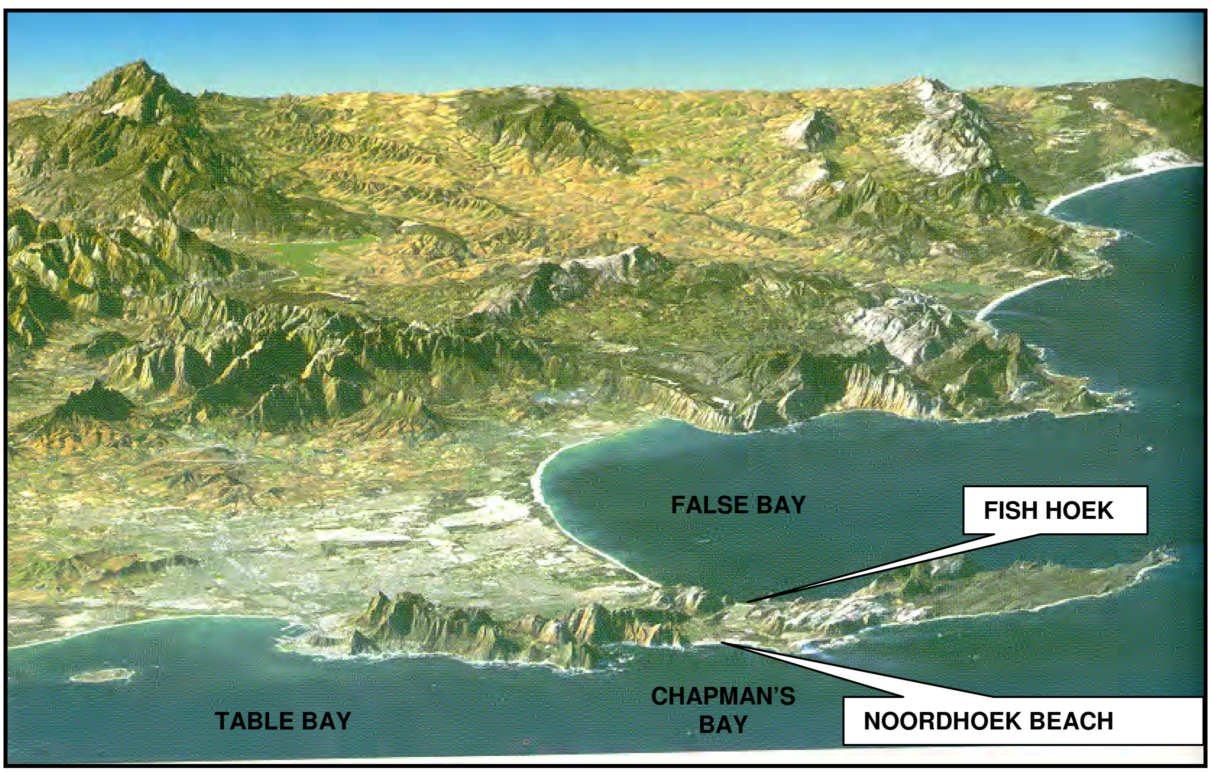


Figure 3.2: Landsat Satellite Image overlaid on the SRTM elevation model of the Cape Peninsula (USGS, 2004)

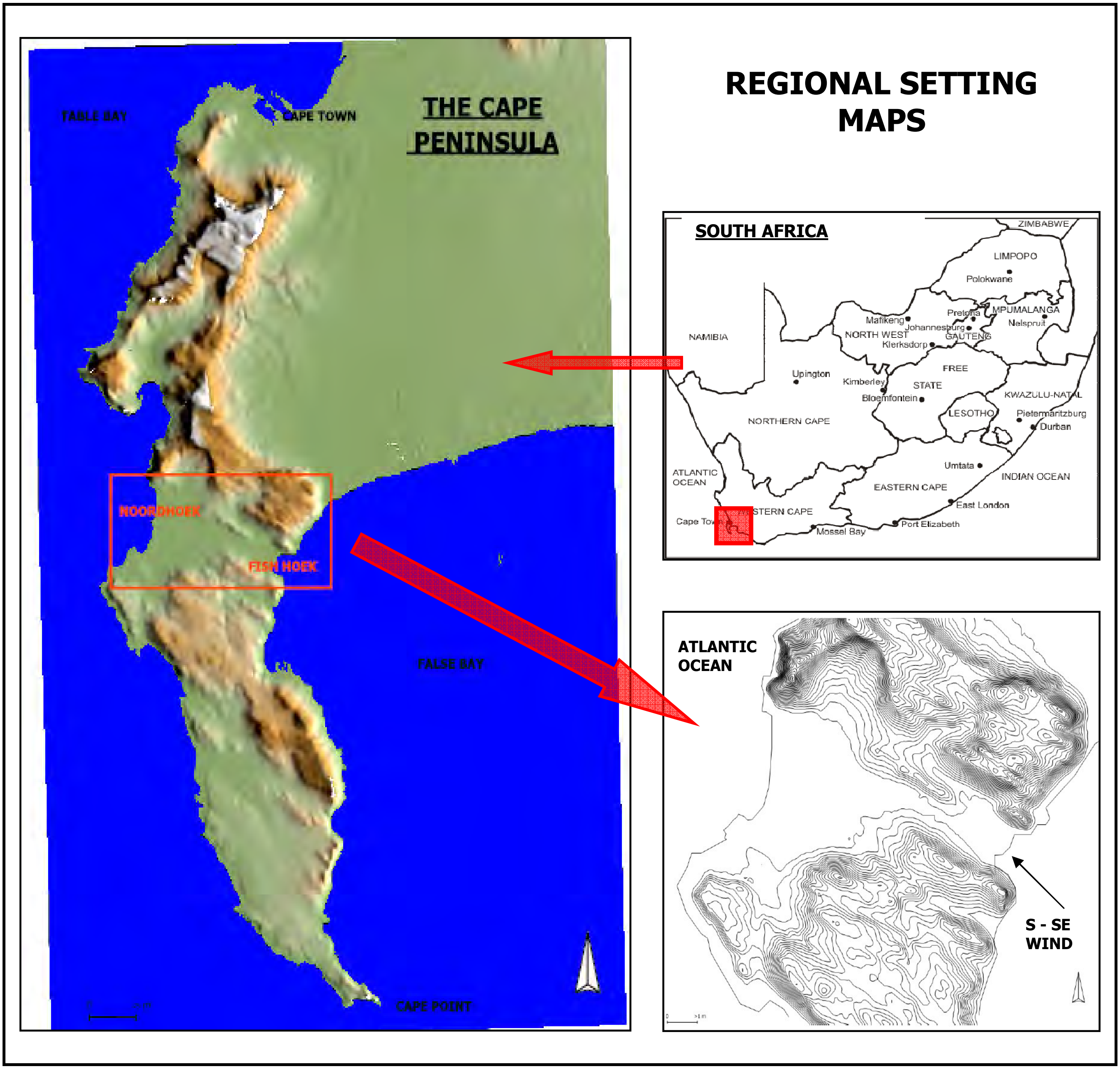


Figure 3.2: Location of the Fish Hoek – Noordhoek Dune Corridor within South Africa, the Western Cape and the Cape Peninsula

3.2 GEOLOGY OF THE FISH HOEK – NOORDHOEK DUNE CORRIDOR

The geology of the study area is an important preliminary aspect to be considered as it describes the way in which the present landscape has evolved over time and thus the nature of the underlying structure of the area and the source of the sand that constitutes the dunes themselves.

The mountains surrounding and bordering on the Fish Hoek – Noordhoek Corridor comprises Table Mountain Group sandstone from the Lower Palaeozoic overlying the bedrock of the corridor which consists of Cape Granite of Late Precambrian formation (Compton, 2004).

During past eras, at times of high and low sea level, the Cape Peninsula took on very different forms. At times of high sea level, such as 60 and 2 million years ago, the peninsula was submerged and became a group of islands separated by a narrow channel which is now the Fish Hoek – Noordhoek Corridor (Macphee and de Wit, 2003). This channel separated the peninsula into northern and southern islands. During these times layers of marine sand were deposited. Thus the dunes found within this valley are remnants of this marine sand, when the valley was a sea passage, as well as comprising of loose littoral sands which were formed as result of the weathering of the rocks that constitute the base of the corridor and the adjacent mountainous sides. These sands have been mapped as belonging to the Holocene or Witsand Formation (Compton, 2004) (see below map).

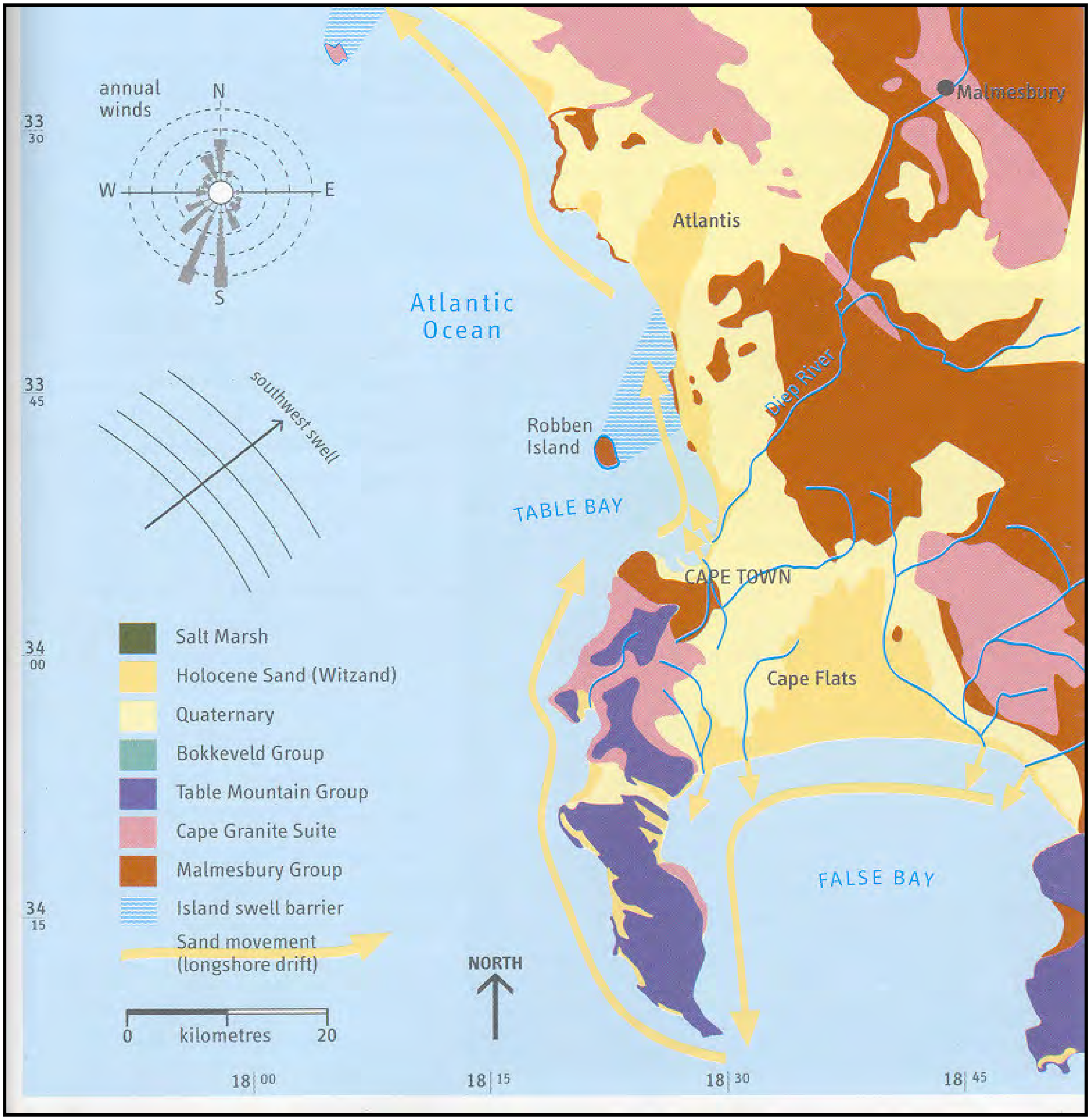


Figure 3.3: Geological Map of the Cape Peninsula (Compton, 2004)

3.3 CLIMATE

The corridor experiences a warm temperate Mediterranean climate with wet winters and warm, dry summers. Strong winds occur along the coast throughout both seasons, with the dominant wind directions being north-westerly or north-north-westerly (in winter) and southerly or southerly (in summer). During the summer months, the potential for aeolian sediment transportation is greatest due to the presence of the prevailing wind, the strong South Easter, associated with anticyclonic high pressure systems that ridge in over the land during this time of year (Holmes and Luger, 1984) (refer to Map 3.3 and Figures 3.3 - 3.6). On the False Bay, Fish Hoek side of the corridor, sea breezes strengthen the already strong South Easters, increasing the sediment transportation potential substantially for the formation and sustained presence of the dunes originating from Fish Hoek beach. North-westerly winds associated with prefrontal depressions dominate during the winter months and have a lower sediment transport potential because the beach and dune sand is predominantly too moist and therefore more cohesive and less able to be transported by wind (Holmes and Luger, 1984).

Greatly increased wind strength is required to initiate movement of damp sand hence the coincidence of strong winds with arid periods or dry seasons becomes crucial in identifying the periods of sand transport.

Consequently, in summary, the unique climatic feature that is of significance to dune formation in this area is that there is a coincidence of the windiest season of the year (Figures 3.2 – 3.6) with the driest time of the year: “strong dune-forming winds occur in the summer dry season as evinced by the series of climbing dunes along the east-facing False Bay coast of the Peninsula” (Tinley, 1985: 89).

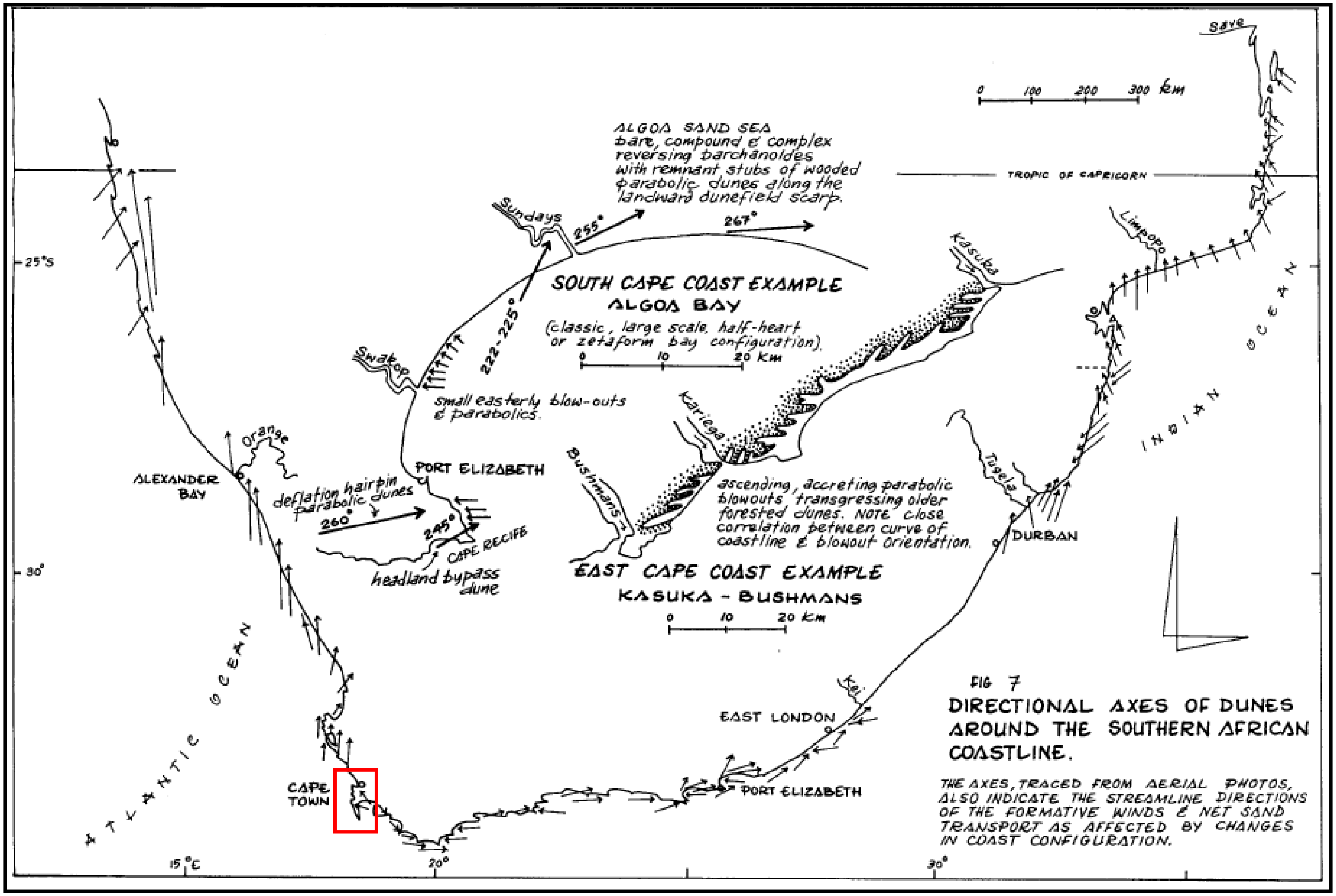


Figure 3.4: Tinley (1985: 35)'s map of the directional axis of dunes situated along the southern African coastline also indicates the direction of the prevailing winds and sand movement direction (red box identifies the location of the study area)

WIND SPEED AND DIRECTION:

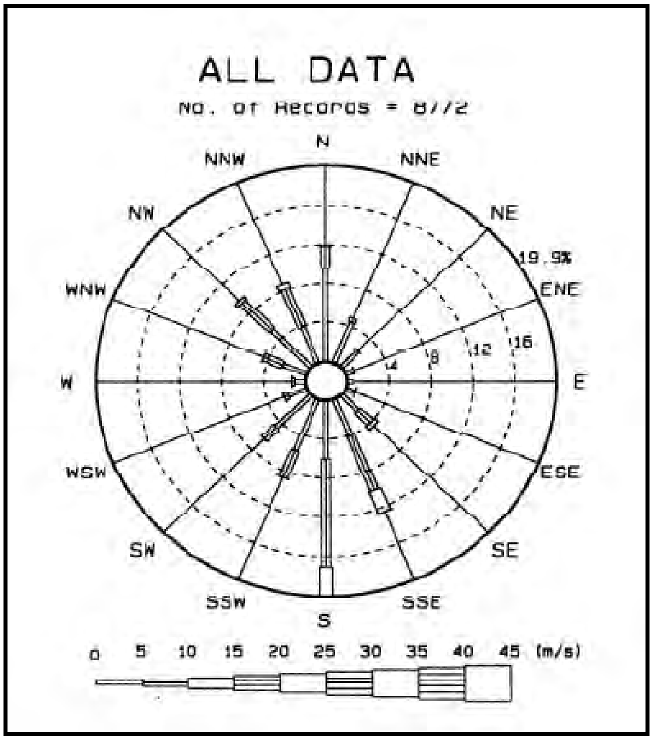


Figure 3.4: Wind Rose for Cape Town, 2005 (SADCO, 2006).

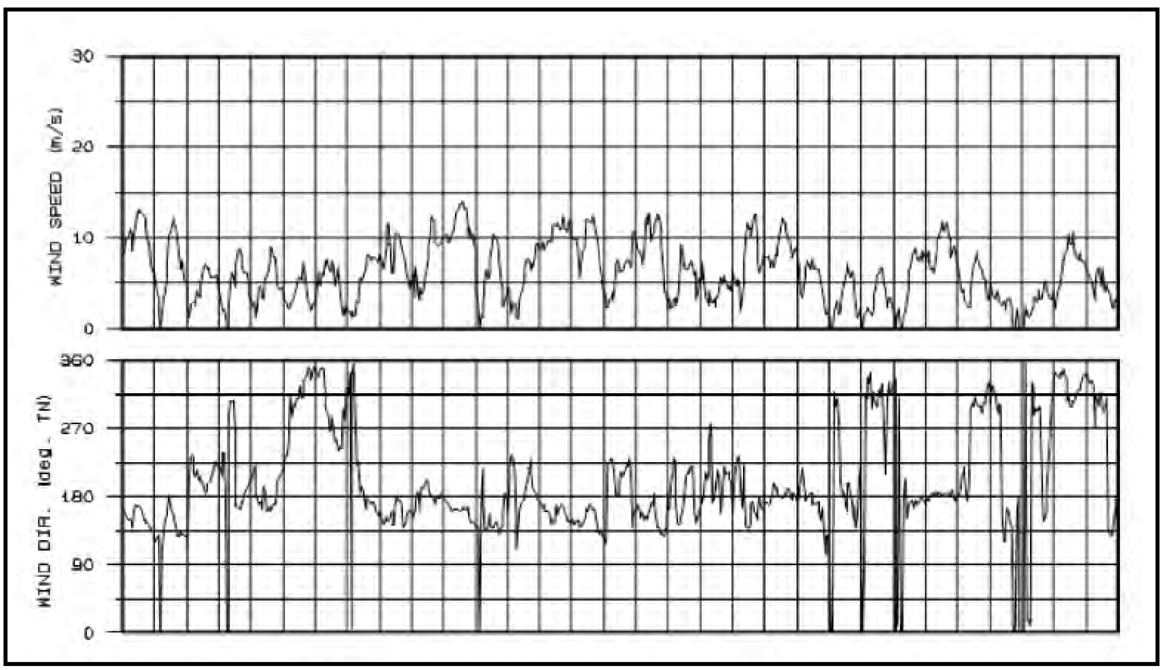


Figure 3.5: Time series graphs for January 2005 for Cape Town, obtained from the South African Weather Service. Top panel: wind speed, bottom: wind direction (SADCO, 2006).

TEMPERATURE AND RAINFALL GRAPHS:

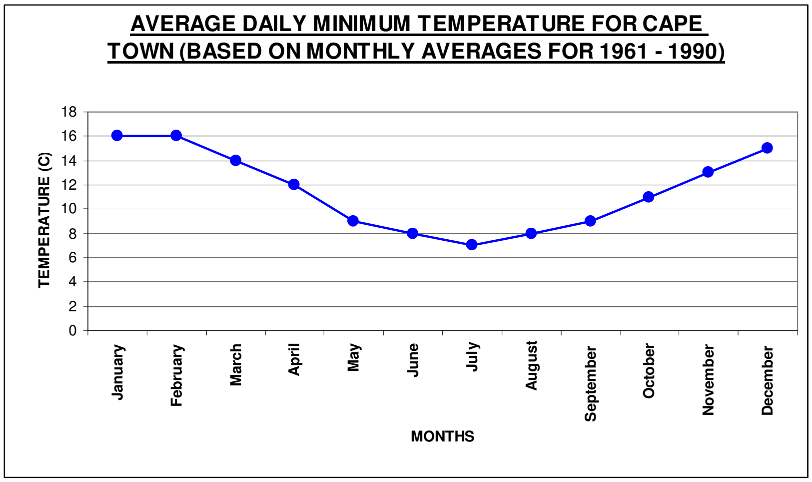


Figure 3.6: Minimum Temperatures for Cape Town: minima in July

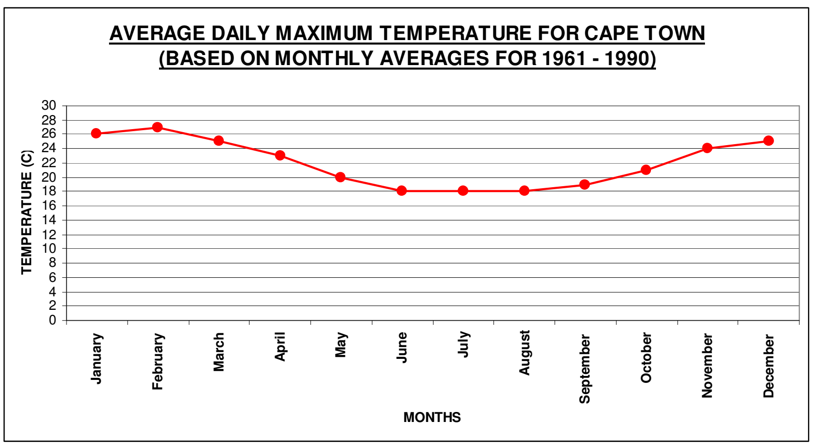


Figure 3.7: Maximum Temperatures for Cape Town: maxima in February

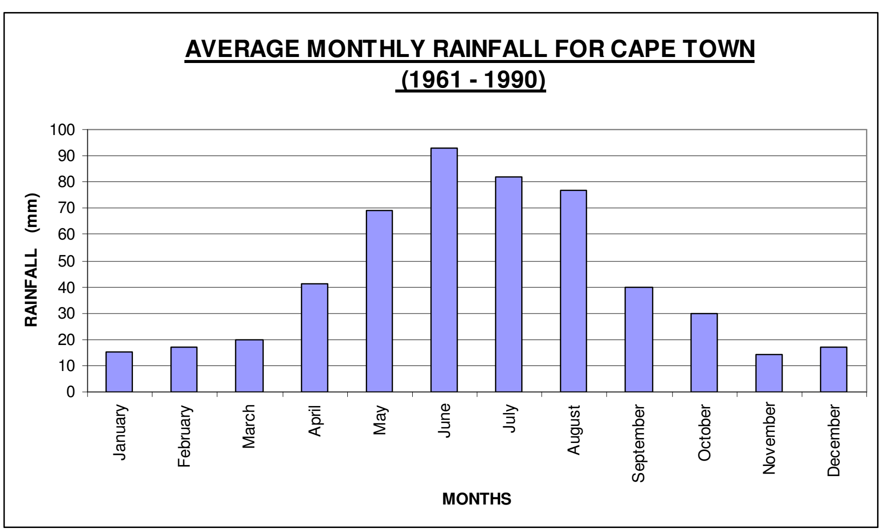


Figure 3.8: Average Precipitation for Cape Town

3.4 VEGETATION

As the previous chapter outlined, the amount and type of vegetation found within the study area is specifically important when considering the extent of stabilization of dune systems: “Dune over-stabilization is as much a threat to the system as dune erosion and can result in an acceleration of succession towards dune–heath climax status, near cessation of sand mobility, fragmentation and isolation of surviving pockets of the original dune habitat and loss of biological diversity (Lucas et al, 2002)”.

The vegetation of the corridor comprises of a diverse assemblage of indigenous sclerophyllous shrubs and herbaceous species characterized by small, thin drought-resisting leaves, many of which are endemic and found nowhere else except in the Western Cape as part of the Fynbos plant community (Cowling *et al*., 1995).

The vegetation of the dune areas is separated into distinctive plant communities extending from the back of the beach onto the dunes themselves which form a patchy zonation parallel to the shoreline (Tinley, 1985)(refer to Figure 3.7 below). The vegetation that occupies the foredunes attached to the backshore of the beach on the Noordhoek side is dune thicket/dune pioneer vegetation. It is dominated by herbs and grasses and has specifically been invaded by *Acacia cyclops* in the northern section of the dunes adjacent to Noordhoek beach (Abunji, 2004).

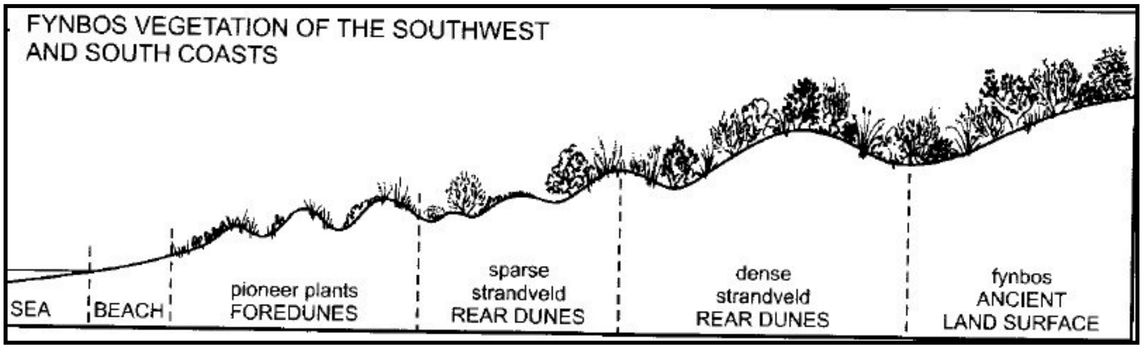


Figure 3.9: An example of the Fynbos vegetation communities extending from the beach inland, for the southwest and southern coasts (Lubke, 2004: 69)

The introduced non-invasive alien Marram grass (*Ammophila arenaria*) occurs on the eastern side of the corridor, spreading from the edge of Fish Hoek beach along the sides of the river up onto the dune area. More commonly found throughout the corridor are invasive alien species such as the Australian wattle (*Acacia cyclops*) known as rooikrans and *A. saligna*. These aliens have encroached onto the dunes found within the corridor and the dune plant communities originally found on the peripheral sides of the mobile dune areas have been out-competed and overgrown by these *Acacia* species.

3.5 CURRENT LAND USE / LAND COVER WITHIN THE CORRIDOR

Land use is the way in which people utilise the land, for example agriculture, housing and recreational purposes. Whereas land cover is simply a description of the current use of the land surface. Land use and land cover can become interchangeable as they both effect upon one another and the overall land use/ land cover changes over time are important for the examination of the changes to the dune systems in particular.

3.5.1 Urban Areas (Figure 3.10)

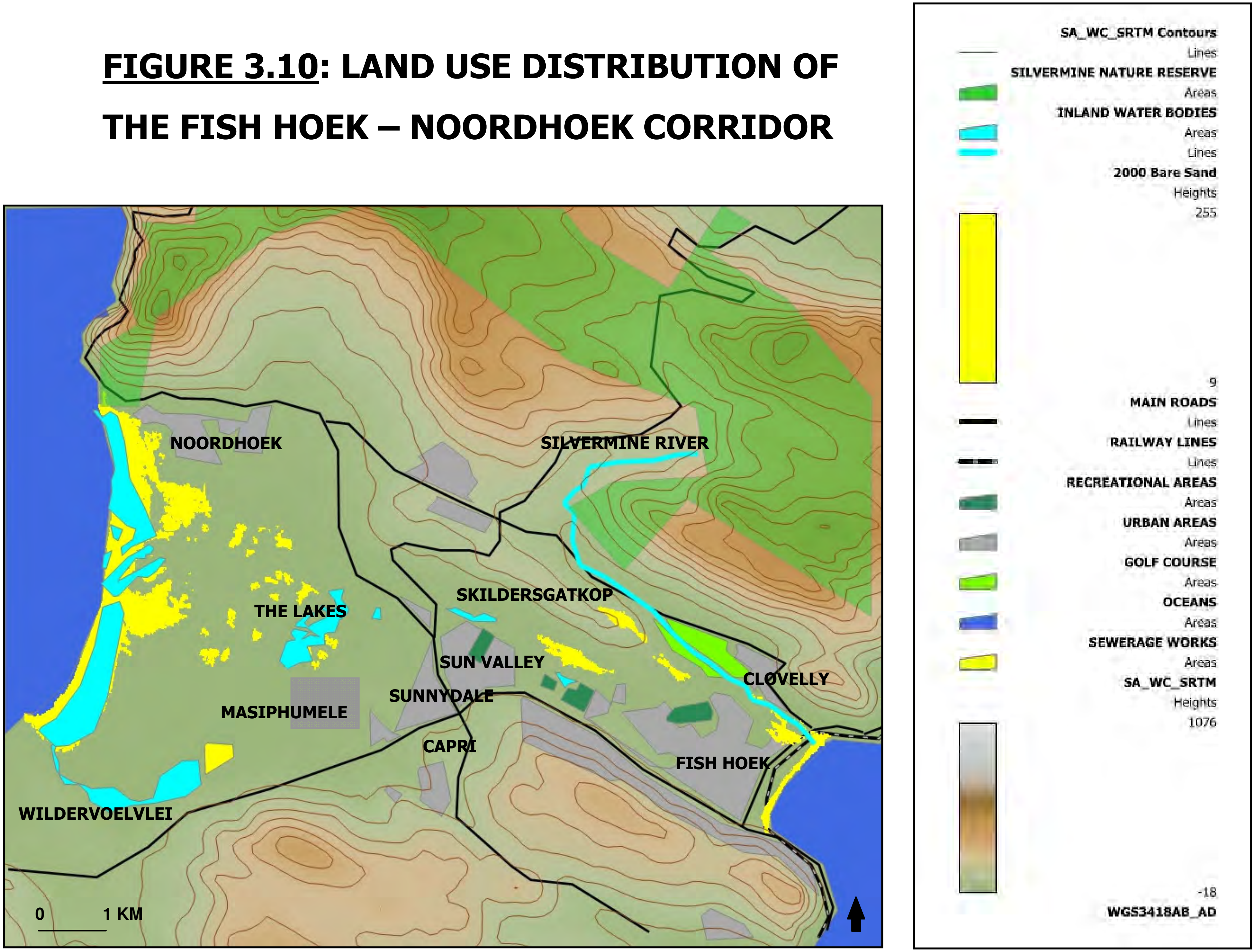
Fish Hoek town with its distinct radial street pattern, lies at the mouth of the Silvermine River and sprawls both upwards, up the mountain slope to the north and inwards towards the west. On its southern border, is the suburb of Clovelly.

Clovelly Golf Club is situated adjacent to Skildersgatkop and the remains of the Fish Hoek sand dunes. At the centre of the corridor are the suburbs of Sun Valley and Sunnydale separated by a major crossroad. Towards the south lies Capri a relatively recently established high income neighbourhood. Within the same vicinity is the informal settlement, Masiphumelele, which is constantly expanding towards the north, encroaching on the marshlands. Adjacent to the informal settlement is the Wildevoelvlei Sewerage Works. To the far north western side of the corridor below Chapman's Peak is the village of Noordhoek surrounded by various small farmlands and open commons. Within the Noordhoek side of the corridor various new estates and retirement villages have been recently established.

3.5.2 General Geomorphic Features of the Corridor (Figure 3.10)

The Fish Hoek – Noordhoek Corridor forms a low broad valley, which runs from west to east across the girth of the Peninsula with mountainous national park regions on its borders encompassing Silvermine Nature Reserve to the north and Cape Peninsula National Park to the south. The Silvermine River runs from Silvermine Nature Reserve to the suburb of Clovelly, through the valley separating Silvermine Nature Reserve from Skildersgatkop. It is the only river in the peninsula that runs its whole course without going through a heavily developed area. Noordhoek borders on the Atlantic coast at the western end of the corridor. Noordhoek's sandy beach stretches nearly 5 km across and is a wide, low gradient beach with two semi-permanent tidal lagoons on either ends. The lagoon on the southern end is linked to Wildevoelvlei. Wildervoelvlei is a twin water body system which used to function as a seasonally regulated system until 1979 when discharge of treated sewerage from the Sewerage Works adjacent to the vlei transformed it into a permanent vlei (Abunji, 2004). To area the north of Wildevoelvlei is predominantly marshland. The marshland part of the corridor has been described as one of the most magnificent stretches of unspoiled landscapes on the Cape Peninsula (Purseglove, 1998 cited in Gassner, 1999)

<u>FIGURE 3.10</u>: LAND USE DISTRIBUTION OF THE FISH HOEK – NOORDHOEK CORRIDOR



3.6 COASTAL DUNE GEOMORPHOLOGY

3.6.1 Identification of the Coastal Dunes found within the Corridor

The broad identification of the main class of the dunes in the study area was made with the aid of Rust and Illenberger (1996)'s description of the two 'morphodynamic classes' of coastal dune systems namely transgressive and retentive and the differing morphological sensitivities of them respectively. The Noordhoek dunes can be classified as retentive dunes according to Rust and Illenberger (1996) definition of retentive dunes being relatively static in term's of sand movement and where the dominant process is sand accumulation within the dune vegetation. The dunes on the eastern side of the corridor would have previously been considered to be transgressive but are now predominantly vegetated and therefore within Rust and Illenberger's (1996) classification would also be retentive. Rust and Illenberger (1996) conclude that this class is the more sensitive and fragile of the two because of the fact that these dunes are vegetated.

Tinley (1985)'s classification of specific dune types was used to identify the specific dune types and systems found within the corridor (see Table 2.1 and Figure 2.4).

3.6.2 Fish Hoek's Climbing – Falling Dune System

The dune system originating from Fish Hoek beach spreading towards the north-west is a climbing-falling dune system according to Tinley's (1985) classification.

Where strong sand-laden winds meet opposing hill slopes a climbing dune is banked up against the windward slope, and the finer sand blows over the hill or ridge, dropping in the lee down the slope to form the falling counterpart, together the whole system becomes known as a climbing – falling dune system (Tinley, 1985). Climbing dunes are generally sand accumulations formed in the standing wave of the wind blasting over a hill, ridge or mountain. The climbing dune that is found in the study are originates from Fish Hoek beach and moves up the windward slope of the Dassenberg ridge and its counterpart the falling dune slopes down the leeward side of the Dassenberg. Fish Hoek's climbing – falling dune system is one of seven of these types of dune systems occurring along the southern African coast (Tinley, 1985) (refer to Figure 2.5). This system was formed and is sustained by the specific climatic factors, mentioned in Section 3.3, of that side of the corridor. The extent of the changes to this system over time as a result of human disturbance will be comprehensively studied in this investigation.

Figure 3.11: The view looking across Skildersgat Ridge towards Clovelly. The last remaining area of bare sand representing the falling component of the Fish Hoek Climbing - Falling dune system is visible.

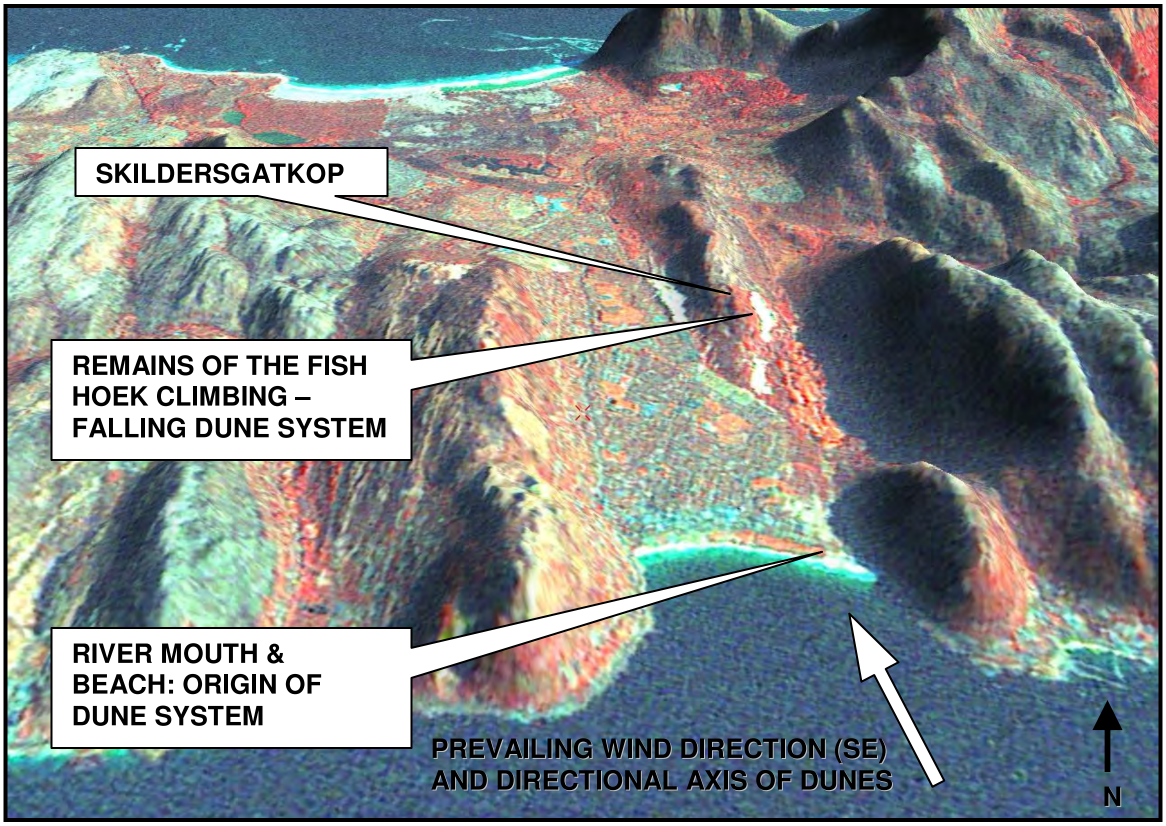


Figure 3.12: Fish Hoek Climbing - Falling Dune System formed by a topographical barrier: Skildersgatkop Ridge (part of the Dassenberg) represents the topographical barrier necessary for the formation of the Fish Hoek Climbing- Falling dune system.
(image created using a LANDSAT ETM 2000 satellite image (resolution 15 m) draped on the SRTM elevation surface of the region, produced in ERDAS IMAGINE)

3.6.3 Noordhoek Dunes

The predominant dune type found on the Noordhoek side of the corridor is hummock dunes (Tinley, 1985). Strand plants are a specialised vegetation type that is able to withstand the harsh conditions of the upper beach and can endure the continual movement of waves, swash and wind that characterises this part of beach profile. Hummock dune topography is formed by sand accumulating amongst and around the aerial parts of these isolated strand plant communities. Several specific forms of hummock dunes were identified:

1. Driftline Embryo Dunes:

This type represents the first phase of dune formation by plants. Embryo dunes form from the small mounds of sand built up around isolated plants on the foreshore. These isolated plants form part of the pioneer strand plant community and are composed of predominantly low creeping grasses with the ability to colonize mobile sand. Embryo dunes can either be eroded or destroyed by high seas and storms or enlarge and coalesce laterally to form an initial temporary foredune (see Figure 3.13).

2. Hummock Dunes:

Further development of the embryo dune may result in the embryo dune growing into a larger hummock dune (Figure 3.14). These are rounded or oval plant formed dunes which can be isolated (Figure 3.15), clumped (Figure 3.16) or in lines (Figure 3.17). The fact that the Noordhoek receives relatively high amounts of rainfall and therefore has a moist subsoil appears to be an important determinant for the continued maintenance of these hummock dunes that line the back of the beach (Tinley, 1985).

The sizes of the hummock dunes found along Noordhoek beach ranges from half a metre in height to over 5m with diameters of 1m to 15m.

3. Parallel Beach Ridge Dunes:

These are hummock dunes that form lines separated by dune slacks or troughs (Figure 3.12).

NOORDHOEK DUNE STRUCTURES:

Figure 3.13: Driftline Embryo Dune

Figure 3.14: Young Hummock Dune

Figure 3.15: Hummock Dune [Marram grass]

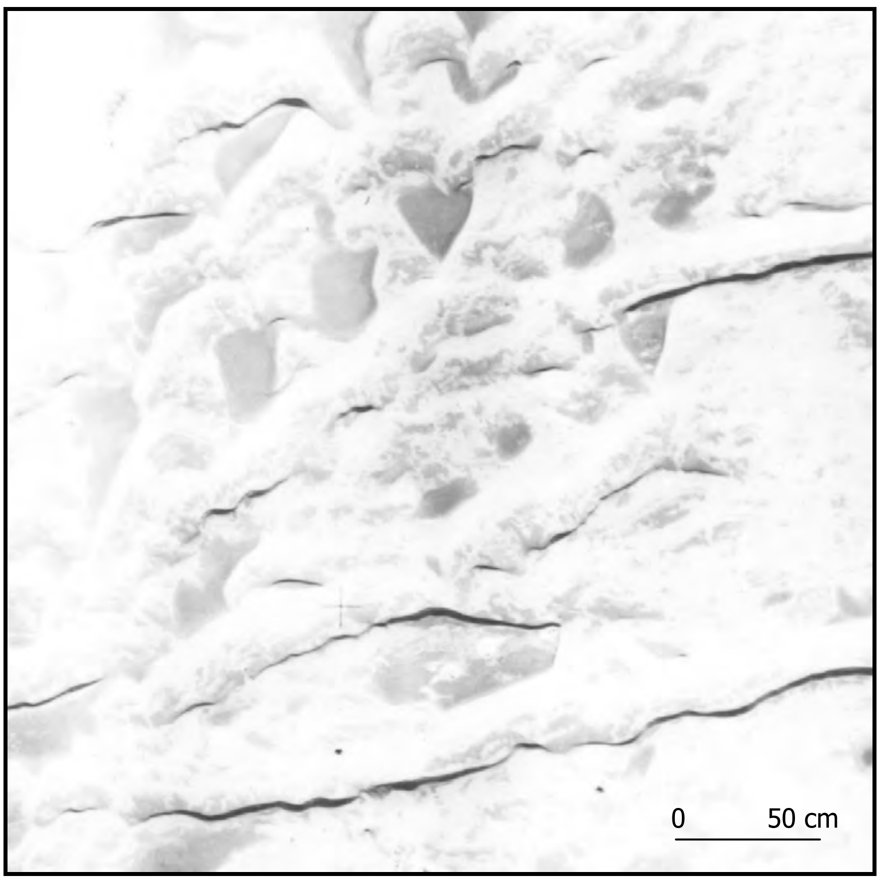
Figure 3.16: Steep Hummock Dunes

Figure 3.17: Dune Slack

Figure 3.18: Foredunes adjacent to the tidal lagoon

3.6.4 Micro-scale Dune Morphology

Micro-scale, dune features can be found within regions of bare sand on Noordhoek beach and on the slopes of Skildersgatkop (within the last remaining area of bare sand of Fish Hoek's Climbing – Falling Dune System. These micro-scale features predominantly take the form of transverse dunes which are parallel, straight or slightly curved dune ridges which have their axes orientated perpendicular to the wind direction (Figure 3.19). These features can therefore give a clear indication of the prevailing, dune-forming wind direction and the direction of the sand transport.



<u>Figure 3.19</u>: Subsection of 1945 Aerial Photograph showing Micro-scale Transverse dune ridges on Noordhoek Beach (these are the lines running parallel to each other, the dark patches are micro-dune troughs inundated with water)

3.7 SUMMARY AND CONCLUSIONS

The geological history and climatic conditions of the corridor provides the details of how and why the coastal dunes originally formed. The coincidence of strong winds on both sides of the corridor with a dry, warm summer season produces high sand transport potentials. This then greatly aids in the formation of the dunes especially on the Fish Hoek side.

The opposing coastal areas of the corridor encompass different types of dune formations and these are discussed and illustrated within the latter part of this chapter. The dunes on the Noordhoek are predominantly various vegetated hummock dune formations and are closely related to the wetlands/vleis and tidal lagoons present within that area. On the eastern side the Fish Hoek Climbing – Falling dune system was identified and discussed.

The present geomorphic state of the dunes identified and discussed within this chapter have been impacted by changes in land use and vegetation, the extent to which these dunes have been changed will be determined from the results of this study found within the Chapter 5.

CHAPTER 4: METHODS

4.1 METHODOLOGICAL APPROACHES TO THE STUDY OF COASTAL DUNES

Coastal dune areas, as indicated in chapter 2, are dynamic systems which are characterised by sand movement, land cover change and dynamic beach morphological changes across widely variable temporal and spatial scales. They therefore represent a significant management challenge as the mosaic nature of these types of environments and the complexity of land cover found within these areas are difficult to monitor using traditional mapping techniques (Lucas, et al., 2002). Remote sensing using satellite images in this respect is one of the most effective suite of tools that can be used to monitor and analyse these areas in a detailed manner. Remote sensing in combination with advanced Geographic Information System (GIS) analysis provides an even greater means for studying coastal dune areas, both visually and quantitatively (Andrews *et al*., 2004). Due to the fact that "GIS and remote sensing tools enable the quantification and understanding of spatial and temporal processes that accompany spatial dynamics and changes as well as the presentation of how extensive the phenomenon is on a spatial scale" (Kurtiel, 2004:12). This, combined with the ability of certain GIS programmes to efficiently integrate newer types of data such as satellite data with more traditional sources such as digitized maps and aerial photography, guarantees that this integrated approach is the most powerful method available (Mitasova *et al*., 2005). This combination has been used effectively to map and analyse coastal dune areas throughout the world (for example: Mitasova, 2005 and Andrews *et al*., 2004 (USA), Sanjeevi, 1996 (India), Hugenholtz and Wolfe, 2005 (Canada), Tsoar *et al*., 2002 and Levin *et al*., 2006 (Israel)).

Despite the fact that the above studies show that remote sensing using satellite images in conjunction with GIS methodologies is one of the best tools for analysis of coastal dune areas, the available satellite images for the study area taken from LANDSAT ™ subsets were not suitable for analysis of the dunes within the study area due to their insufficient spatial ground resolution of 57, 30 and 15 metres respectively (see Figures 4.1, 4.2 and 4.3). In addition, it is not possible to gain a historical perspective of the morphological changes to coastal dune systems using satellite images due to their low temporal frequency for the years within the earlier decades of last century (Brown and Arbogast, 1998). For example LANDSAT only started producing images in the 1970's (Arnold, 1996) and the earliest available LANDSAT image for the specific region encompassing the study area was from 1978 (see Figure 4.1).

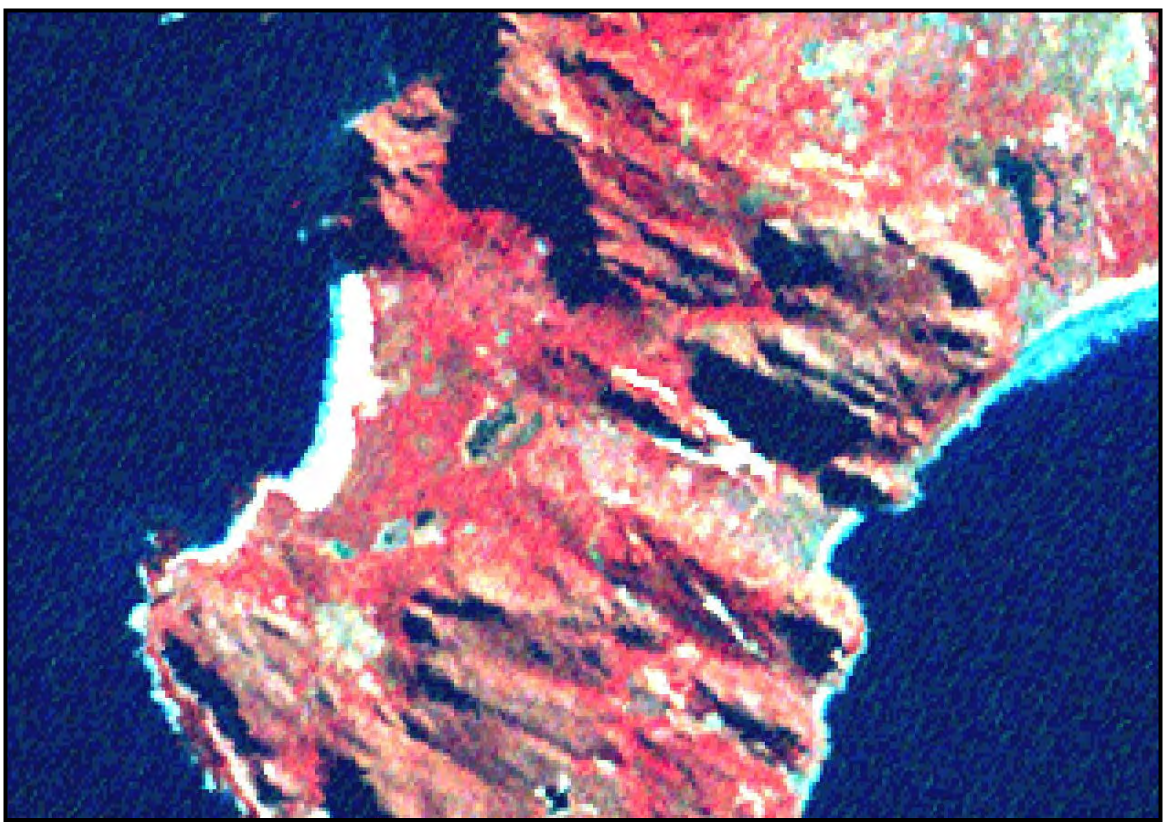


Figure 4.1: LANDSAT TM FALSE COLOUR COMPOSITE (year: 1978 & resolution: 57m)

<u>Figure 4.2</u>: LANDSAT ETM FALSE COLOUR COMPOSITE (year: 2000 & resolution: 30m)

<u>Figure 4.3</u>: LANDSAT ETM (year: 2000 & resolution: 15m)

The alternative to using satellite imagery is the analysis of aerial photography within a GIS format. Aerial photographs represent the most viable option for the analysis of the coastal dune systems found within the study area due to their availability, relatively high temporal frequencies and appropriate spatial resolutions (Brown and Arbogast, 1998). Another advantage of analysing aerial photography is "the accuracy of the interpretation in a complex landscape and the ability to clearly distinguish different types of land use as well as land cover" (Wentz *et al*., 2006: 321).

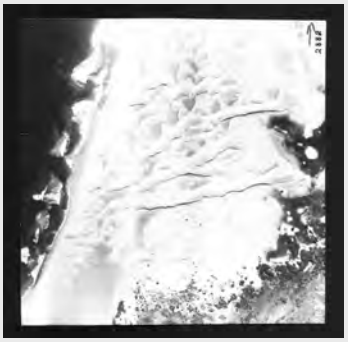
4.2 METHODOLOGICAL FRAMEWORK

The general methodological framework was therefore modelled on the Holmes and Luger (1996) paper on the study of the Hout Bay headland bypass dune system as sequential aerial photography was used in their study to establish the extent of stabilisation of the dune system and to determine the reduction in the spatial extent of the dunes within this area over a given period of time. This project accordingly makes use of sequential aerial photography as its primary resource to analyse the changes to the dunes within the Fish Hoek – Noordhoek Corridor. The Chief Directorate: Surveys and Mapping (CD:SM) provided aerial photographs as well as digital copies of these photographs covering the study area for the years outlined in the Appendix A (also see Plate 1 for thumbnails of selected images).

The above methodological review acted as a guideline to perform the necessary analysis, making it possible for the desired outcome to be achieved. The specific steps taken to carry out the aforementioned processes as well the details of the acquisition of additional supplementary primary resources are outlined within this chapter.

4.3 TIME PERIOD:

The aerial photograph record for the study area was investigated at the CD: SM. The earliest photographs in their archive for this region dated to 1937, however this particular year's images did not cover the entire area of interest and the quality of these photographs was not acceptable due to their poor illumination conditions and the poor quality of the film used. Consequently this project's time period starts at 1945 and stretches over a 55-year time span, with the study years being spaced at irregular intervals (refer to Appendix A).



1945a.jpeg

1945d.jpeg

1945h.jpeg

1945j.jpeg

1958a.jpeg

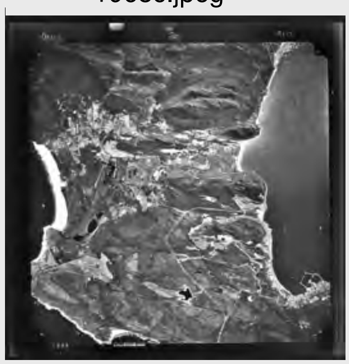
1958b.jpeg

1968a.jpeg

1968c.jpeg

1968e.jpeg

1977.jpeg



1989.jpeg

2000.jpeg

<u>Plate 1</u>: Selected thumbnail aerial photographs of the study area over the time period of 1945 – 2000

4.4 INITIAL MANIPULATION OF AERIAL PHOTOGRAPHS

To become familiarised with the study area and the content of this project's primary data source; the aerial photographs obtained from CD: SM, initial manual observation of the raw photographs was undertaken. This involved studying the aerial photographs and compiling mosaics of the images to view the whole study area and to compare the features found within the images to the topographical map of the area.

Once the connections between the different images for the available years became more evident, it then was possible to view the digital images of the aerial photographs (once again obtained from CD: SM) in Adobe Photoshop. This programme handles image manipulation very well and is able to adjust the transparency of images to make the joining of photographs into mosaics for each year a relatively simple process. The correct mosaicing of the photographs was done with the aid of the guidelines for uncontrolled mosaic layout found in Arnold (1996). However some difficulties did arise due to the fact that the photographs were not all orientated in exactly the same way because the photographs were taken at different angles and from differing flight paths/lines. This meant that when joining sequential photographs by aligning certain features commonly found in the photographs, for example road networks, some roads would match up and others in a different part of the image would not match perfectly together. To correct this problem manual rotation of selected images had to take place within Photoshop. Once cropping (carried out to remove borders), joining (using transparency), rotation and finally merging processes were completed, the images (one for each year except for 1958 and 1945 which were divided into two images due to the inability to match them up perfectly into one image) were saved as JPEG's for easy data storage and handling.

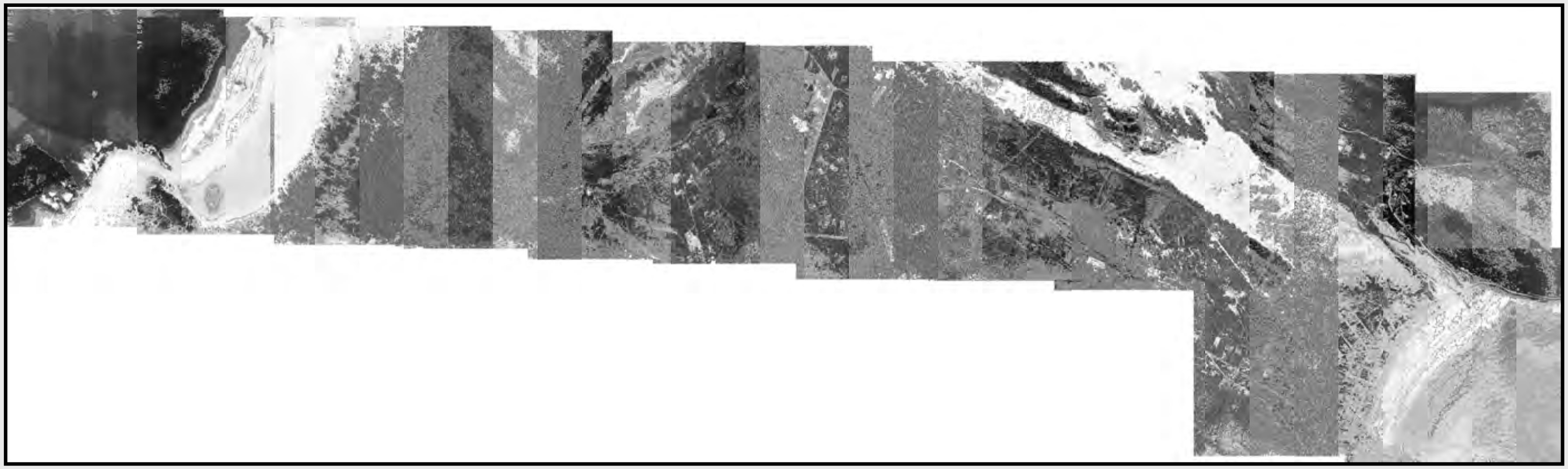


Plate 2: 1968 Mosaic

These files were then imported into the GIS programme Manifold System 6.50 as new images into a new project theme.

4.5 GIS METHODOLOGY

The analysis of the aerial photographs and the mosaics was done digitally, using Manifold.

Within Manifold, the SRTM elevation surface (refer to appendix B) was imported and the area containing the Cape Peninsula was selected and then separated from the entire southern African region. A suitable colour palette was selected from the display options so that the elevation features of the Peninsula could be clearly identified. This modified surface was then copied into the project file.

The 1:50 000 topographical map for the Cape Peninsula was obtained and imported into Manifold. The SRTM and digital topographic map were needed to carry out the GIS process of which details are provided within the next subsection.

4.5.1 Georeferencing:

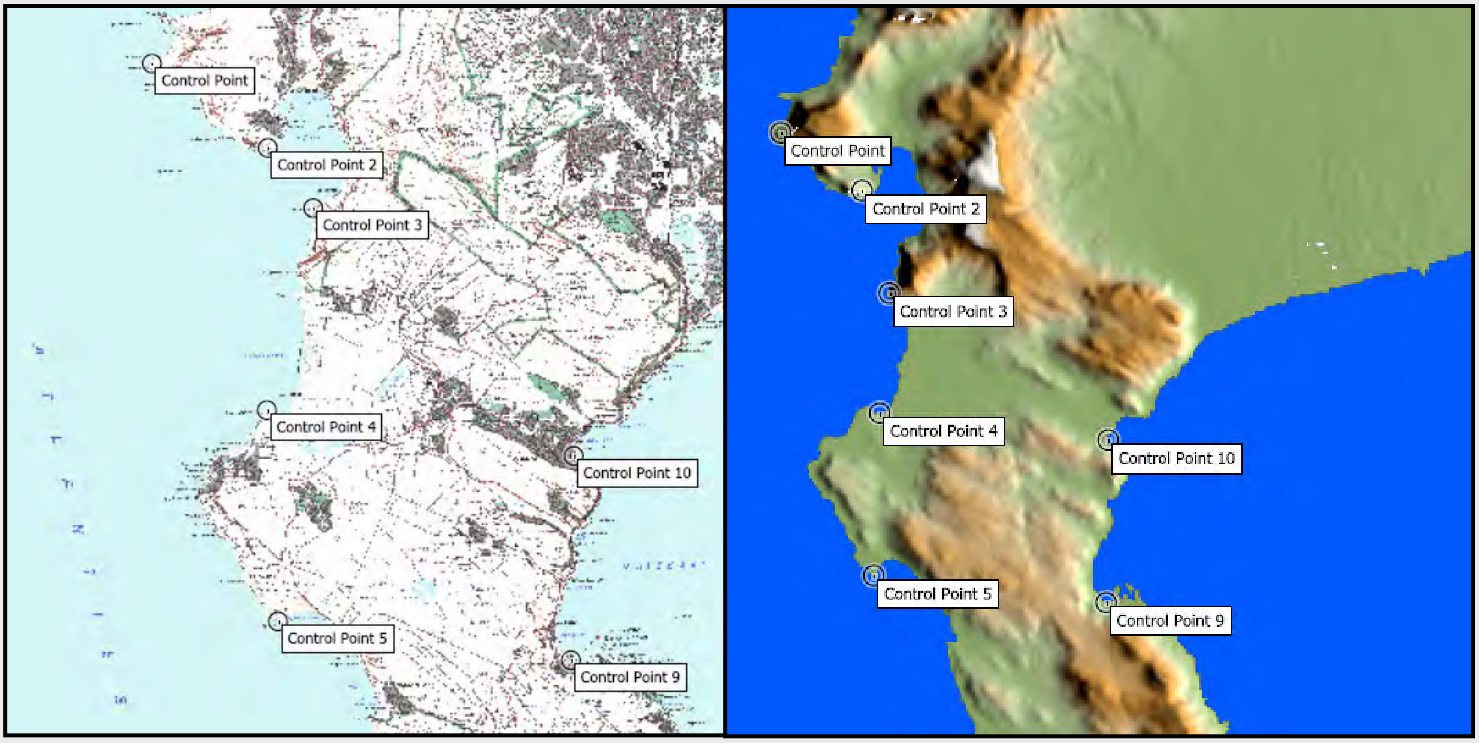
Due to the fact that the aerial photographs were taken by a variety of optical cameras and had markedly different scales, which makes their comparison somewhat difficult, the digital copies of the photographs and the compiled mosaics needed to be brought into one geographic framework (Tsoar and Blumberg, 2002).

To do this, to work within the correct geospatial format so that it is possible to correctly and accurately establish a relationship between each years' composite aerial photographic files within the same frame of reference and to then extract certain information content from these images, the process of georeferencing had to take place.

Manifold refers to georeferencing as georegistration. This is the process of adjusting an image to an actual geographic location of a known reference drawing, image, surface or map. This is achieved by the use of ground control points (GCPs). During georegistration the target image (the image that is being adjusted) will be re-projected to match the reference drawing/surface using the control points as a guide.

The key to successfully georegistering an image to a surface or drawing is to create enough control points and to place the control points (both in the image and reference surface) as accurately as possible. They should also be as evenly distributed through the target image and the reference component as possible (Levin and Ben-Dor, 2002).

The SRTM surface was used as the primary reference component. The first phase of georegistration took place by placing control points on the SRTM and the same control points on the topographical map in order to georegister the map to the surface so that both could be used in the second phase of the process.

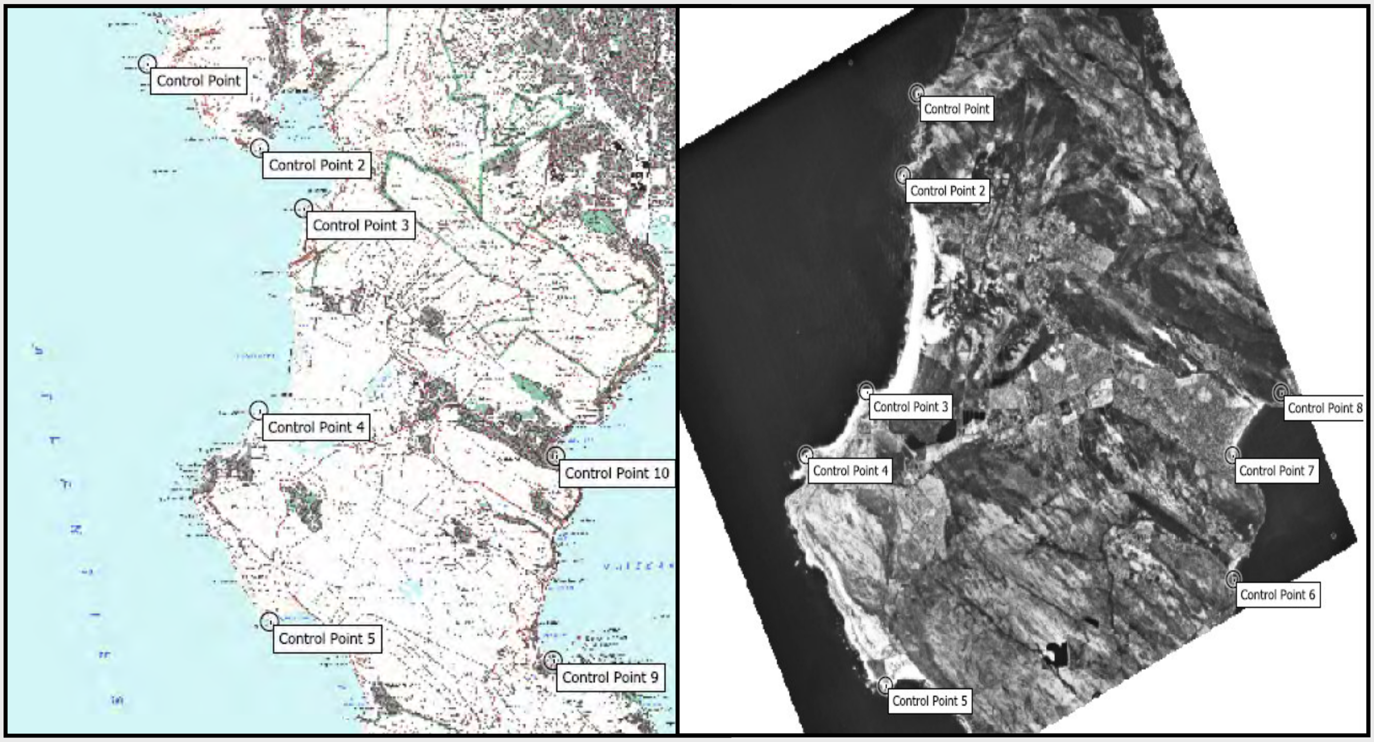


1: 50 000 3418AB Digital Topographical Map

SRTM Cape Peninsula

<u>Plate 3</u>: Georegistration Phase 1

The second phase was to georegister the latest images (1977 to 2000) to the topographical map as they encompassed the largest areas and contained large recognizable geomorphic features that could be easily georegistered to the map.

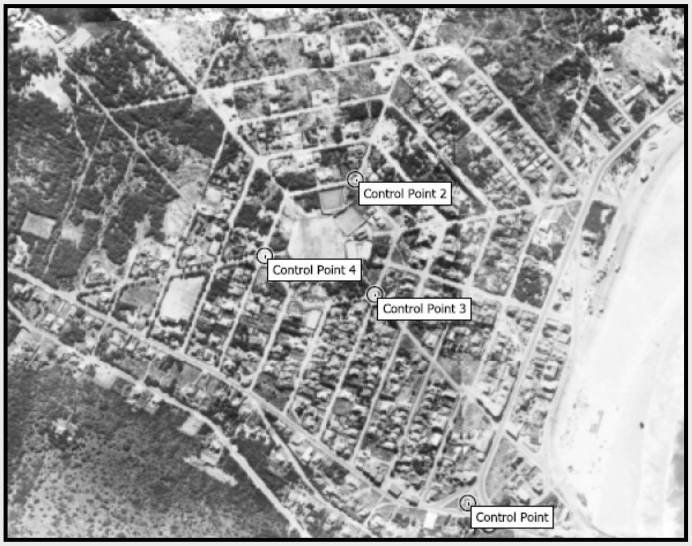


Topographical Map (reference component) 2000.jpeg (the target)

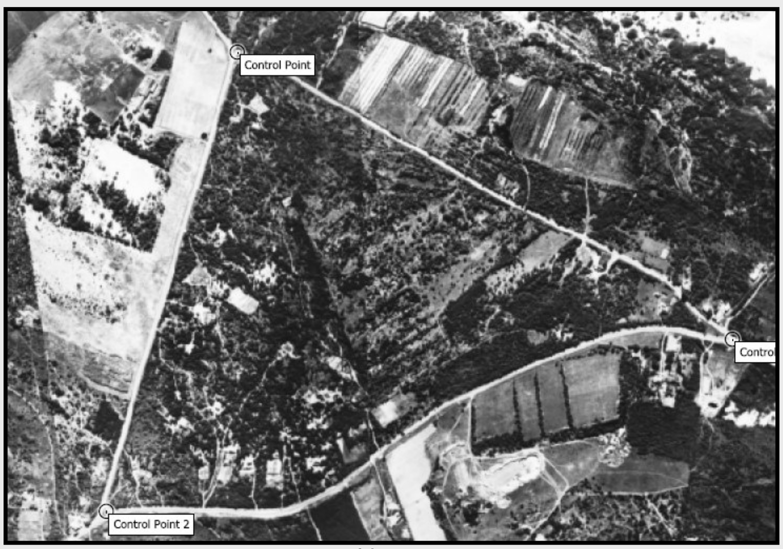
<u>Plate 4</u>: Georegistration Phase 2

Large geomorphic features such as coastal headlands and bays found on both sides of the Peninsula were used as control points for the 2000, 1989, 1977 and 1968 images. These points worked well and it soon became clear that only needed between 6 – 9 control points per image were needed (as opposed to the 100 GCPs proposed by Levin and Ben-Dor (2004).

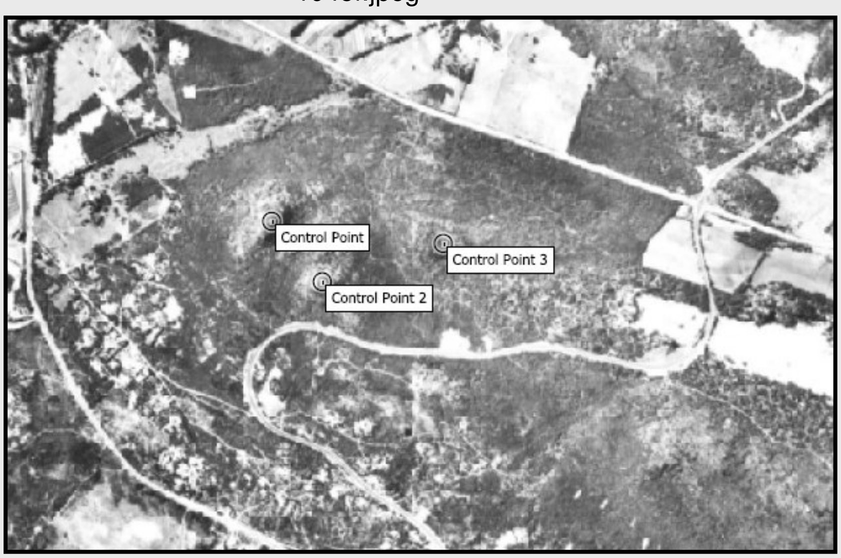
For the earlier years it was not possible to use these large features as the scale of the images was much smaller and these images covered a smaller area but were more detailed. Good GCPs for these images included road network junctions, traffic circles, the river mouth, rocky outcrops etc. Georeferencing without these types of features would have been very problematic as is the case when georeferencing aerial photographs of larger dune fields within which these types of features are not present (Kutiel, 2002).



1945g.jpeg



1945f.jpeg



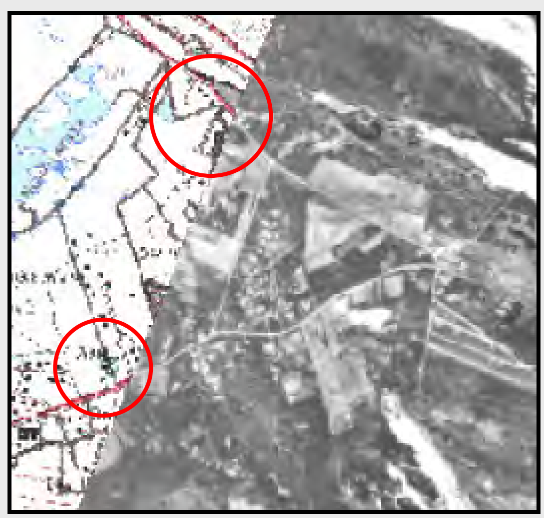
1945e.jpeg

<u>Plate 5</u>: Examples of control points for 1945 images

Once good control points are established for the target image and the reference component, Manifold will match those control points in the reference component to the target component by name and will re-project the target component so that its control points are in the same locations as the reference component. Therefore for the second phase, the aerial photographs, once successfully georegistered, are overlain on the topographical map and SRTM.

This process of georegistering was then carried out for each year. Georegistering the earliest year's image files to the map or surface was not possible due to the scale differences, so georegistering was done using the later years – that had already been correctly georegistered – as the reference component instead of the map or surface. Due to the lack of large recognizable areas that could be used as control points in these earlier years' images the resultant georegistered images did not match up perfectly with the features in the map. However the dune areas themselves were of the most importance and they were well represented in the overlain images.

An example of a poorly georegistered area



An example of very successful georegistration

<u>Plate 6</u>: Examples of different georegisteration outcomes

Manifold matches those control points in the reference component to the target component by name and re-projects the target component so that its control points are in the same locations as the reference component. This is done using a georeferencing method known as a local affine transformation which is a linear combination method that uses transformation, rotation and scaling functions to georeference the component onto the target.

4.5.2 A Note on Projections

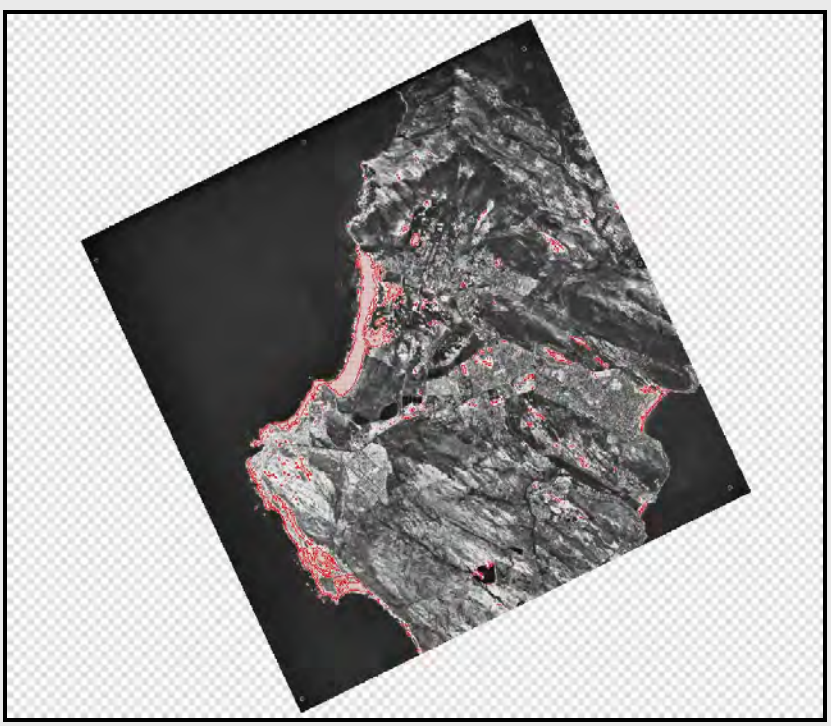
For the process of georegistration to be successful the images, elevation surface and topographical map must be in the same projection. Initially the process was carried out without projecting the data files but in order to calculate distances and areas a suitable projection was needed. The following projection was used: Universal Transverse Mercator (south), Zone 34 which uses the WGS 1984 ellipsoid description of the earth (Tsoar and Blumberg, 2002). This projection resulted in metric coordinates that made it easier to perform quantitative analysis. All components were set to the abovementioned projection and all created data had this projection so that overall, the resulting images had a ground resolution of roughly between 1 to 4 m per pixel.

4.5.3 Selection of the Dune Areas:

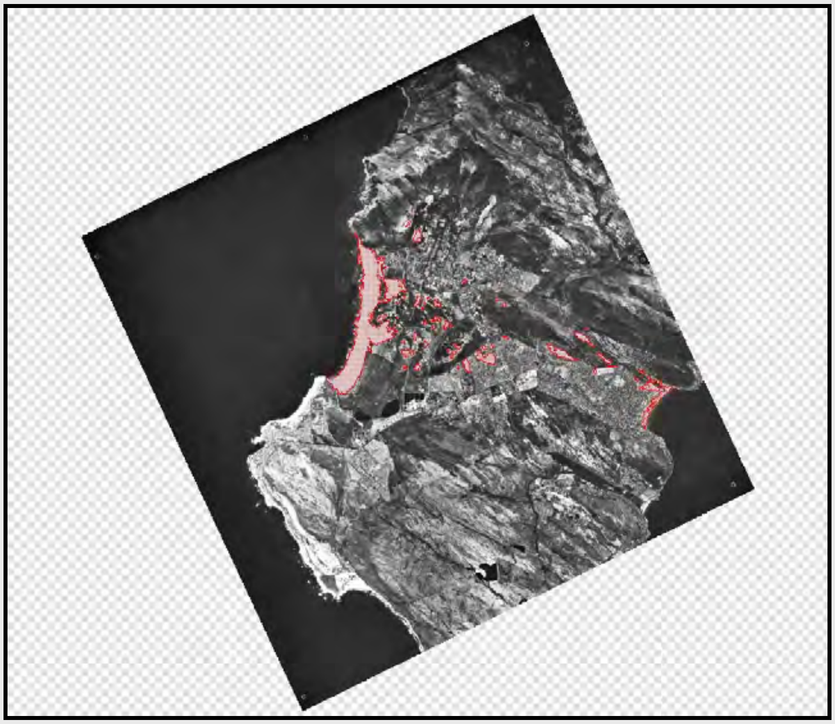
One method of selecting the regions of bare sand representing dune areas in the study area within Manifold is to use the selection toolbar. Within the selection toolbar, one must choose to select pixels by touch. This method works well and is relatively fast due to the fact that the areas of bare sand in the images all have the same or very similar pixel values. There is also a very high colour contrast between bare sand areas and vegetated regions as bare sand has a very high reflectivity in contrast to vegetation which absorbs greater quantities of light (Kutiel et al., 2004). Thus by selecting the brightest pixels, which represent the sand, using the select by touch tool, all pixels of the same nature are selected.

One must also be careful to set the tolerance level to the same value for consecutive selections (found within the Tool Properties pane).

This automatic selection represents the first phase in the overall selection for the sand areas. Once this is completed, the process of manual selection and de-selection can begin in order to edit the initial automatic selection which could hold areas that do not actually fall into the region of interest or that do not represent part of the dune systems found in the image. For the second phase – the manual selection and de-selection – to be successful a thorough knowledge of the study area is essential in order to be able to recognize the relevant features of the landscape represented in the images. Once the editing of the selection is complete it is possible to save the selection within the selection pane.



Automatic Selection by pixel value



Manual Selection done after Automatic Selection

<u>Plate 7:</u> Selection Phases 1 & 2

Once the areas that represent bare sand have been successfully isolated from the types of land cover, these selections needed to be converted into separate images so that they could be overlain on the map. This however proved to be not a simple procedure in Manifold. The selections for each year had to first to be converted to surfaces as it was not possible to produce images directly from the saved selections. Once this was done, the display properties of the produced surfaces were modified so that the surfaces contained no shading, shadowing or contrasting effects and so that the backgrounds become uniformly black. Then secondary surfaces were created using the information content of the initial ones, these are the final products and can overlain onto the map.

4.5.4 Calculation of Bare Sand Areas:

Calculation of the exact areas covered by bare sand representing the dune systems in the study area was also not possible within Manifold. This was because the images which were actually surfaces were in a raster format which made it impossible to directly calculate areas within this programme. Therefore the surface files of the selected regions of bare sand had to be exported in a BIL file format out of Manifold and into the remote sensing programme ERDAS IMAGINE as floating point raster surfaces. As this programme is raster based, its image processing capabilities are more suitable for the type of process that needed to be completed in order to obtain area estimates. Once importing the files into ERDAS, the process of unsupervised classification had to be performed in order to group the pixels within the images into two classes, one containing the pixels which represent the regions of bare sand and another representing the background. This is possible because all pixels that represent bare sand had very similar or exactly the same pixel values. From this point one can view the image attributes and extract the exact number of pixels that represents bare sand areas for each year. Then by taking the individual pixel size (found in the original Manifold project using the fact that all the images are georegistered and therefore the pixel sizes are displayed in the projection window) and the number of pixels (from the ERDAS classification) it was possible to calculate the spatial extent of the dunes for each year (see Appendix C).

4.6 HISTORICAL GROUND-BASED PHOTOGRAPHS

To contrast the changes seen from an aerial view and further illustrate these changes, historical photographs were obtained from local archives and journals found in the Fish Hoek Library. These photographs were scanned in order to work with them as digital images.

The earlier photographs were very poor in quality and the resultant digital images appeared blurred. To improve their appearance, sharpening, contrast and colour adjustments were made in ERDAS. Filtering and stretching processes were performed to further enhance the dune areas as opposed to the build environment.

4.7 METHODS DISCUSSED

4.7.1 Photogrammetric Considerations

Ideally, the selected photographs for a given study area should have the same solar illumination, similar or the same camera types and have been taken at a similar time of year and at a similar time of day (Hugenholtz *et al.*, 2005). This was not the case for the photographs selected for this study as the acquisition times, sun elevations and flight paths differed from year to year. Therefore some level of compromise with respect to these conditions was required. Due to these types of inconsistencies shadowing effects were noticed in some of the images, although they were considered to be negligible and ultimately irrelevant.

The major difficulty in analysing and working with these photographs was the fact that they had widely differing scales and were taken at irregular time intervals. The older aerial photographs were taken at much lower spatial resolutions whereas the latest images had higher spatial resolutions but therefore contained less surface detail (see appendix A).

A further photogrammetric consideration that could cause inaccuracies to form is the inherent distortion in aerial photographs. This potential source of error is known as the error of parallax or image displacement (Arnold, 1997). This type of distortion occurs in any vertical aerial photographs of land features that lie above or below the mean surface elevation or the elevation at the centre of the photographs. Features that extend above the mean surface elevation are displaced on the aerial photograph away from the centre and can thus produce distortion in the image (Kirsten, 2005).

As the above discussion outlines, all aerial photographs have some degree of distortion and therefore when analyzing them, there will always be some margin of error: “Image data gathered by a satellite or aircraft are representations of the irregular surface of the Earth. Even images of seemingly flat areas are distorted by both the curvature of the Earth and the sensor being used” (ERDAS Field Guide, 1999: 343)

4.7.2 Additional Sources of Error

The processes of rotating and mosaicing the images in Photoshop could never have been done timeously with some compromise as to the quality of the final mosaics. Poor matching of some features such as minor roads was inevitable but all effort was made to ensure that the dune areas themselves were very well aligned.

The digital aerial photographs for 1945 were very difficult to mosaic due to their low spatial resolution. Also the flight plans for this year varied considerably from the other years and it was discovered that the central area of the study region was not photographed. Therefore it was not possible to produce a single mosaic for 1945 instead two separate mosaics were made from the northern and southern parts of the area.

Within Manifold, the georeferencing of the earliest years’ images was problematic as there were few suitable positions for the placing of GCPs due to the small spatial extent covered in each image. After several attempts and many changes to the GCPs locations, the images were reasonably well georeferenced. However, in general, the georeferencing method employed by Manifold is aimed at producing results quickly using few GCPs and therefore a compromise is made on the accuracy of the process. A more precise outcome would have been achieved if a more thorough georeferencing method was employed (ERDAS Field Guide, 1999).

During the process of selection, there are many potential sources for error. Recognizing when the automatic selection was incorrect, that is when it selected areas that did not fall into the dune systems due to the fact that these areas also had a high reflectivity or actually did contain bare sand but was not part of the dunes, was difficult but a thorough knowledge of the different land uses within the study area made the process more successful.

The procedure used to extract the selections of bare sand from the original mosaics and create separate images by converting the selections to surfaces, is arguably not the most effective method in terms of correct Manifold procedure. Tracing areas in a drawing overlaid on a map surface would have been a better option as this would directly result in area estimates. However this would mean manual tracing and due to the fragmented nature of the distribution of bare sand within the study area this would not have produced an accurate result. Therefore automatic selection within the original image followed by manual de-selection was considered the most appropriate method to produce the desired outcome.

Due to the fact that the above method was followed instead of creating drawings, it was not possible to measure areas directly within Manifold. The alternative was to export the selected surfaces into ERDAS which has superior raster surface processing abilities. The extraction of the precise number of pixels representing bare sand and the resultant calculations performed thereafter could have contained potential errors.

4.7.3 Quantifying Procedural Error

A procedure that could have been initiated to analyse the error in the process of georeferencing would have been by calculating the root mean square (RMS) error of the distance between the reference GCPs and the resulting GCP in the image after the process is completed. However this would only be possible for the first phase of georeferencing as RMS does not provide information regarding the relative error between images (Tsoar and Blumberg, 2002).

4.7.4 Additional Procedure that could have Reduced Errors

To create a more uniform basis for extracting the dune areas and to reduce the photogrammetric inconsistencies inherent in the aerial photographs the photographs could have been adjusted using the relative normalization technique. A description of the details of this technique can be found in Shoshany (2000). The technique is based on identifying permanent features of the landscape with a different spectral return that constitute a reference level for determining a ranking of shades of gray (Kutiel, 2004). This would then have minimized the contrasting shades of grey that resulted from the photogrammetric inconsistencies (for example: see plate 8 below).

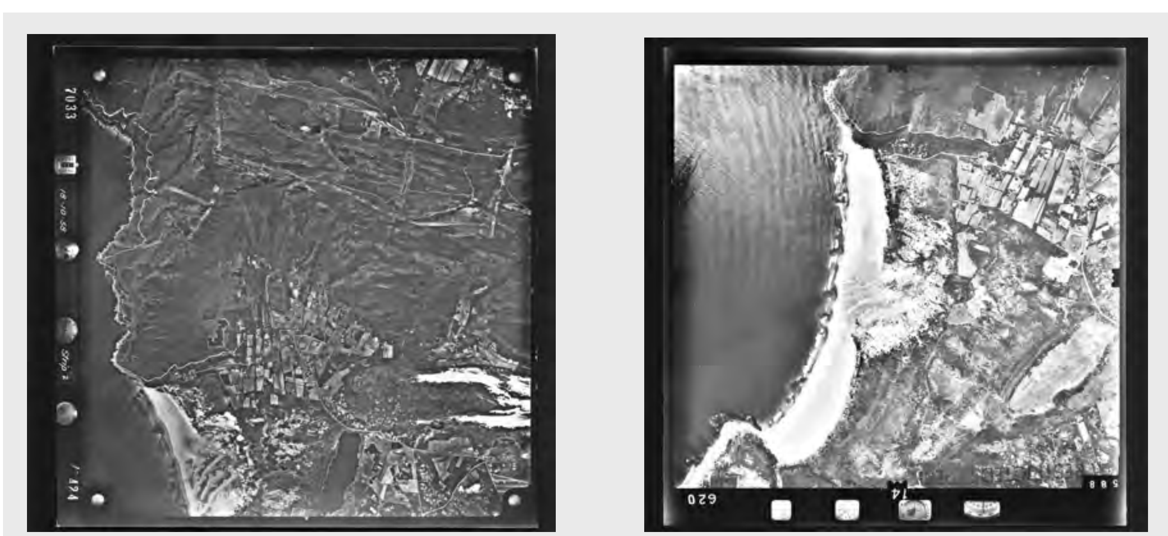
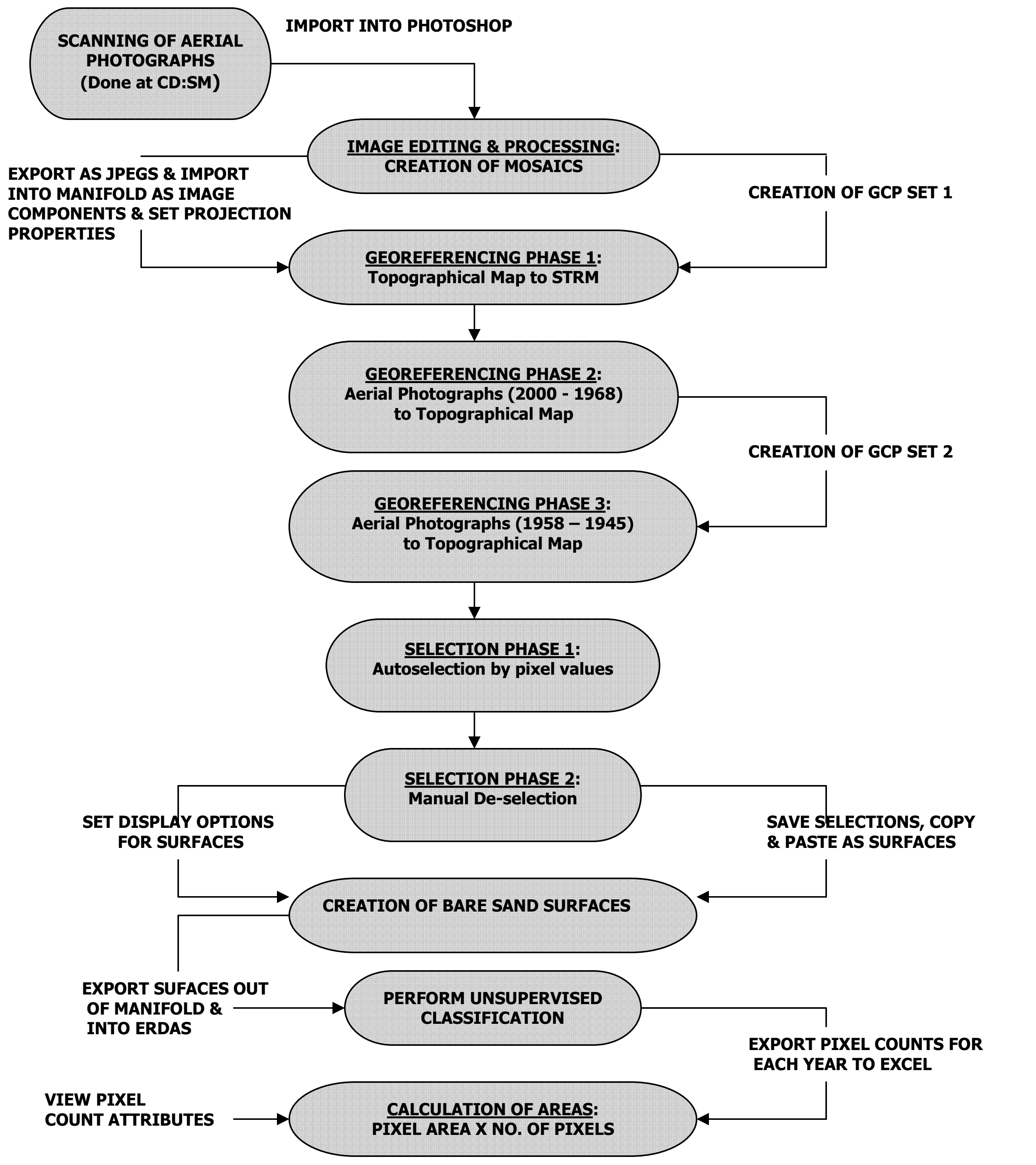


Plate 8: Variations in the shades of grey for different years

4.8 SUMMARY

The following diagram is a flow chart representing a summary of the steps taken to produce the study's desired results:



4.9 CONCLUSION

The process of extracting information on the dune systems represented in the raw digital aerial photographs and generating new surfaces within Manifold System was an approach that has not been documented before and therefore inconsistencies in the method was expected. Despite any inaccuracies, irregularities and sources of error that might be present in this methodology, the resultant images and area estimates were satisfactory for the purpose of this study. In addition, the detailed steps taken to achieve these results represent a replicable approach to working specifically with aerial photography with a focus on land cover change in Manifold, and therefore could be useful to future research analysis

CHAPTER 5: RESULTS

This chapter provides the final results of the investigation into the changes to the dune systems within the Fish Hoek – Noordhoek Dune Corridor from the years 1945 to 2000. The results are in the form of image overlays, graphs and photographs. An interpretation of the visual results is provided. This is followed by a detailed description of the more specific changes to the Fish Hoek dune system which was made possible with the accompaniment of historical details of the development of the town.

5.1 CHANGES TO THE DUNE AREAS WITHIN THE WHOLE CORRIDOR

Figure 5.1 provides an overview of the changing spatial extent of bare sand representing active sand dune areas within the entire Fish Hoek – Noordhoek Dune Corridor (see Appendix D for the individual overlay images for each successive year).

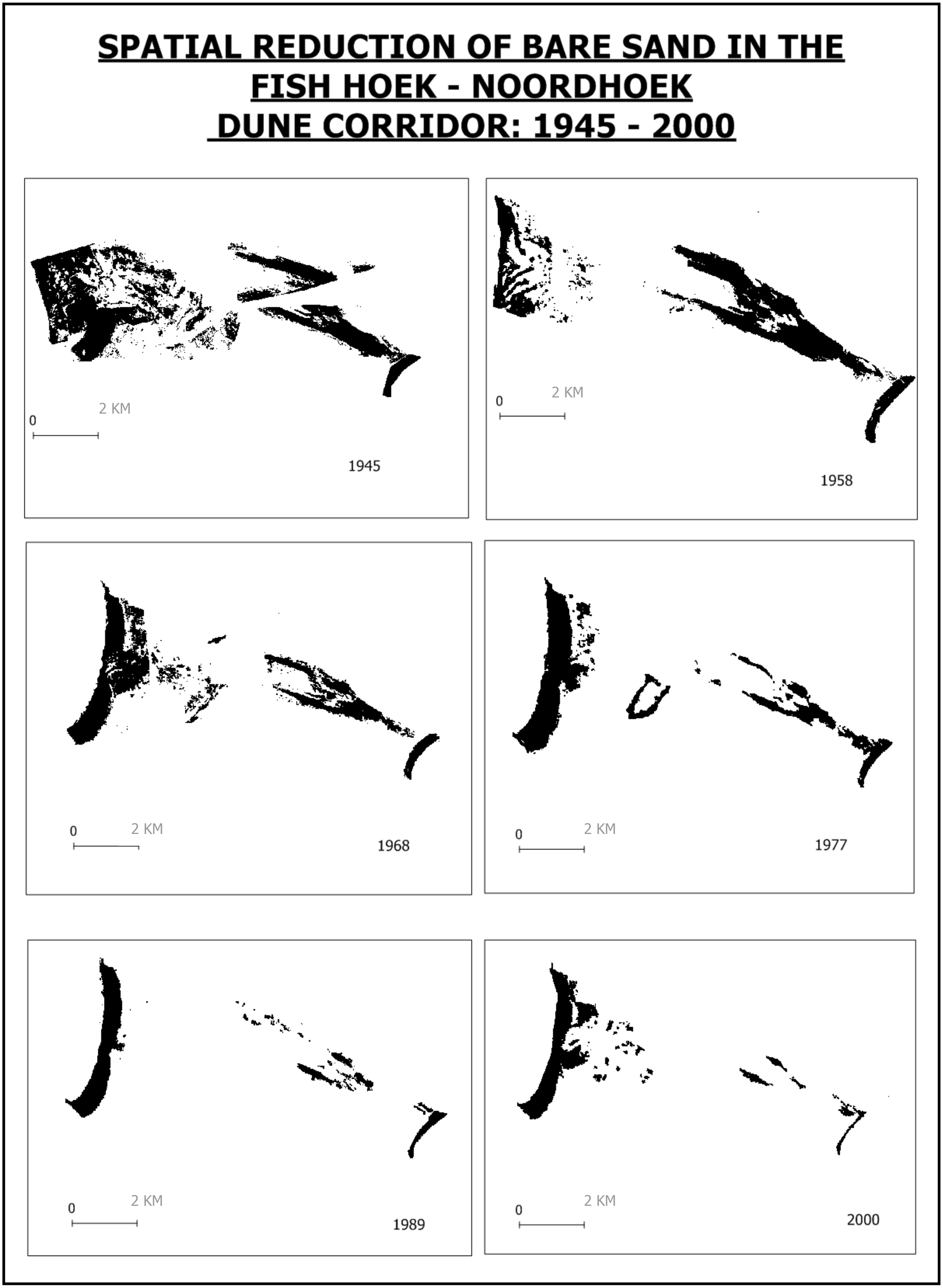


Figure 5.1: Changes in the spatial extent of bare sand within the Fish Hoek – Noordhoek Dune Corridor for the years 1945 – 2000.

Figure 5.1 very clearly indicates how the spatial extent of exposed sand representing mobile dune areas and beach sand has changed over the above years. The following summary provides a description of the observed changing sand distribution for the time period outlined above:

The sand distribution for 1945, as illustrated in Figure 5.1, represents the base year for comparison with the subsequent years in the time period for the study. By studying the mosaic constructed for this year and the spatial overlay (displayed in Figure 5.1 and Appendix C) in conjunction with the knowledge of the specific land use and major geomorphological distributions of the corridor (outlined in Chapter 3) it can be concluded that bare sand areas represent the beaches on either ends of the corridor, the climbing – falling dune system extending from the beach along the Silvermine river and onto the Dassenberg, the coastal dunes originating from the backshore area of Noordhoek beach and the sand within and around the marshland and vleis further inland from Noordhoek beach approaching the Lakes.

Despite the fact that there are inconsistencies within the overlay sections for this year involving overlapping and omitted areas (identified in Chapter 4), both sides of the corridor exhibit a markedly larger spatial coverage of bare sand compared to subsequent years.

The 1958 spatial overly (found in Figure 5.1 and in Appendix C) contain inconsistencies that need to be taken into account when analysing this image. A further restriction is the fact that the southern region of Noordhoek beach was not covered in the aerial photographs that were used in this analysis, therefore it was not possible to study this section. Also by studying the original aerial photographs it became clear that most of Noordhoek beach was covered by two semi-permanent tidal lagoons. The water-logging of the sand within this section accounts for the webbed appearance of the sand on the Noordhoek side for this year and 1945's overlay. The bare sand dune areas adjacent to the beach were more extensive than the following years. The Climbing – Falling dune system on the Fish Hoek side encompassed a substantial area; covering both sides of Skildersgatkop and extending westward over the ridge. Fish Hoek beach was broader than in the following years and the link between the beach and the dune system was intact.

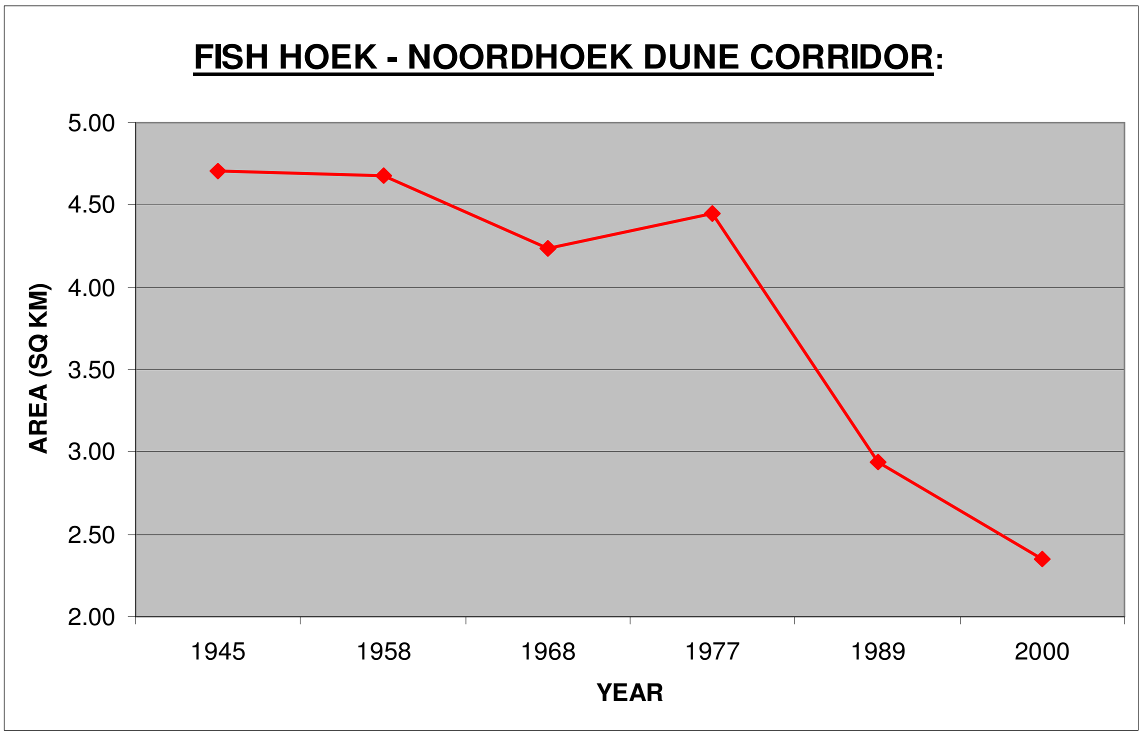
For 1968 the following was observed: On the Noordhoek side the beach – dune area was similar to the previous years, but due to the improved extent of the original aerial photographs the entire beach is shown. There does however seem to be a slight increase in bare sand inland of Noordhoek beach in comparison to 1958. On the Fish Hoek side there is a clear separation between the beach and the dune system and a fragmentation of the large areas of bare sand (the appearance of the dunes are more speckled).

1977's images showed that the bare sand on the Noordhoek side inland of the beach has been reduced except for an area of sand around the Lakes in the centre of the corridor. There seems to be an increased spatial coverage of bare sand extending from Fish Hoek beach up towards Skildersgatkop but less exposed sand on the hill itself.

The 1989 image showed a dramatic reduction in the extent of bare sand for the entire corridor compared to the previous years. Noordhoek beach reduced in size with the dunes attached to the backshore no longer as active or exposed. On the Fish Hoek side, the beach is much smaller especially in comparison with 1945 and 1958. The bare sand of the Climbing Falling dune system has almost entirely disappeared but for the first portion of the slopes of Skildersgatkop.

There seems to be an increase in bare sand adjacent to the northern part of Noordhoek beach for 2000. Fish Hoek beach has been further reduced in size and the bare dunes on the slopes of Skildersgatkop have been isolated to three distinct patches on either side of the hill.

Figures 5.2 and 5.3 represent the graphed results of the area estimates for each year in the study period constructed from the extraction of the number of pixels representing bare sand taken from the images in Figure 5.1. The area of bare sand within the entire corridor has almost been halved during the time period analysed.



<u>Figure 5.2</u>: Area estimates of bare, exposed sand for the corridor

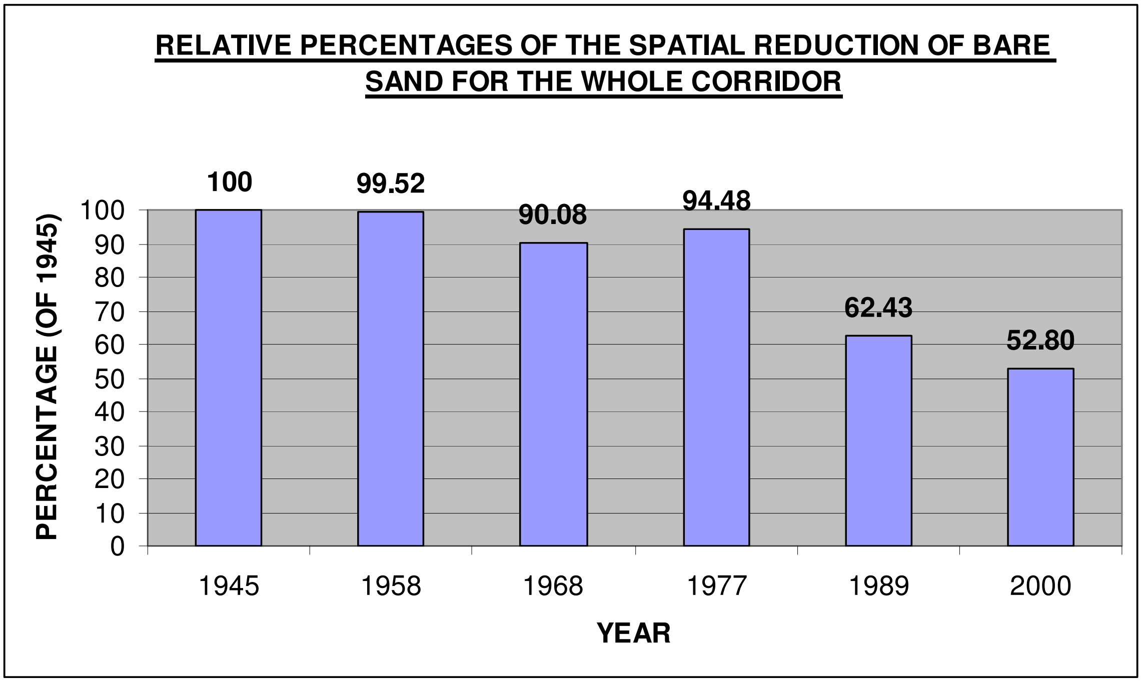


Figure 5.3: Relative percentages of the areas for the years 1958 - 2000 taken from the total area for 1945

5.2 THE CHANGES TO FISH HOEK'S CLIMBING – FALLING DUNE SYSTEM

Figures 5.5. and 5.6 show the dramatic reduction over the years in the areas covered by bare sand representing the active climbing – falling dune system originating from Fish Hoek beach and moving up Skildersgatkop onto the Dassenberg. The regions of bare sand have been reduced by over 80% from 1945 to 2000, shrinking in size from just over 2 km^2 to less than 0.5 km^2, indicating that this system has been severely altered.

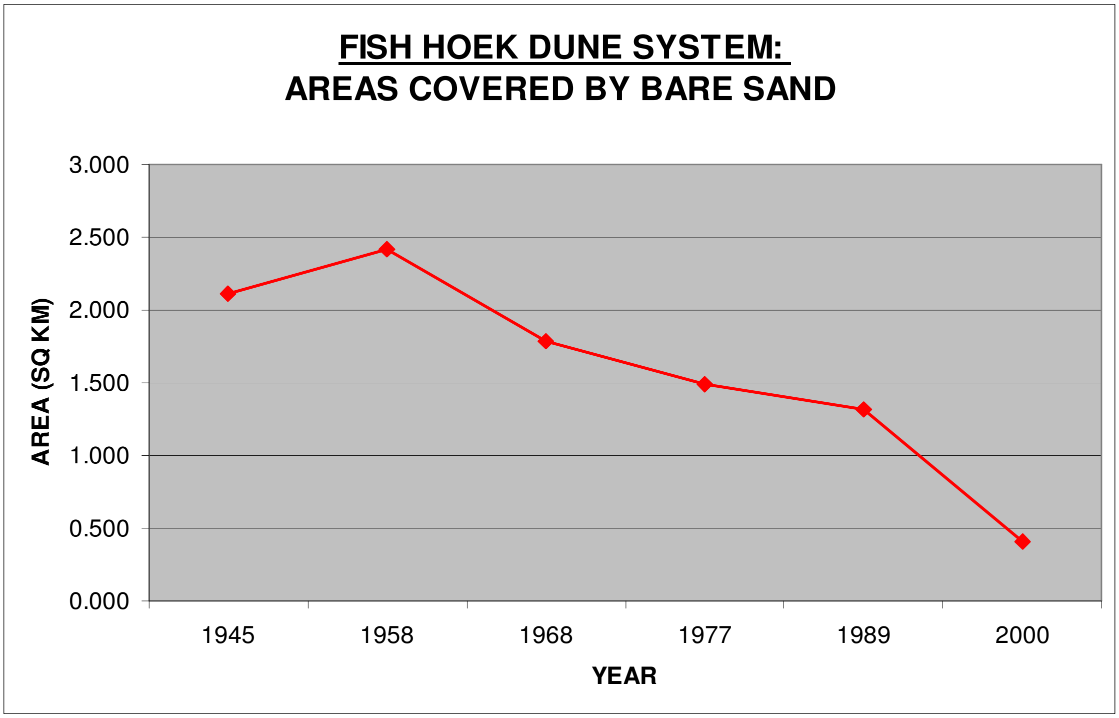


Figure 5.4: Area estimates for the Fish Hoek Dune System

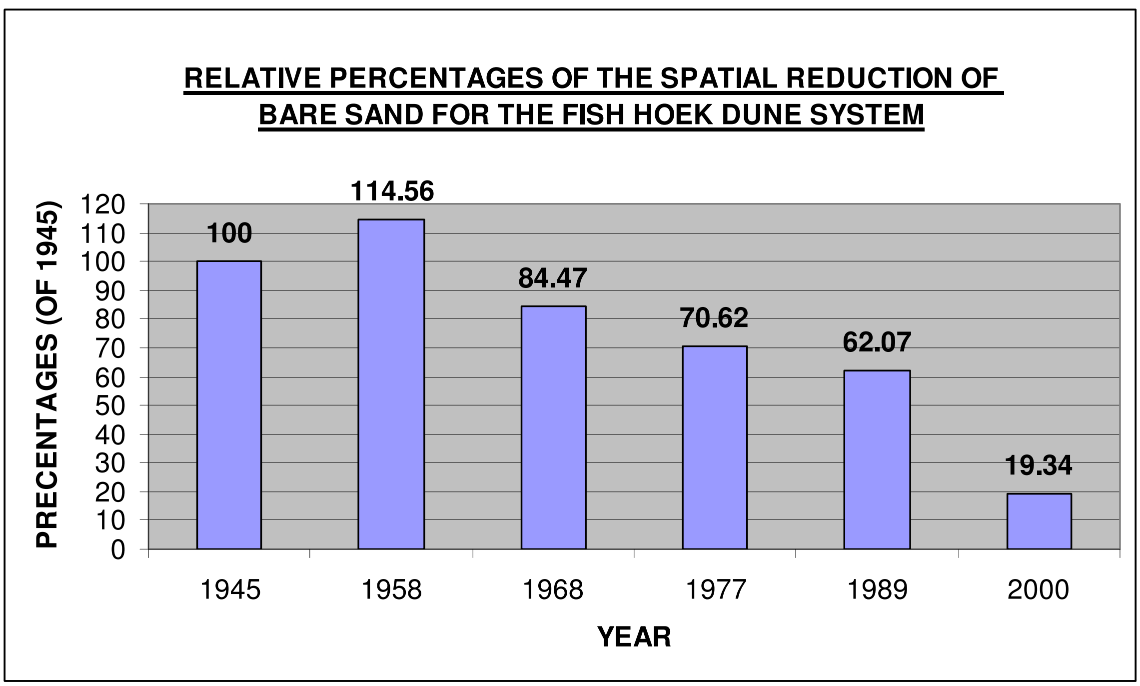
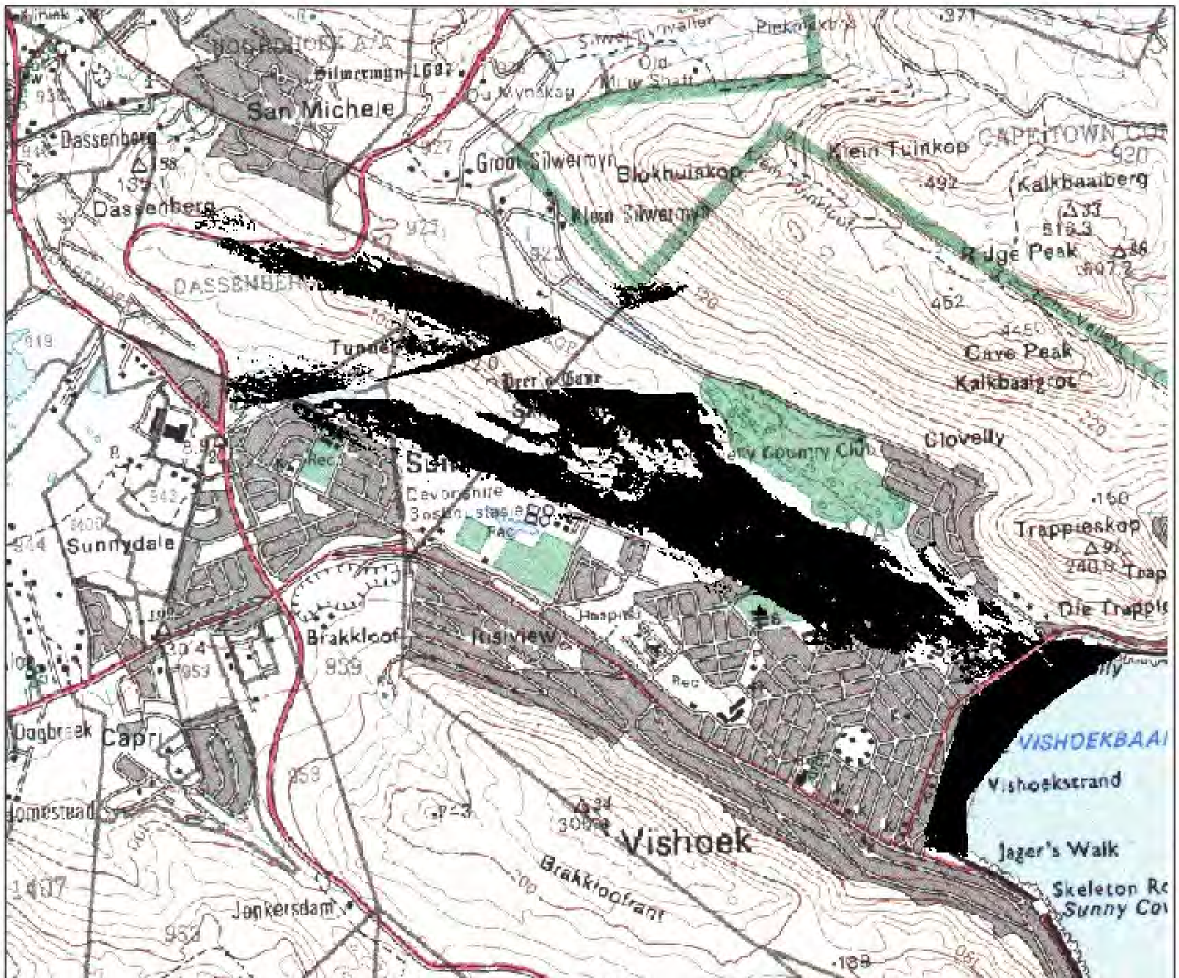


Figure 5.5: Relative percentages for the area estimates for the Fish Hoek Dune System (taken as a percentage of 1945's area i.e. the maximum extent)

The following figures juxtapose the historical photography with the spatial overlays extracted from the aerial photographs overlaid on a portion of the georeferenced topographical map. These figures therefore provide a complete visual record of the changes to the system for the study period from both ground-based and aerial perspectives.

FISH HOEK: 1945 & 1947

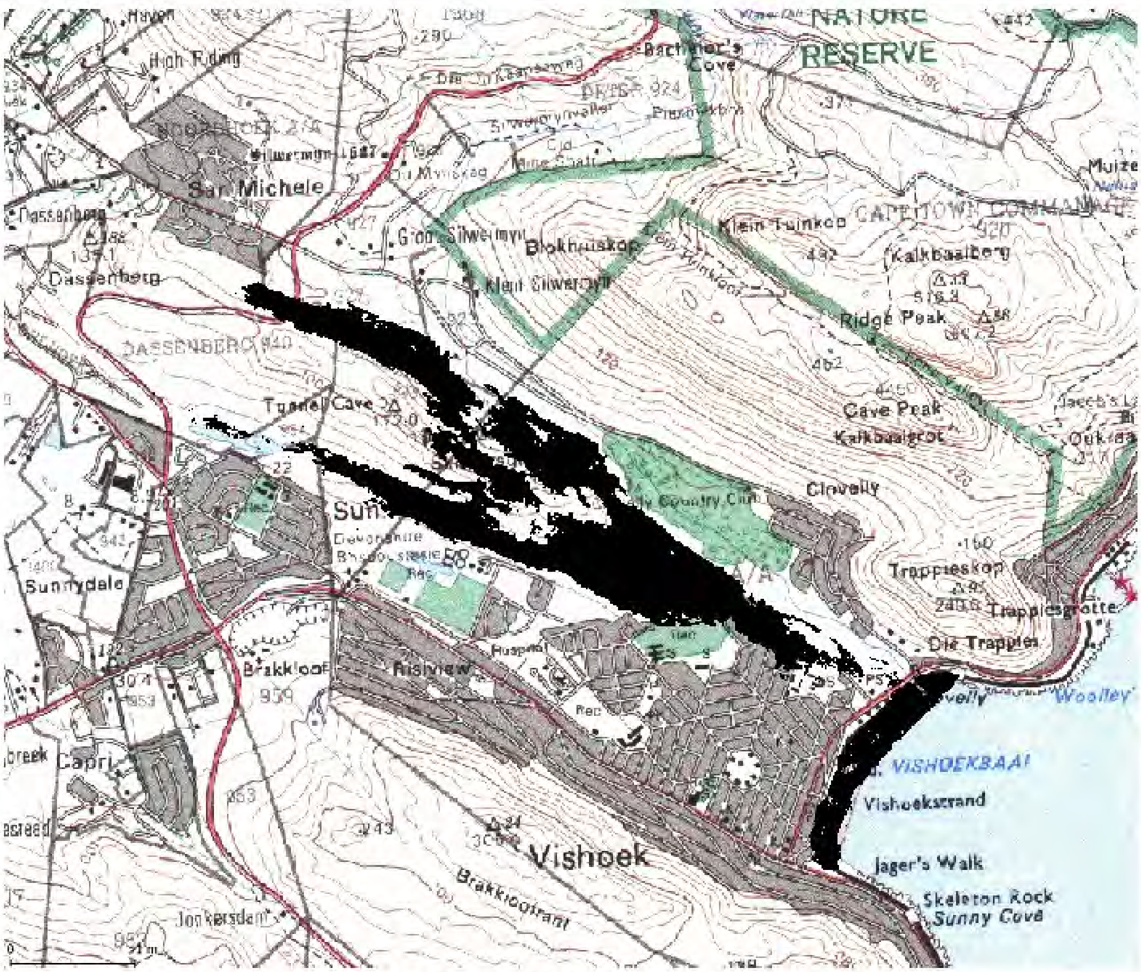
Fish Hoek 1947



FISH HOEK 1945 BARE SAND

Figure 5.6: Spatial extent of bare sand for 1945 and ground-based photograph from 1947

FISH HOEK:
1954 & 1958

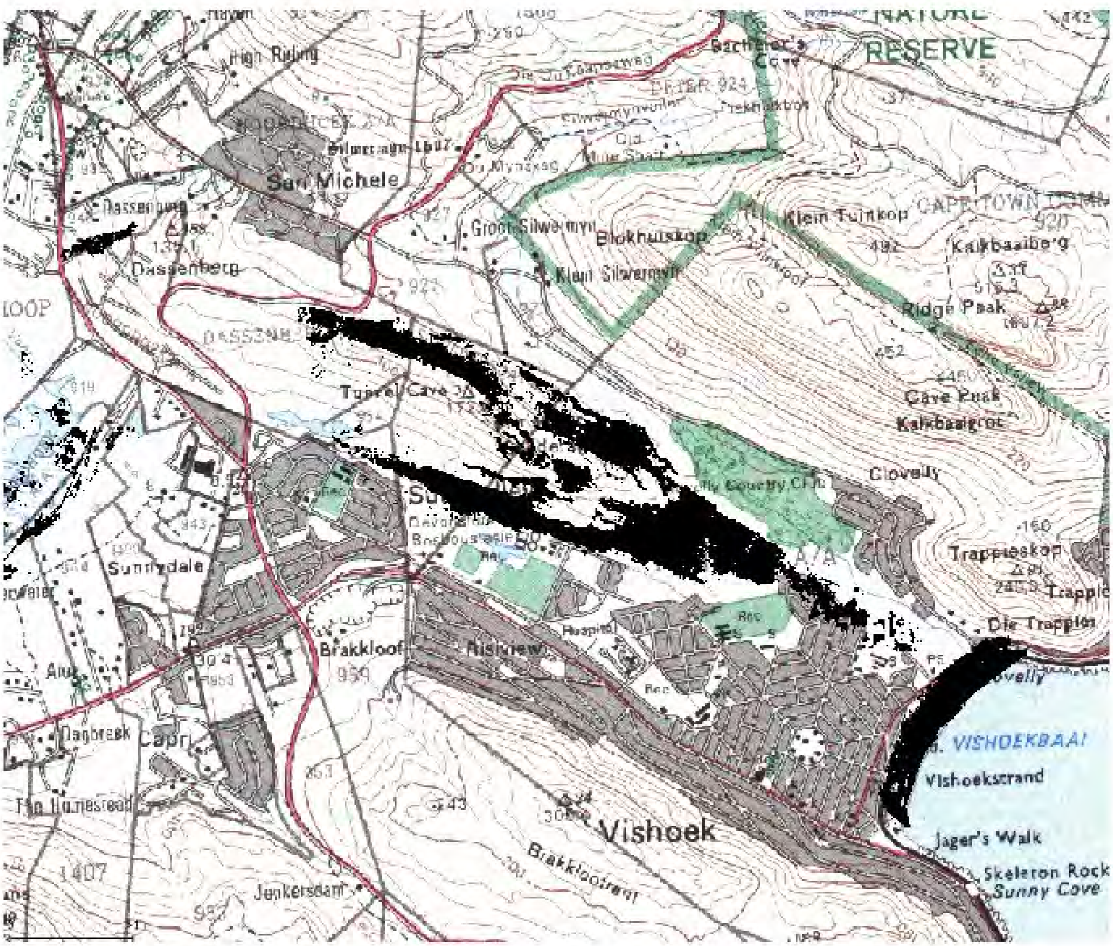


FISH HOEK BARE SAND 1958

Figure 5.7: Spatial extent of bare sand for 1958 and ground-based photograph from 1955

FISH HOEK: 1968

FISH HOEK 1968

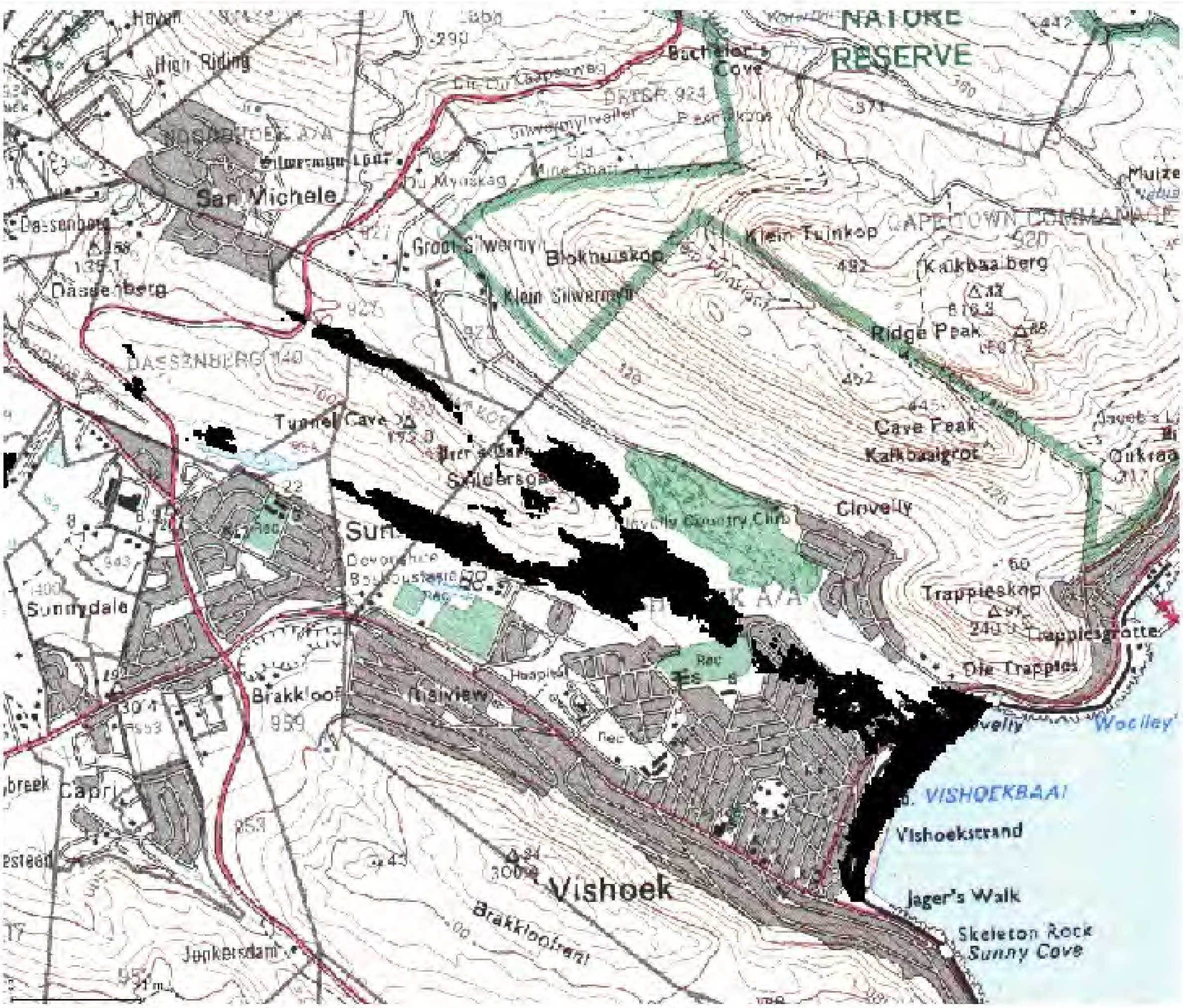


FISH HOEK BARE SAND 1968

Figure 5.8: Spatial extent of bare sand for 1968 and ground-based photograph from 1968

FISH HOEK: 1970 & 1977

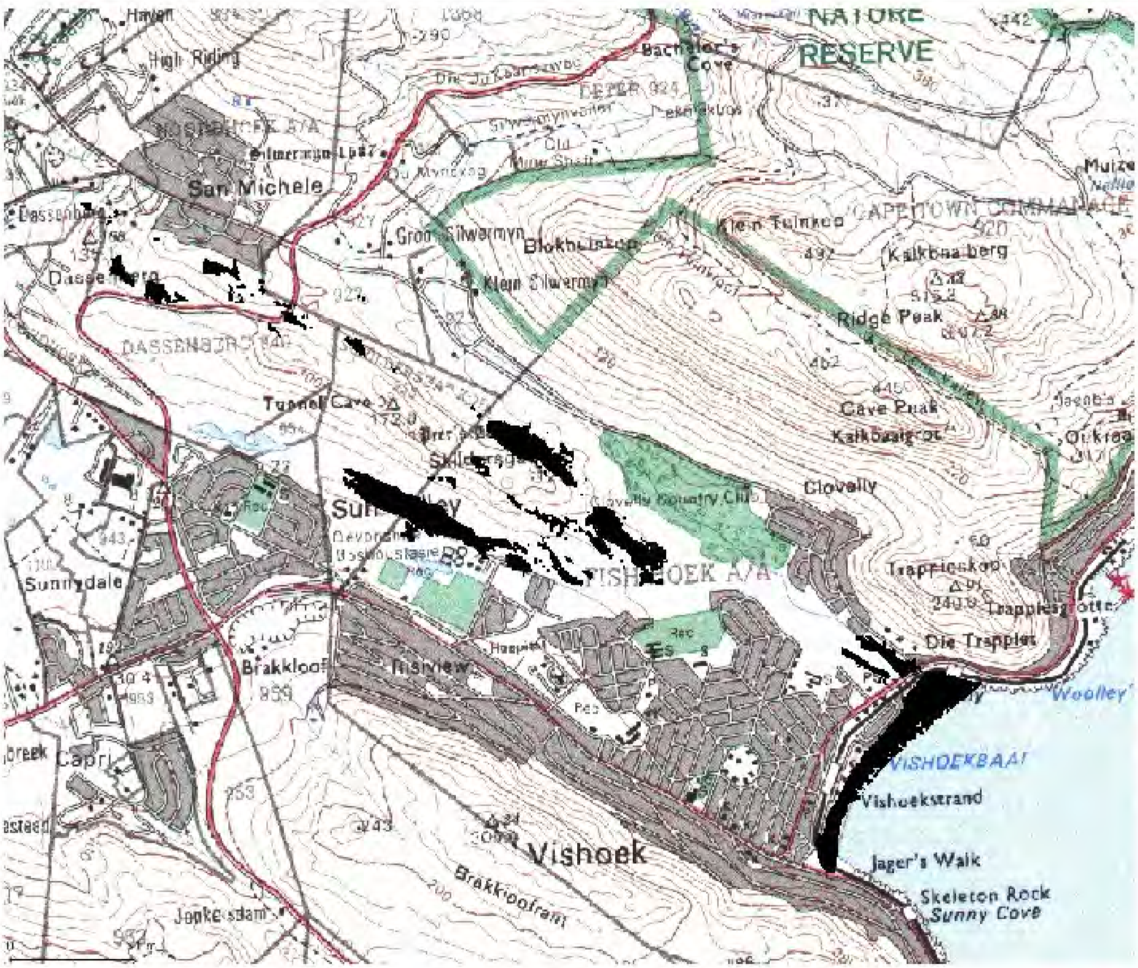
OBLIQUE AERIAL PHOTOGRAPH 1970



FISH HOEK BARE SAND 1977

Figure 5.9: Spatial extent of bare sand for 1977 and ground-based photograph from 1970

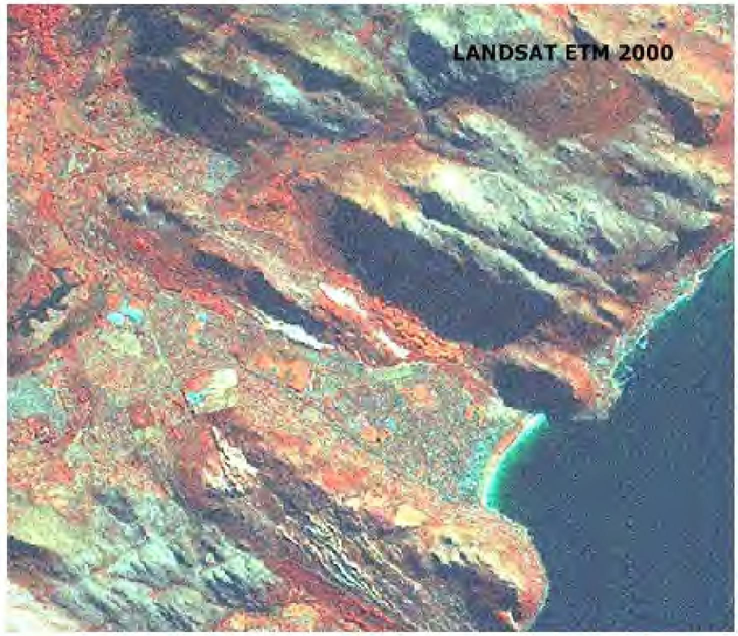
FISH HOEK:
1987 & 1989

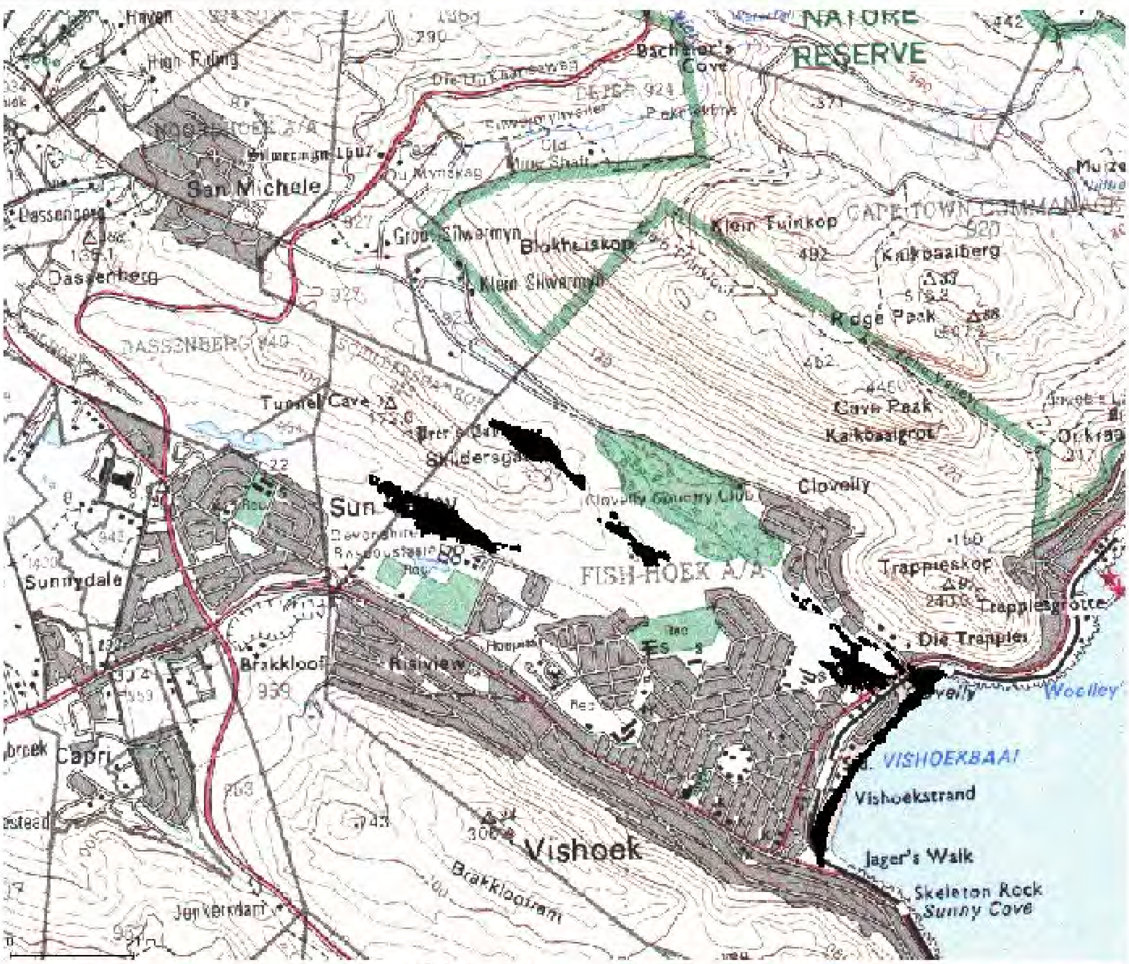


FISH HOEK BARE SAND 1989

<u>Figure 5.10</u>: Spatial extent of bare sand for 1989 and ground-based photograph from 1987

FISH HOEK: 2000





fish hoek bare sand 2000

Figure 5.11: Spatial extent of bare sand for 2000 and the corresponding LANDSAT ETM satellite image for the same year

The dramatic reduction and near complete extinction of the active climbing - falling dune system (represented by bare sand) can been seen from the above figures.

5.3 SUMMARY AND CONCLUSIONS

The results outlined above very clearly show the reduction in the spatial coverage of bare sand on both sides of the corridor for the time period starting in 1945 and ending in 2000.

According to Figure 5.2 (and Appendix E) the spatial extent of bare sand situated across the whole corridor has reduced by 48% from 4.70 km^2 in 1945 to 2.35 km^2 in 2000.

The changes to the Fish Hoek climbing – falling dune system has been even more striking as the spatial coverage of bare sand has reduced by approximately 80% from 2.1 km^2 in 1945 to 0.4 km^2 in 2000.

The possible explanations for these dramatic changes to the dune systems in this corridor will be discussed in the next chapter.

CHAPTER 6: DISCUSSION

Through the examination of the raw aerial photographs, the creation of the spatial overlays of the dune areas from the photographs and the calculation of the spatial extent of the dune areas (represented by bare sand) it became clear that the spatial coverage of bare sand within the corridor has reduced substantially over the time period analysed in this study. This chapter will investigate the specific reasons for the observed changes by outlining the three major factors that have dramatically effected and continue to impact, the dune-beach systems on both ends of the Fish Hoek – Noordhoek Dune Corridor. The nature and effectiveness of the impacts of these factors on dune systems will also be discussed in the context of the literature introduced in Chapter 2.

6.1 CHANGES TO THE NOORDHOEK DUNES

The temporal resolution of the aerial photographic record analysed was not suitable to study the precise changes to the dunes bordering on the beach as they are influenced by events over a shorter time spans such as wave dynamics, changing nature of the tidal lagoons found on the beach and storm events. However a general reduction of bare sand areas is definitely evident from studying the raw aerial photographs in conjunction with the spatial overlays in Figure 5.1. The reduction of bare sand on this side of the corridor has been due to the expansion of Noordhoek and the establishment of new urban areas within the northern regions of this corridor which have been effectively removed areas of vegetated dunes. Table 6.1 (after Akunji, 2004) corroborates the decline in spatial extent of beach/dune areas and the increase in what Akunji terms ‘built up’ areas over the time period 1944 to 2000. The initial development in urban settlement on the Noordhoek side of the corridor in 1958 was, according to Akunji (2004) stimulated by the earlier development of Fish Hoek (discussed in the Section 6.2). Before this the Noordhoek side was predominantly utilised as agricultural land (Akunji, 2004).

The remaining coastal dunes on this side of the corridor have been impacted by the encroachment of alien vegetation. According to Akunji's (2004) research the Noordhoek area lost more than 30% of its natural vegetation within a period of 56 years. The strengthened stabilization process as a result of alien vegetation encroachment has led to the foredunes acting as a sediment trap for sand therefore restricting the progression of the system inland (refer to Figure 3.7)

YEARS	URBAN AREAS	AGRICULTURE	BEACH & DUNES	ALIEN VEGETATION	FYNBOS VEGETATION	WATERBODIES
1944	0	11	17	20	49	3
1958	1	16	10	26	45	2
1989	9	11	9	28	41	2
1996	14	15	5	26	37	3
2000	24	14	8	18	32	4

Table 6.1 Relative percentages in land use change for 1944 to 2000 (Akunji, 2004, Table 5.21: 92)

6.2 CHANGES TO FISH HOEK'S CLIMBING – FALLING DUNE SYSTEM

The major changes to this system are in part the result of human interference and the development and expansion of Fish Hoek town and the associated development of its infrastructural capacities.

One of the most singularly important factors which has led to dramatic changes to the nature and extent of the dune system has been the establishment of a railway line and station that runs parallel to the main road and the beach and connects Simon's Town in the south to Kommetjie in the north. At the time of its initial construction, the railway engineers and planners did not investigate the impact of the railway system on the dunes in the immediate vicinity or consider the dunes a threat to the effective operation of the railway. Therefore during construction and almost immediately after completion of the railway line and station, the battle between nature in the form of swift-moving dune sand and human development began.

The so -called South-Easter wind, the major mechanism behind the mobility of the dune system (refer to Chapter 3), blew sand onto the tracks and into the station situated initially on the Clovelly side of Fish Hoek near the mouth of the Slivermine River (Corbern, 2003). Manual clearing of this sand had to be done on a very regular basis by railway workers.

In the late 1920's it was decided to remove the sand dunes bordering the beach, in order to prevent sand from encroaching on the railway line (Corbern, 2003). Men were hired to remove sand from the dune area and load the sand onto railway trucks. Apart from just physically clearing and removing the sand from the dune site, Maram grass (*Ammophil arenaria*) was planted along the beach to artificially stabilise the shifting sands (Tredgold, 1985). This resulted in an artificial foredune forming at the edge of the beach. This was not the desired outcome that the railway officials anticipated and they subsequently resolved to remove the entire dune area bordering on the beach. All the sand was removed and dumped in the then open area between the Salt River Station and the junction between the Liesbeek and Salt Rivers (Tredgold, 1985).

The process of removing the sand dunes bordering on the beach and the planting of vegetation to stabilize the remaining dune areas influenced the foredune profile sequence mentioned in Chapter 2 causing a shift in the dynamics of the system which have ultimately led to the rapid reduction in spatial extent of the active regions of this system.

The following three sections outlines the three overarching factors that has led to the observed changes in the dune areas within the Fish Hoek – Noordhoek Dune Corridor in relation to pertinent case studies within the Cape Peninsula as well as further a field.

6.3 ALIEN VEGETATION ENCROACHMENT

The entire corridor, as well as a large part of the Cape Peninsula, has been to some degree invaded by alien vegetation, predominantly Australian *Acacia* species such as the Port Jackson (*Acacia saligna*) and Rooikrans (*Acacia cyclops*). The encroachment of this type of alien vegetation has led to the spatial reduction of the active dune areas (clearly illustrated in the assemblage of figures presented in Chapter 5). Alien vegetation growth is most probably also responsible for the nonlinear nature of the observed spatial changes in the reduction of bare sand due to the fact that threshold densities of alien plant stands could have been reached which would lead to an rapidly increased reduction of bare sand. For example the extreme drop in spatial coverage of bare sand from 1989 to 2000 on the Fish Hoek side (refer to Figures 5.4 and 5.5) and the sudden drop observed from 1977 to 1989 for the whole corridor (refer to Figures 5.2 and 5.3).

A more localised example of alien plant invasion is the remains of the foredunes on Fish Hoek beach having been artificially stabilized by *Ammophila arenaria* (Marram grass). However as discussed in Chapter 2, Marram grass does not represent an aggressive invasive species so the impacts of the introduction of this species is not as severe as the *Acacia* species (Lubke, 2004).

Alien invasive vegetation, as discussed in Chapter 2, have the ability to grow rapidly, have low demands on their habitats and are able to cope with strong winds and seawater spray close to the coast. Over the study period these plants have expanded their range and now cover broad areas, and in the process they have managed to stabilize large parts of the bare sand dune areas and have ultimately modified the landscape by altering both the geomorphic and biological functions of these systems. Alien vegetation encroachment also directly threatens the growth of the endemic flora and fauna species that are specifically adapted to the habitat of exposed, moving sands.

As outlined in Chapter 2, alien vegetation growth is the major causative factor in the process of stabilization of coastal dunes not only in southern Africa (for example: Helstrom, 1996) but also in many other part of the world where coastal dunes predominate (Nordstrom and Lotstein, 1989, Hellmaa, 2000 and Kutiel *et al*, 2005,).

The Holmes and Luger (1996) study on the Hout Bay headland bypass dune system (described in Chapter 2) is testament to the effectiveness of alien vegetation encroachment in stabilizing coastal dunes within the Cape Peninsula. This study concluded that alien vegetation encroachment was the cause of the impaired sediment exchange between the two beaches on either ends of the system in 1958. At this time there was limited residential growth so the changes in sediment supply could be linked directly to the encroachment of predominantly *Acacia* spp. alien vegetation. By 1968 alien vegetation growth had almost entirely cut off the sediment linkage between the two beaches, by 1977 complete separation between the two beaches had been achieved due to increased residential growth coupled with further alien vegetation encroachment.

This above description of the sequence of increased stabilisation through the encroachment of alien vegetation for the Hout Bay – Sandy Bay dune corridor mirrors the stabilization process that has occurred in the Fish Hoek – Noordhoek corridor. This process therefore has not occurred in isolation and has far reaching effects for the sediment budget for the whole Peninsula as impaired sand movement through these corridors effects sand supply further up the Peninsula. Thus alien vegetation encroachment resulting in stabilization of mobile dune systems not only results in a loss of indigenous vegetation and less mobility of the system but can also have a detrimental effect to the entire coastline.

6.4 URBAN GROWTH

The earlier expansion of Fish Hoek, the later development of Noordhoek and the creation of newly developed estates and villages on the Noordhoek side have destroyed some of the dune areas and have led to a greater amount and increased rate of stabilization of the remaining dune areas within this corridor.

The establishment of the railway line and station running through Fish Hoek brought about the initial phase of artificial stabilization of the climbing – falling dune system. This was accompanied by the general residential growth of Fish Hoek which led to the replacement of dune areas with urban regions. The increases in urban growth within the corridor have not only exacerbated the process of stabilization but also had impacts on the wind dynamics which is the major driving factor behind the mobility and activity of these dune systems resulting in a modification to the natural sediment transport regime attached to these systems.

Urban growth has had similar impacts on many other dune systems along the southern African coast (for example: Holmes and Luger, 1996, La Cock and Burkinshaw, 1996) and in various other parts of the world (Nordstrom and Lotstein, 1989, Hellamaa, 2000 and Kutiel *et al*, 2004).

For example, the poorly planned expansion of urban areas in Cape St Francis, as briefly discussed in Chapter 2, has led to the disruption in the natural functioning of the headland bypass dune system in this area (La Cock and Burkinshaw, 1996).

Future increased population growth within the corridor will exacerbate the already clearly degraded natural functioning of the dune systems as well as various other sensitive natural systems found within the corridor such as the wetlands and vleis.

6.5 OTHER ANTHROPOGENIC IMPACTS

The physical removal of the majority of the foredunes on Fish Hoek beach has severely impacted the system. Further human disturbance to the dunes on both sides of the corridor include the number and use of footpaths, increased access to the beach and dune areas and increased building and construction especially on the Noordhoek side.

The remaining bare sand dune areas on the flanks of Skildersgatkop are within the Cape Peninsula Nature Reserve and access to these areas is monitored and restrictions and prohibitions are in place for the protection of these remaining patches of dunes.

The effects of increased recreational use of coastal dunes in Israel's Sharon Park were investigated by Kutiel et al. (1999). This study provides details on the specific impacts that human disturbance of dune areas though increased footpaths and access routes can have on the systems as a whole. The vegetation cover, height and species richness and diversity, as well as soil organic matter content was analysed and the study showed how recreational use changed the attributes of the soil and vegetation not just locally where pedestrian paths/ walking trails had cut into the dunes but several metres beyond the boundaries of these trails (Kurtiel et al., 1999).

6.6 SUMMARY AND CONCLUSIONS

The reduction in the spatial extent of the bare sand representing coastal dune areas on both sides of the corridor, clearly illustrated in Chapter 5, can be directly attributed to the impact of increased and sustained alien vegetation encroachment and urban growth coupled with additional anthropogenic disturbances. The effectiveness of alien vegetation encroachment specifically *Acacia* spp within the Cape Peninsula in stabilising coastal dune systems is attested to by Holmes and Luger (1996) and the timing of the stabilisation process in their study area, Hout Bay, is comparable to the timing of the reduction in the Noordhoek – Fish Hoek Corridor. Abunji (2004)'s study of the land use/ environmental change to the Noordhoek valley also confirms the validity of the results presented in this project.

In conclusion, the combined and dynamically-interacting effects of the three factors discussed within this chapter have led to a reduction in bare sand dune areas and an increase in the stabilization of these systems within the study period. The historical development of the introduction and increased rate of these three factors has ultimately led to the severing of the sediment/sand linkage between Noordhoek and Fish Hoek beaches (Heinecken, 1985) and has therefore altered and continues to change the sediment dynamics and natural functioning of the entire corridor.

CHAPTER 7: CONCLUSIONS

7.1 INTRODUCTION

This final chapter initially provides a review of the aims and objectives (presented in Chapter 1) and considers the extent to which these aims and objectives have been fulfilled by the completion of this project. It outlines the major difficulties encountered when carrying out the specific objectives and discusses the degree to which these methodological limitations impact on the reliability of the findings presented in this study.

7.2 REVIEW OF AIM AND OBJECTIVES

The central aim of the project was to establish the nature, extent and timing of the changes to the coastal dune systems within the Fish Hoek – Noordhoek Corridor. The results presented in Chapter 5 clearly provide the answers to the extent and timing of the changes to the dune systems. The exact nature and reasons for the change is comprehensively discussed in Chapter 6. The reduction in the spatial coverage of bare sand representing mobile dune areas has been a very significant and obvious process within this corridor with the rate of reduction increasing dramatically after 1977. The combined effect of alien plant encroachment and growth of the urban centres within this corridor, particularly Fish Hoek and Noordhoek themselves, have severely impacted on the dune systems and significantly increased the rate of stabilisation of this systems, this has ultimately led a change in the functioning of these systems and has effected the sediment dynamics of the entire area.

To achieve the goals of this project, specific objectives were designed and are outlined in Chapter 1. There objectives are individually presented and discussed below to access the achievement of the study.

- *Review the literature on coastal dune systems found both within southern Africa as well as in other parts of the world:*

  Chapter 2 represents the review element of the research done, it emphasises the great importance of coastal dune systems and the importance of conserving and preserving them in their natural geomorphic states. It also outlines the research done both within southern Africa and around the world that provides insightful details pertaining to the study of coastal dunes in general that then can act as an essential base for the research done to carry out the study.

- *Obtain sequential aerial photographs of the study area for as long a time as possible from Department of Land Affairs Chief Directorate: Surveys and Mapping (CD:SM):*

  The aerial photographs were obtained and digital copies of these photographs represented the primary resource used in this study. The details of the aerial photographs are presented in Appendix A. The photogrammetric inconsistencies found within the aerial photographs are the major sources of error identified within the study and the results need to be carefully assessed taking this element into account. Another fault of the aerial photographic record obtained was the low temporal resolution. These aspects affected the results as the dunes and beach area on the Noordhoek side of the corridor was poorly presented in the photographs making it difficult to track the changes to the dunes on this side.

- *Describe the environmental characteristics of the study area including geomorphology, climate and vegetation, in order to understand the context from which this study will be investigated and also to identify and describe the geomorphic systems encompassed within the study area.*

  Chapter 3 comprehensively explored the environmental characteristics of the corridor and identified the important factors relating to the formation and continued existence of the dune systems within this area. The current land use of the corridor was also explored and described. The dune systems found at the two opposing coasts were successfully identified and described within Chapter 3.

- *Input aerial photographs into a GIS programme, identify appropriate land uses and produce map overlays so that the land use changes can be clearly identified over the chosen time period*.
  The GIS work was done in Manifold 6.5 and the successes and difficulties experience are presented in detail with the methods chapter. The resultant overlays, despite the errors, unmistakably illustrated the reduction in the extent of bare sand within the corridor. Although the methodological approach used was at times unconventional (refer to Chapter 4), the outcome was accurate and the only major source of potential error was the quality of the digital aerial photographs themselves. Therefore the methodological approach used was successful and this objective was thus fulfilled.

- *Derive quantitative information on the changes in spatial extent of the dune systems in the form of actual area estimates for each year under investigation.*
  The method of obtaining these area estimates was perhaps convoluted (refer to Chapter 4) but the resultant figures were sufficient to quantify the changes observed in the spatial overlays. Therefore this objective was achieved.

- *Describe the changes identified from the sequential aerial photographic analysis and explore possible reasons for the observed changes.*
  This objective was met in Chapter 6, within which the changes to the dune systems was comprehensively described and the reasons for the changes were discussed at length. The three major factors effecting the dune systems, alien vegetation encroachment, urban growth and other

anthropogenic activities were identified and considered in relation to other studies within the Cape Peninsula, more specifically the Holmes and Luger (1996) study on the Hout Bay dune system and the Akunji (2004) environmental change study on the Noordhoek valley, as well as various studies beyond the Peninsula along the southern African coastline and in other part s of the world.

The description of the past changes to these coastal dune systems is important so that their current degraded state is not thought of as their original natural, pre-impacted state. Thus the establishment of a description of these systems dynamic nature and past character can be used as an accurate baseline which management could use to attempt to restore to some degree these sensitive and extremely valuable natural systems.

7.3 CONCLUSION

Coastal dune systems represent enormously valuable natural geomorphic assets on global, regional and local scales. But unfortunately due to the often deceptively simple appearance of these systems as “just bare sand” their great importance in terms of their geomorphic dimensions, environmental heterogeneity and high species variability are often disregarded in favour of urban expansion and development.

Future development in coastal areas should take place with due cognizance of the importance of these systems and the role they play in maintaining sediment dynamics. With increasing demand for recreational usage of these coastal areas, management needs to prevent poorly planned development and become aware of the fact that coastal dune areas need to be managed as a whole.

This study indicates that the coastal dune systems found within the Fish Hoek – Noordhoek Corridor has been severely altered by the encroachment of alien vegetation and the expansion and development of the urban areas within the corridor. This study provides dramatic evidence of this fact and consequently this project alerts one to the fact that the remaining dune ecosystem pockets found in the Cape Peninsula could possibly in the future be permanently and irreversibly consumed into the ever-expanding built environment without due attention being paid to the importance of the preservation and conservation of their natural geomorphic states.

In conclusion, this study through the primary use of aerial photographic analysis managed to describe and quantify the changes to the dune systems in the Fish Hoek – Noordhoek Corridor, and it demonstrated that human impact (especially through the combined impact of alien encroachment and urban growth) on the dune systems is remarkably rapid and significantly alters the natural functioning of the entire corridor.

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APPENDIX A: AERIAL PHOTOGRAPH DETAILS

YEAR	JOB NO: STRIP NO: PHOTO NO(S)	SCALE
1945	203B: 013: 2882, 84, 86, 88, 90, 92, 94, & 96 203B: 014: 2859, 61, 63, 65, 67, 69, 71, 73, 75, 77 & 79 203B: 015 2945 & 47	1 : 6000
1958	424: 002: 7033 424: 004: 7010	1 : 30000
1968	620: 014: 588, 90 & 92 620: 015: 502 & 04	1 : 20 000
1977	786: 021: 1473	1 : 50 000
1989	919: 020: 9468 Season: Winter (May)	1 : 50 000
2000	1033: 024: 7668 Season: Summer (November)	1 : 50 000

APPENDIX B: SRTM SURFACE PROPERTIES

SRTM: Shuttle Radar Topography Mission

Format: seamless raster elevation model created from the SRTM DTED®

Location: southern Africa (Area 9)

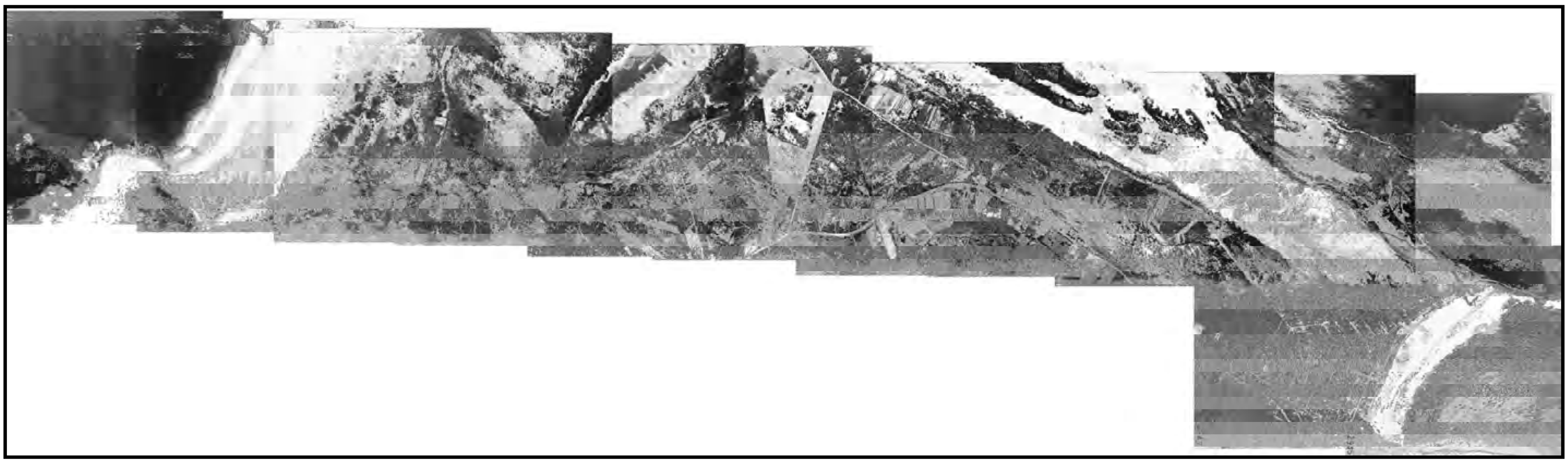
“Finished” SRTM product information:

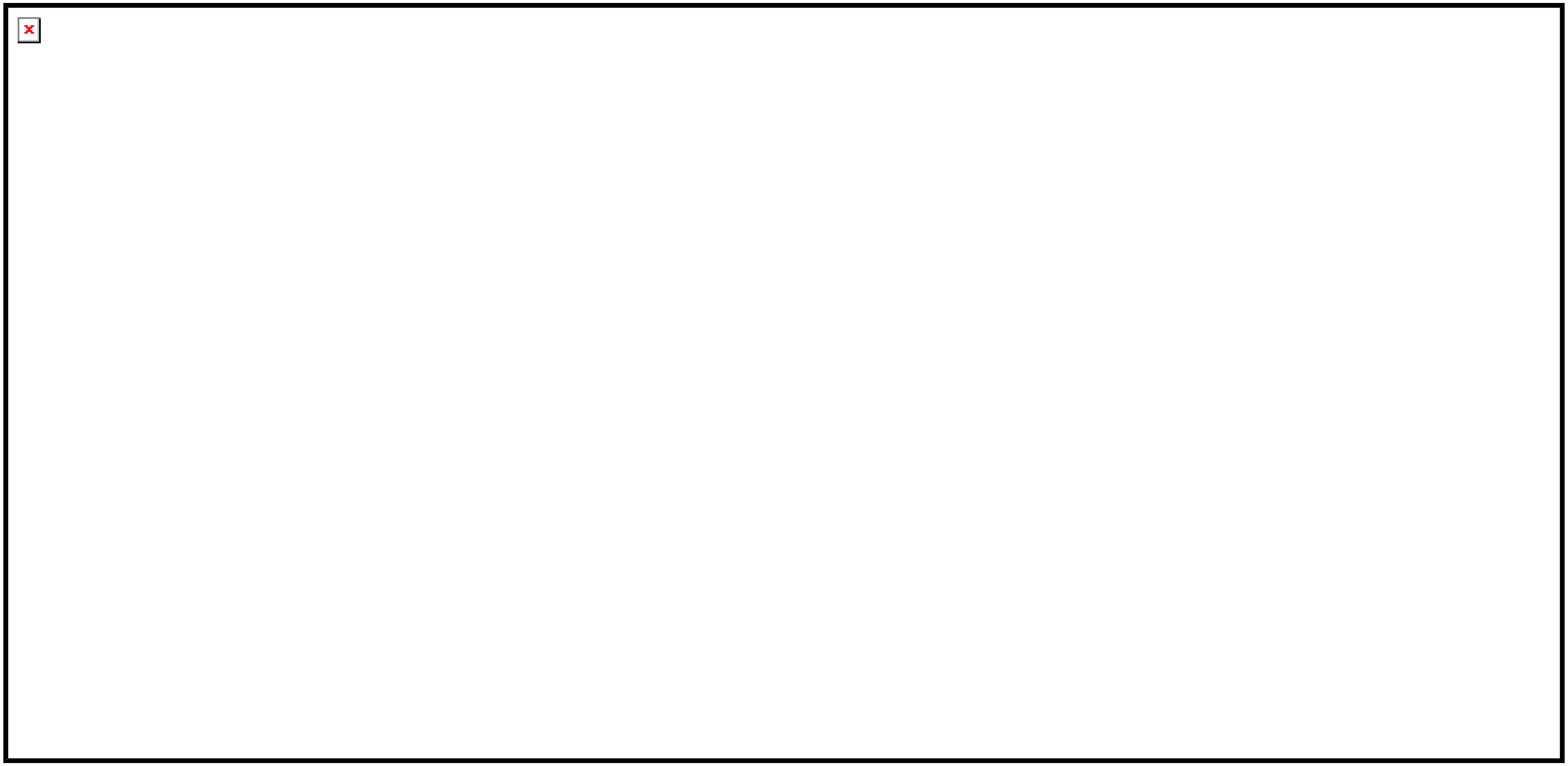
Resolution:	3 arc second (approx 90m)
Projection:	Geographic
Horizontal Datum:	WGS84
Vertical Datum:	WGS84/EGM96 geoid
Vertical Units:	metres

Originally obtained from USGS: United State Geological Survey’s EROS Data Centre (Environmental Resources Observation and Science)

APPENDIX C: GEOREFERENCED AERIAL PHOTOGRAPHS AND MOSAICS

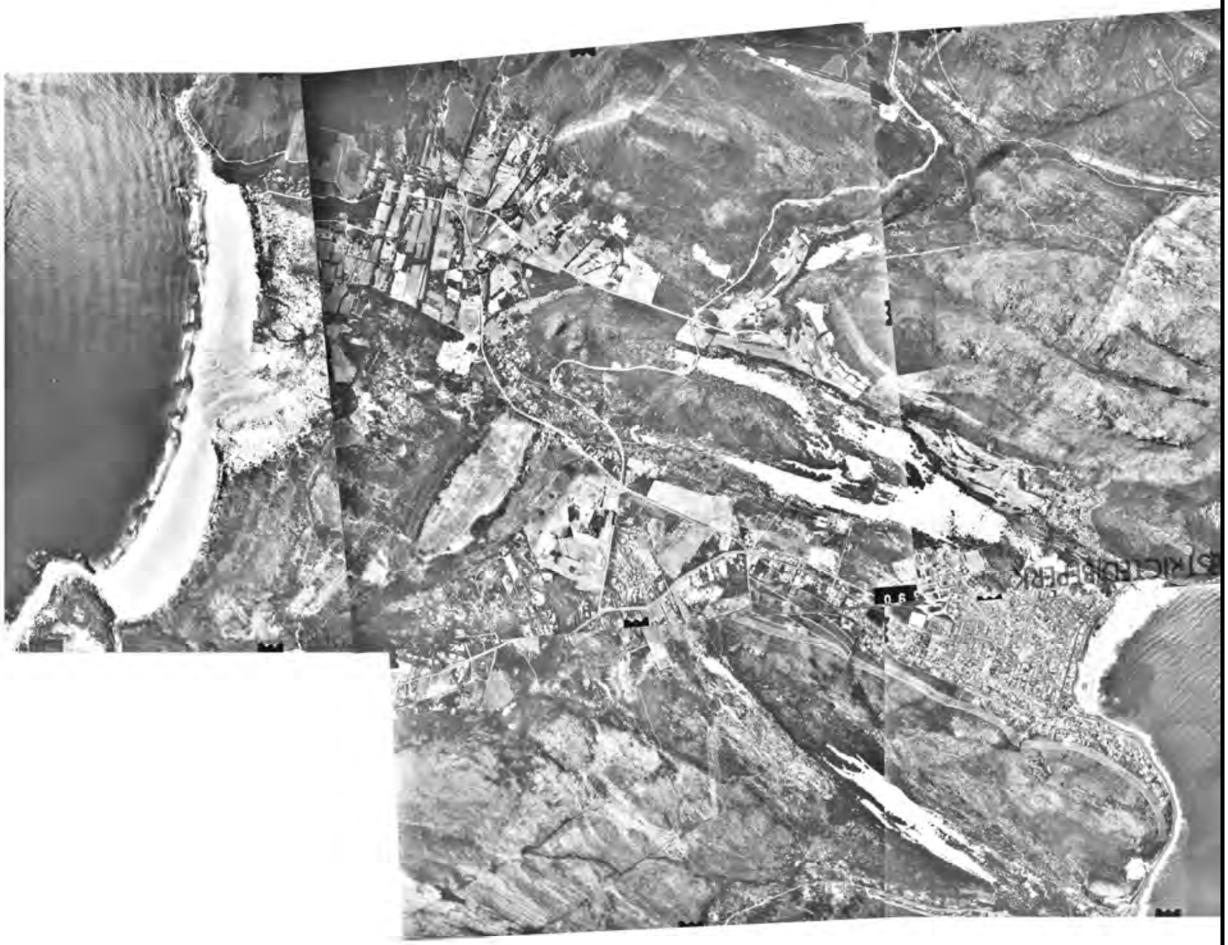
1945 north (above) and 1945 south (below)



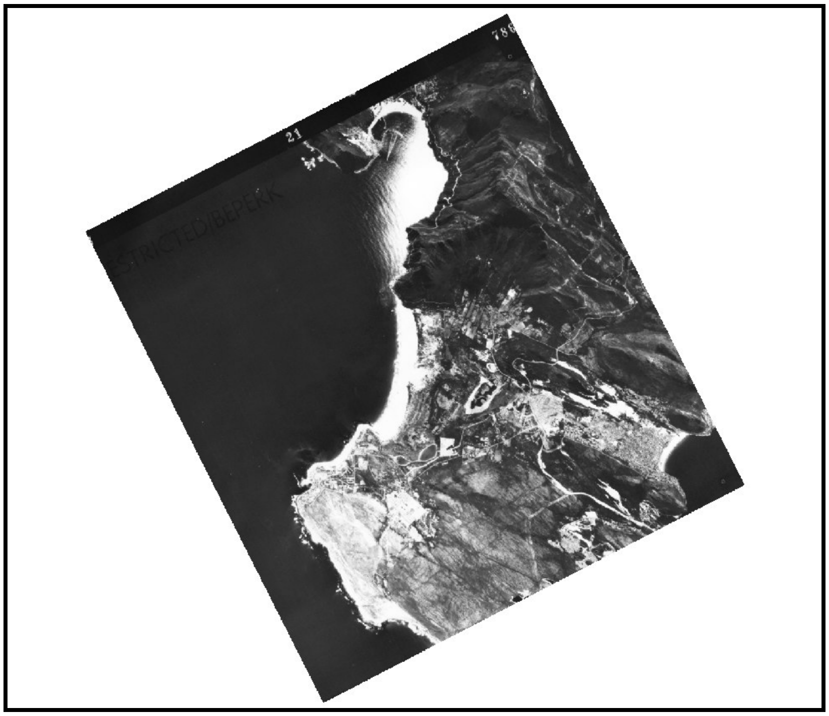


Georeferenced 1945 Mosaics – showing the discontinuity between the two sides

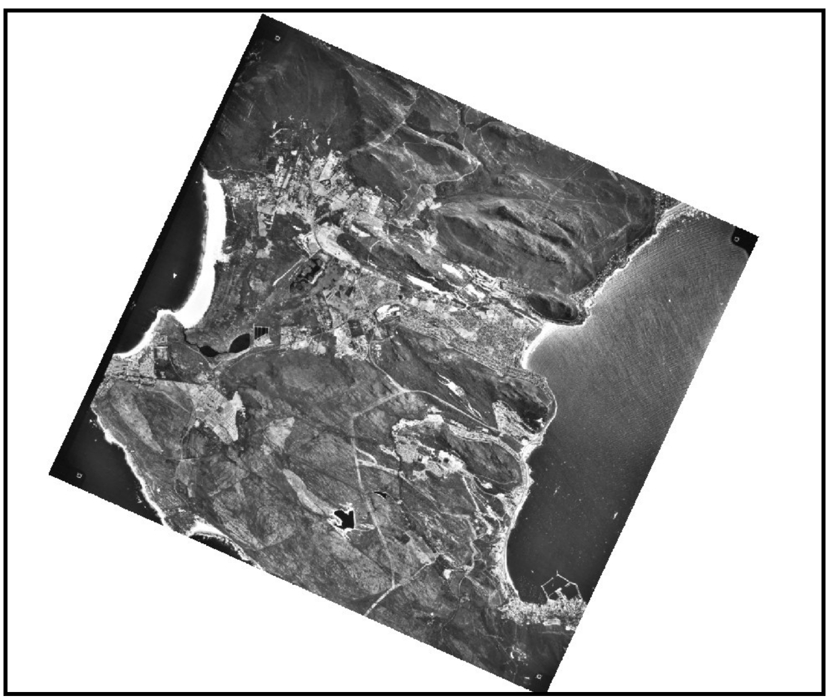
1958 Georeferenced Aerial Photographs



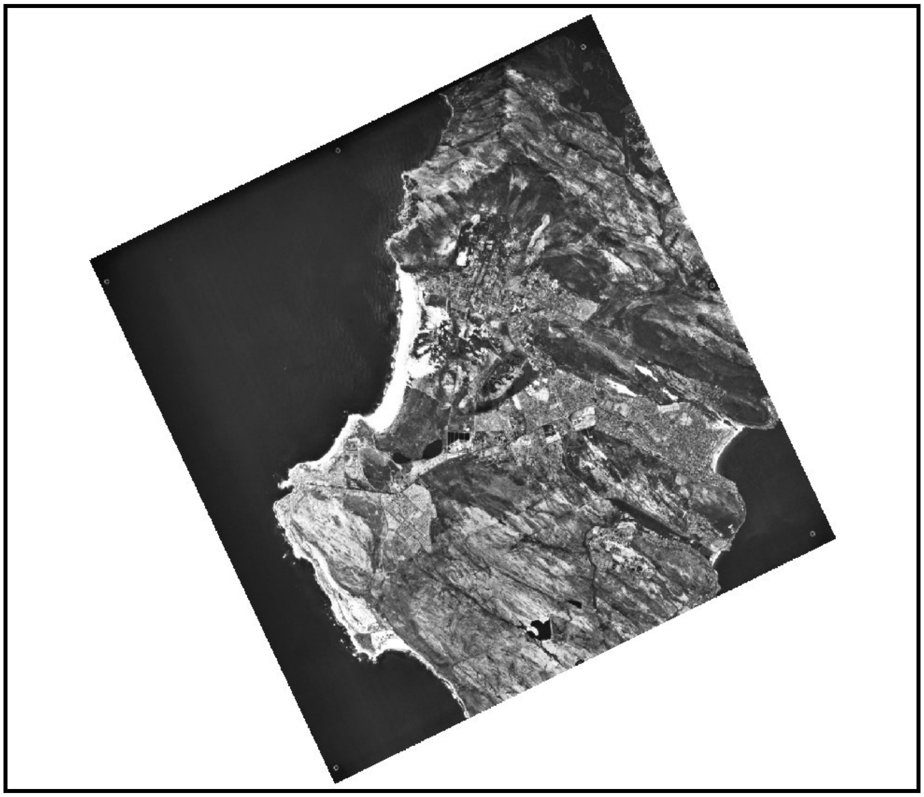
1968 Georeferenced Mosaics



Georeferenced 1977 Aerial Photograph

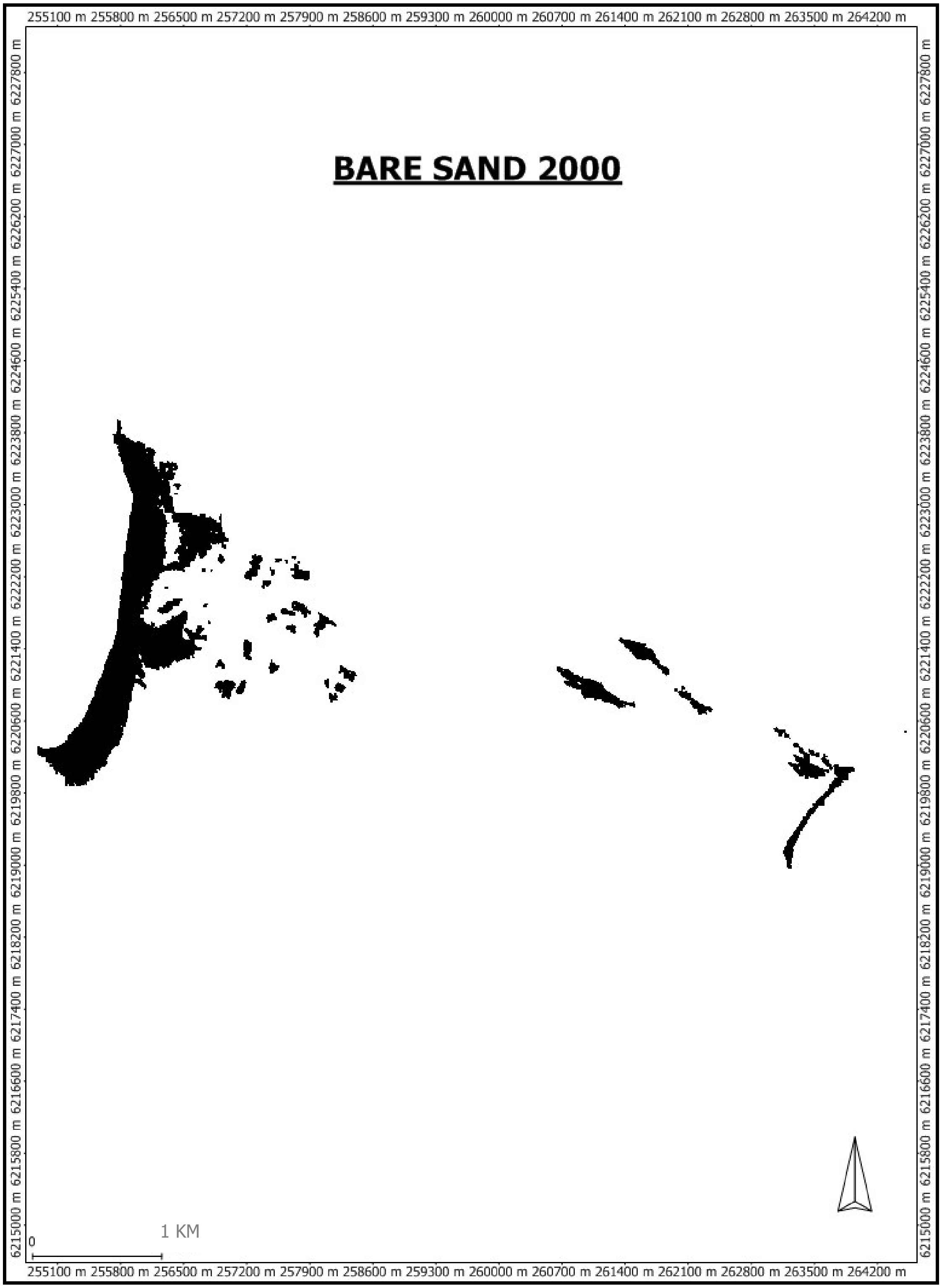


Georeferenced 1989 Aerial Photograph



Georeferenced 2000 Aerial Photograph

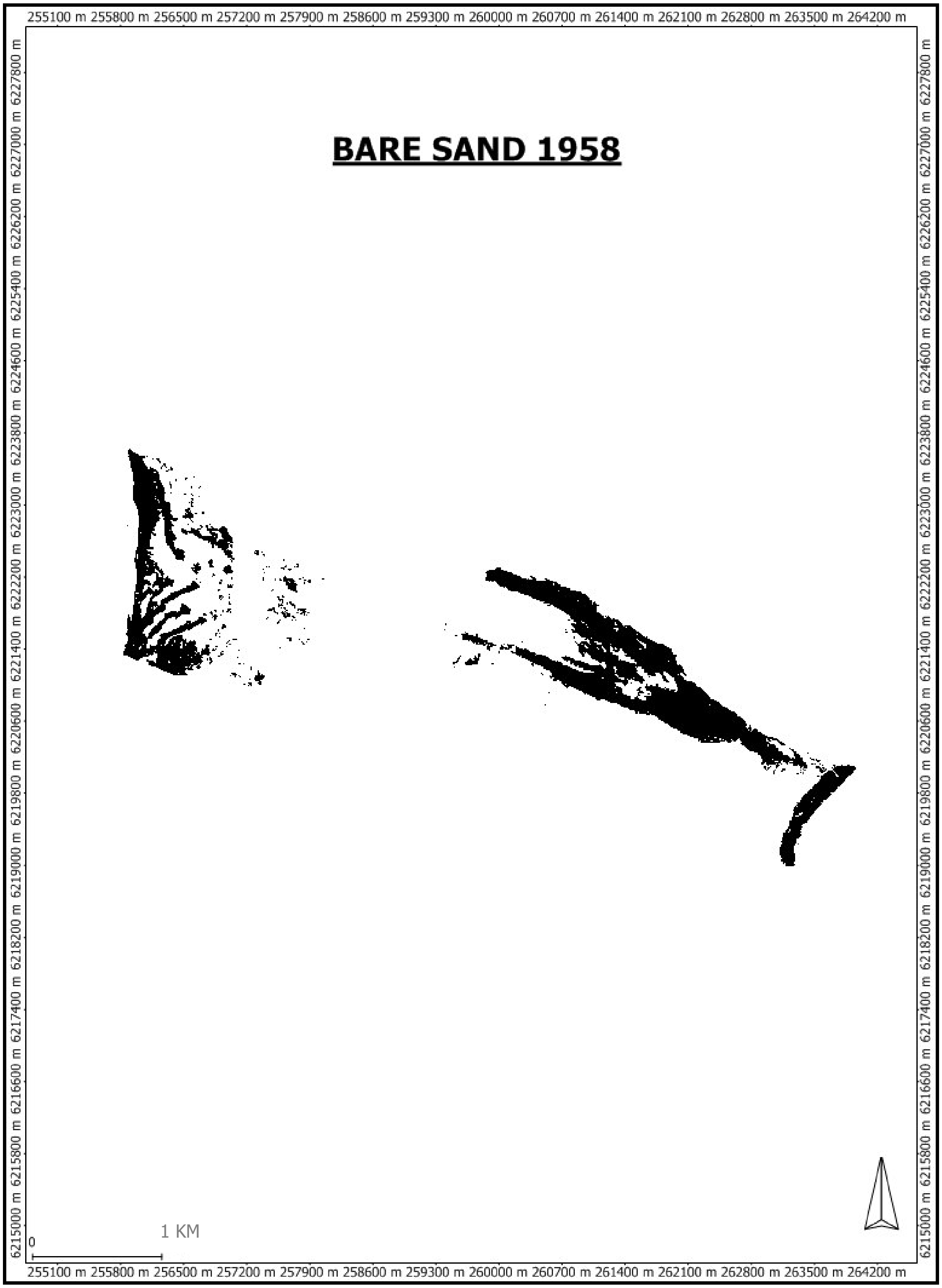
APPENDIX D: SPATIAL OVERLAYS

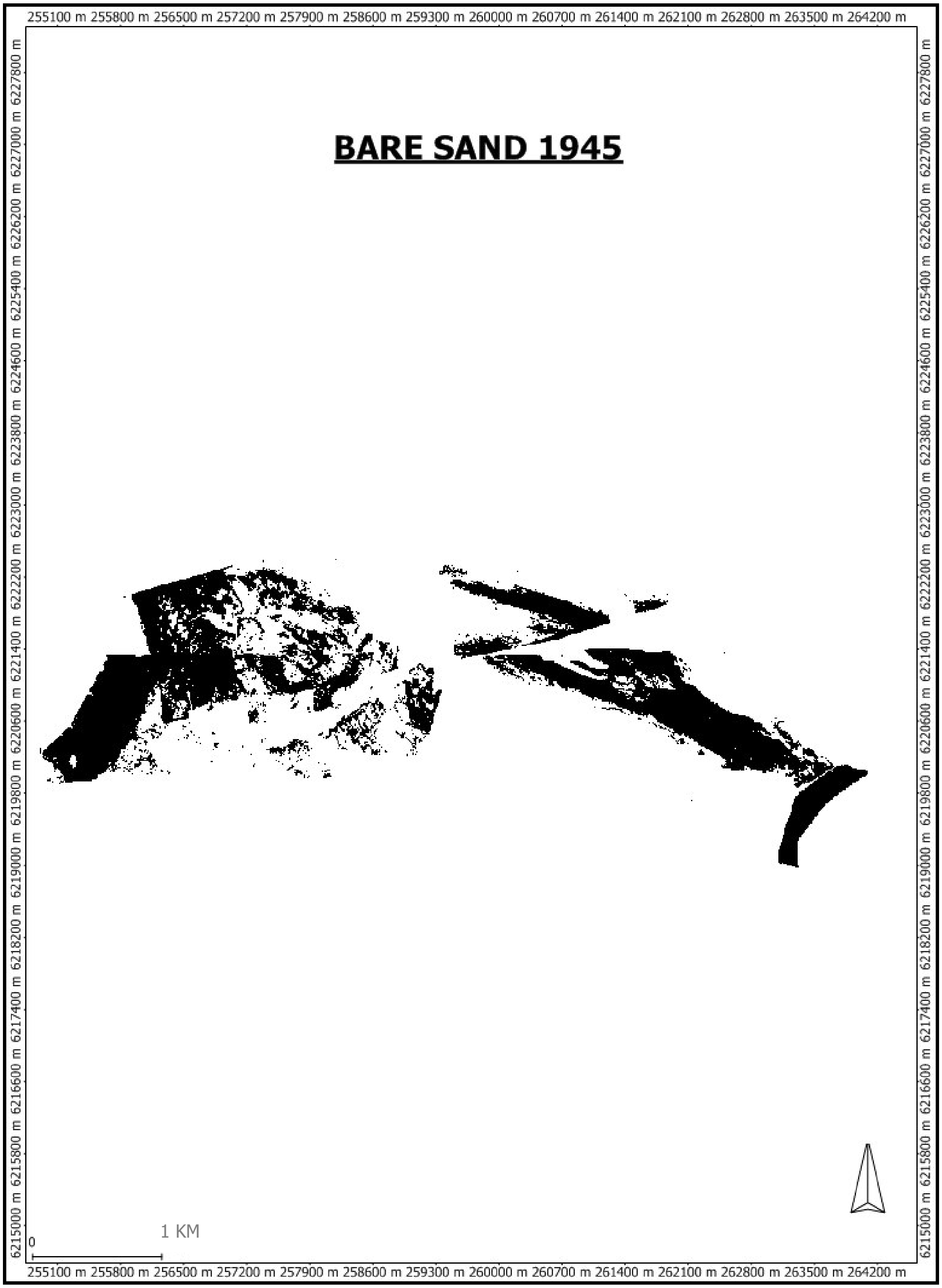



BARE SAND 1989
255200 m 255900 m 256600 m 257300 m 258000 m 258700 m 259400 m 260100 m 260800 m 261500 m 262200 m 262900 m 263600 m
6215400 m 6216200 m 6217000 m 6217800 m 6218600 m 6219400 m 6220200 m 6221000 m 6221800 m 6222600 m 6223400 m 6224200 m 6225000 m 6225800 m 6226600 m 6227400 m
0
1 KM


BARE SAND 1977
255200 m 255900 m 256600 m 257300 m 258000 m 258700 m 259400 m 260100 m 260800 m 261500 m 262200 m 262900 m 263600 m
6215600 m 6216300 m 6217000 m 6217700 m 6218400 m 6219100 m 6219800 m 6220500 m 6221200 m 6221900 m 6222600 m 6223300 m 6224000 m 6224700 m 6225400 m 6226100 m 6226800 m
0
1 KM


BARE SAND 1968
255300 m 256000 m 256700 m 257400 m 258100 m 258800 m 259500 m 260200 m 260900 m 261600 m 262300 m 263000 m 263700 m
6227400 m 6226600 m 6225800 m 6225000 m 6224200 m 6223400 m 6222600 m 6221800 m 6221000 m 6220200 m 6219400 m 6218600 m 6217800 m 6217000 m 6216200 m 6215400 m
0
1 KM


BARE SAND 1958
255100 m 255800 m 256500 m 257200 m 257900 m 258600 m 259300 m 260000 m 260700 m 261400 m 262100 m 262800 m 263500 m 264200 m
6215000 m 6215800 m 6216600 m 6217400 m 6218200 m 6219000 m 6219800 m 6220600 m 6221400 m 6222200 m 6223000 m 6223800 m 6224600 m 6225400 m 6226200 m 6227000 m 6227800 m
0
1 KM


255100 m 255800 m 256500 m 257200 m 257900 m 258600 m 259300 m 260000 m 260700 m 261400 m 262100 m 262800 m 263500 m 264200 m
6215000 m 6215800 m 6216600 m 6217400 m 6218200 m 6219000 m 6219800 m 6220600 m 6221400 m 6222200 m 6223000 m 6223800 m 6224600 m 6225400 m 6226200 m 6227000 m 6227800 m
BARE SAND 1945
0
1 KM

APPENDIX E: AREA CALCULATION TABLES

Area estimate tables used to calculate the spatial extent of bare sand found in the whole corridor:

YEAR	X PIXEL SIZE (m)	Y PIXEL SIZE (m)	SINGLE PIXEL AREA (m^2)	NO. PIXELS	AREA (m^2)	AREA (km^2)
1945a	0.676	0.676	0.456976	3578928	1635484.202	1.635484202
1945b	0.713	0.713	0.508369	6214694	3159357.774	3.159357774
1958a	3.433	3.433	11.785489	143118	1686715.615	1.686715615
1958b	3.686	3.686	13.586596	247777	3366445.997	3.366445997
1968	1.833	1.833	3.359889	1260975	4236736.032	4.236736032
1977	7.615	7.615	57.988225	76627	4443463.717	4.443463717
1989	6.351	6.351	40.335201	72794	2936160.622	2.936160622
2000	6.764	6.764	45.751696	51283	2346284.226	2.346284226

Area estimates of the overlapping regions found in 1945 and 1958:

OVERLAPS	AREA (km^2)
1945 overlap	0.091521
1958 overlap	0.372532

The final area estimates and relative percentages for the whole corridor minus the overlapping areas:

YEAR	AREA (km^2)	RELATIVE PERCENTAGES (%)
1945	4.70	100
1958	4.68	99.52
1968	4.24	90.08
1977	4.44	94.48
1989	2.94	62.43
2000	2.35	52.80

Area estimate tables used to calculate the spatial extent of bare sand found on the Fish Hoek side only:

YEAR	X PIXEL SIZE (m)	Y PIXEL SIZE (m)	SINGLE PIXEL AREA (m^2)	NO. PIXELS	AREA (m^2)	AREA (km^2)
1945a	0.676	0.676	0.456976	3539915	1617656.197	1.617656197
1945b	0.713	0.713	0.508369	973557	494926.1985	0.494926199
1958a	3.433	3.433	11.785489	46521	548272.7338	0.548272734
1958b	3.686	3.686	13.586596	137777	1871920.437	1.871920437
1968	1.833	1.833	3.359889	531123	1784514.325	1.784514325
1977	7.615	7.615	57.988225	25729	1491979.041	1.491979041
1989	6.351	6.351	40.335201	32511	1311337.72	1.31133772
2000	6.764	6.764	45.751696	8930	408562.6453	0.408562645

Final area estimates for the Fish Hoek side only:

YEAR	AREA (km^2)	RELATIVE PERCENTAGES (%)
1945	2.113	100
1958	2.420	114.56
1968	1.785	84.47
1977	1.492	70.62
1989	1.311	62.07
2000	0.409	19.34

Area estimates for the Noordhoek side only:

YEAR	AREA (km^2)
1945	2.59
1958	2.26
1968	2.45
1977	2.95
1989	1.62
2000	1.94

APPENDIX F: ADDITIONAL PHOTOGRAPHS ILLUSTRATING THE STATE OF THE CORRIDOR IN 2006

NOORDHOEK BEACH SIDE

VIEW OF FISH HOEK FROM CLOVELLY GOLF COURSE

VEGETATED SAND DUNES ON SKILDERSGATKOP

ONE OF THE LAST REMAINING PATCHES OF EXPOSED SAND ON SKILDERSGATKOP

BUILDING CONSTRUCTION CLOSE TO NOORDHOEK BEACH

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