

**DUNES AND DUNE MOVEMENT
IN THE WALVIS BAY AREA OF NAMIBIA,
AND
IMPLICATIONS FOR FUTURE LAND-USE
PLANNING AND DEVELOPMENT**

DISSERTATION

**Submitted in partial fulfillment of the requirements for the
Degree of MASTER OF PHILOSOPHY IN ENVIRONMENTAL SCIENCE,
University of Cape Town**

by

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July 1996



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Figure 1 Landsat image of the central Namib Desert, illustrating the strong contrast between the dune sea to the south and the gravel plains to the north of the Kuiseb River. The large sand spit at Walvis Bay is evident at the left centre of the page.

ACKNOWLEDGEMENTS

I would like to thank the following people and organisations for their contribution to this dissertation:

My supervisor, Professor Mike Meadows, for the support, ideas and time that he provided me during the production of this dissertation. I sincerely hope that I produced something to be proud of.

Debbie Hawkins of the Environmental Evaluation Unit who assisted me with the final creation of several maps and figures.

Jane Du Preez, soon to be Jane Taylor, for helping me with the final production of several graphs and tables.

Nicky Espey and Valerie Wild for all their time and effort with the typing and layout of my thesis.

Mary-Anne Shaw of Struik Publishers, for the loan of several photographic slides of the study area which are presented in this dissertation.

Mr Brummer of the Walvis Bay Municipality, for supplying many maps and copies of unpublished manuscripts.

The University of Cape Town, the South African Breweries and the Foundation for Research and Development for financial assistance during the last year and a half of study.

The Danish Cooperation for Environment and Development for affording me the opportunity of experiencing such a beautiful part of the world, and for working on a project of such significance.

My class mates, for an incredible eighteen months, the friendship and for all that I learnt from them.

Belinda, for putting up with me through thick and thin, and for her love, interest and encouragement.

Finally, I am most grateful to my parents for their support over so many years, and for providing me with the opportunity to study for such an extended period.

ABSTRACT

Dunes are an integral part of the Walvis Bay environment. Their dynamics significantly influence the functioning of the coastal system and have major implications for both the ecological and socio-economic environments. In light of residential, commercial and industrial requirements for the Walvis Bay area, dune encroachment needs to be seriously considered in the future planning of land-use and resource utilisation. The overall objective of this report, therefore, is to provide a better understanding of the dominant role dunes and sand drift play in the study area and in so doing promote the more judicious future planning and management of the region. In order to achieve this aim, several specific objectives were addressed, these being:

- * to identify and clarify all dune types occurring in the study area, and discuss the geomorphological and ecological characteristics of each;
- * to provide an analysis of the long-term stability of dunes in the Walvis Bay area by means of aerial photograph interpretation;
- * to highlight all factors that contribute to dune encroachment and to assess the ramifications of this movement upon the ecological and socio-economic environments;
- * to emphasise elements that need to be considered with any future planning of land-use and development;
- * to review dune management practices in the Walvis Bay area and provide recommendations for the more effective management of the system in the future.

Three broad categories of dune were identified in the study area, namely vegetated hummock dunes, crescentic dunes and linear dunes. Each of these categories was sub-divided into various dune types, based on morphology, vegetation cover and distribution. Hummock dunes were split into coastal, river delta and flood-plain forms. Crescentic dunes were separated into barchans, small transverse barchanoids and large transverse barchanoids. Of the linear dunes, only complex linear types were identified in the study area. Each dune type has specific characteristics that determine the role they play in the study area, both ecologically and geomorphologically. Hummock dunes are significant in that they are typified principally by pioneer vegetation communities that provide an important refuge and food source for many desert animals. In addition, these plants play a prominent role in trapping and stabilising the northward movement of unconsolidated sands in the study area. Crescentic dunes, by comparison, are generally characterised by little or no vegetation, are highly mobile and have been recorded migrating across the Kuiseb Delta at rates of up to 20 metres per year. Complex linear dunes are typically sparsely vegetated and more stable than the former, advancing at a rate of not more than 1-2 metres per year.

In examining the landscape dynamics of the study site, multi-temporal comparisons of the various dune types were undertaken with the aid of five sets of aerial photographs, dating between 1943 and 1980. Each of the dune types identified, as well as other dominant features, was mapped with the aid of a PC ARC-VIEW GIS package. In addition, the area encompassed by each of these features for the various years was calculated. Findings showed several trends that are linked primarily to the geomorphological role played by vegetation in the dune systems of the Kuiseb Delta. The most significant observations are as follows:

- * a reduction in the area covered by vegetated hummock dunes in the Kuiseb Delta between 1943 and 1980, with the area encompassed by flood-plain hummocks decreasing from 27.93% to 15.61% and river delta hummocks from 11.5% to 5.95%;
- * an increase in the extent of mobile crescentic dune forms in the Kuiseb Delta for the same period, with the area encompassed by barchans increasing from 3.9% to 10.88% and small transverse dunes from 11.91% to 27.51%;
- * a slight increase in the overall size of the Swakopmund/Walvis Bay Dune Field between 1963 and 1980, particularly along the northern leading edge which is dominated by mobile barchans and small transverse dune types;
- * a decrease in the size of the salt marsh from an area of 53 km² in 1963 to just 25 km² in 1980.

These trends are indicative of a desertification process *par excellence*. This process can be attributed primarily to the reduction in the frequency and magnitude of flood events in the lower Kuseb River that limits the provision of water to deltaic shrubs and trees. This reduction appears to be a result of both natural and human induced changes, caused by climatic fluctuations, upstream impoundments and inappropriate catchment land-use practices. These impacts are being compounded by the over-abstraction from aquifers in the lower Kuseb River and Delta, and the development of a 7.3 km long flood diversion wall. The movement of sand, on a more local scale, is being influenced by off-road vehicles, urban expansion and the development of salt recovery pans. It is apparent that, unless flows with the magnitude to reach the sea and recharge groundwater levels become more frequent, the trends observed in this study will continue.

The impacts of this change and the consequential increase in the encroachment of mobile dunes are significant and are being experienced both ecologically and socio-economically. The greatest ecological problems were found to be the loss and fragmentation of habitat across the delta and within the lower reaches of the Kuseb River. This could result in the local disappearance of several species of animals and plants, and possibly even extinctions. Of international significance is the accelerated siltation of the Walvis Bay Lagoon, a registered Ramsar site. From previous research it is evident that sedimentation is rapidly reducing habitat for macrobenthic fauna and in turn limiting food supplies for wading birds.

In an attempt to analyse socio-economic impacts, a series of interviews was undertaken with various authorities and private companies, and a questionnaire survey was carried out in the suburbs of Kusebmond (a lower income black residential area), Narraville (a lower to middle income coloured residential area) and Meersig (a middle to upper income white residential area). Results indicated that dune encroachment is causing immeasurable damage to residential houses, municipal buildings, infrastructure and several businesses in the Walvis Bay area. The enormous economic costs involved are lowering the standard of living of many residents. In order to limit many of the impacts of dune encroachment in the future, zones of severe, moderate and slight sand encroachment were delineated and mapped out. The need to design and plan around these areas is of particular importance in light of the rapidly expanding population of the region, the enormous requirement for low cost housing, as well as the proposed development of Export Processing Zones (EPZs).

Even though the management of dunes in the study area is a common concern to several government agencies, private companies, and landowners, the control of dune movement to date has been site-specific, conflicting and relatively uncoordinated between management authorities. In order to promote the more effective management of dunes in the study area, it has been suggested that an approach which involves local on-site management that recognises, and is based on, regional ecological and geomorphological processes be adopted. For this management to succeed, however, national coastal zone management policies are required, authorities need to co-ordinate activities, and the local population must be informed and become involved in the planning process.

TABLE OF CONTENTS

Acknowledgments	ii
Abstract	iii
Table of Contents	v
List of Figures	viii
List of Tables	ix
List of Plates	x
List of Appendices	xi
List of Abbreviations	xii
1. INTRODUCTION	
1.1 Background to the Project	1
1.2 Aims and Objectives of Study	2
1.3 Boundaries of Study Area	5
1.4 Methodology of Study	5
1.4.1 Information Gathering	5
1.5 Assumptions and Limitations	7
1.5.1 Assumptions	7
1.5.2 Limitations	7
1.6 Structural Outline	8
2. ENVIRONMENTAL CHARACTERISTICS OF THE STUDY AREA	
2.1 Introduction	10
2.2 Biophysical Environment	11
2.2.1 Geological Origin of the Study Area	11
2.2.2 Climate	13
2.2.3 Geomorphology	16
2.2.4 Soils	18
2.2.5 Vegetation	19
2.2.6 Fauna	22
2.3 Socio-economic Environment	25
2.3.1 Population	25
2.3.2 Housing	27
2.3.3 Economic Trends and Industrial Development ..	31
2.4 Conclusion	34
3. CHARACTERISTICS OF DUNES IDENTIFIED IN THE STUDY AREA	
3.1 Introduction	36
3.2 Determinants of Dune Development	38
3.3 Classification of Dunes	38
3.4 Sediment Sources and Coastal Processes	43
3.4.1 Sand Sources	43
3.4.2 Ocean Currents and Sediment Movement	44

3.4.3	Aeolian Sand Movement	45
3.5	Dunes Identified in the Study Area	47
3.6	Hummock Dunes	47
3.6.1	Distribution	47
3.6.2	Physical Characteristics	48
3.6.3	Flora and Fauna	48
3.6.4	Conservation Significance	52
3.7	Crescentic Dunes	53
3.7.1	Distribution	53
3.7.2	Physical Characteristics	54
3.7.3	Flora and Fauna	56
3.7.4	Conservation Significance	57
3.8	Linear Dunes	57
3.8.1	Distribution	58
3.8.2	Physical Characteristics	58
3.8.3	Flora and Fauna	58
3.8.4	Conservation Significance	62
3.9	Conclusion	63

4. HISTORICAL CHANGES AND STABILITY OF DUNES IN THE STUDY AREA

4.1	Introduction	65
4.2	Aerial Photography as a tool for Comparative Interpretation and Change	66
4.3	Limitations of using Aerial Photography	66
4.4	Approach used to Identify and Map Dunes using Aerial Photographs	67
4.5	Historical Changes and Stability of Dunes	76
4.5.1	Observations 1943 - 1963	76
4.5.2	Observations 1963 - 1969	77
4.5.3	Observations 1969 - 1976	78
4.5.4	Observations 1976 - 1980	79
4.6	Discussion	80
4.6.1	Hummock Dunes	80
4.6.2	Unvegetated Mobile Dunes	81
4.6.3	Larger Dunes	81
4.6.4	Salt Marsh	81
4.6.5	Sand Plate	82
4.6.6	Beach and Spit	82
4.6.7	Vegetation	82
4.7	Conclusion	83

5. ENVIRONMENTAL IMPACTS AND FUTURE LAND-USE IMPLICATIONS OF SAND MOVEMENT IN THE WALVIS BAY AREA

5.1	Introduction	84
5.2	Factors Influencing Sand Movement in the Study Area ...	85
5.2.1	Decreased Flood Frequency	85
5.2.2	Over-abstraction of Groundwater	89
5.2.3	Flood Diversion Wall	89
5.2.4	Off-road Vehicles	91
5.2.5	Urban Expansion	93
5.2.6	Salt Recovery Pans	94
5.2.7	Dune Stabilisation	94

5.3	Environmental Impacts of Driftsands	96
5.3.1	Ecological Impacts	96
5.3.2	Socio-economic Impacts	102
5.4	Considerations for Future Land-use Planning and Development	114
5.4.1	Town Planning Considerations	115
5.4.2	Engineering Considerations	118
5.4.3	Global Warming and the Rise in Sea Level ...	119
5.5	Conclusion	120
6.	DUNE MANAGEMENT IN THE WALVIS BAY AREA	
6.1	Introduction	122
6.2	Dune Stabilisation	122
6.2.1	Historical Development of Dune Management Practices in Southern Africa	123
6.2.2	Early attempts at combating Driftsands by the Water Affairs branch of the South- West African Administration	124
6.2.3	Methods undertaken by the Department of Forestry	126
6.2.4	Methods undertaken by the Walvis Bay Municipality	129
6.2.5	Problems associated with Dune Stabilisation	132
6.3	Future Management Considerations	134
6.3.1	The need for an Ecological Approach to Dune Management	134
6.3.2	Administration Requirements	135
6.3.3	Legislative Requirements	136
6.3.4	Archaeological Value	136
6.3.5	Economic Value	137
6.3.6	Stabilisation Requirements	138
6.3.7	Educational Requirements	139
6.4	Conclusion	140
7.	CONCLUSIONS	141
	REFERENCES	144
	APPENDICES	156

LIST OF FIGURES

1.1	Key Features of the Study Area	4
2.1	Simplified Geological Map of the Kuiseb Drainage System	12
2.2	Mean Monthly Rainfall at Walvis Bay	15
2.3	Mean Monthly Fog Frequency at Walvis Bay and Gobabeb	15
2.4	Average Monthly variation in Wind Direction and Frequency	17
2.5	Veld Types of the Central Namib	20
2.6	Population Growth Scenarios for Walvis Bay	26
2.7	Map of Future Spatial Requirements for Walvis Bay	30
3.1	Distribution of Dune Types in the Namib Sand Sea	37
3.2	Types of Dunes	42
3.3	Regional Airflow Patterns in the Central Namib	46
4.1	Geomorphological Features of the Walvis Bay Area 1943	69
4.2	Geomorphological Features of the Walvis Bay Area 1963	70
4.3	Geomorphological Features of the Walvis Bay Area 1969	71
4.4	Geomorphological Features of the Walvis Bay Area 1976	72
4.5	Geomorphological Features of the Walvis Bay Area 1980	73
4.6	Historical changes in the percentage area of Hummock Dunes in the Kuiseb Delta (1943-1980)	74
4.7	Historical changes in the percentage area of Crescentic Dunes in the Kuiseb Delta (1943-1980)	74
4.8	Historical changes in the percentage area of Salt Marsh, Sand Plate, Beach and Spit in the Kuiseb Delta (1943-1980)	75
4.9	Historical changes in the area of the Swakopmund/Walvis Bay Dune Field (1963-1980)	75
5.1	Downstream Limits of flows in the Lower Kuiseb River(1942-1988)	86
5.2	Flood Frequency Curve for the Kuiseb River (Sclesien Weir)	87
5.3	Flood Hydrograph for the Kuiseb River (Sclesien Weir)	87
5.4	Growth in Water Demand for the Walvis Bay Area (1951-1994)	90
5.5	Rooibank Borehole No. 2: Water Table Levels (1968-1988)	90
5.6	Urban Expansion of Walvis Bay (1943-1980)	95
5.7	Average Water Tariffs (1979-1995).....	110
5.8	Key issues pertaining to Dune Movement in the Study Area	113
5.9	Zones of Slight, Moderate and Severe Sand Encroachment in the Walvis Bay area.....	116
6.1	Growth of the Artificial Dune from 1950-1961.....	125

LIST OF TABLES

2.1	Contribution of various activities to the GDP (1987-1994)	33
3.1	Wilson's Hierarchy of Aeolian Bedforms	40
3.2	Mabbutt's Classification of Aeolian Sand Forms	40
3.3	McKee's Classification of Aeolian Sand Forms	41
3.4	Tinley's Classification of the Coastal Dunes in southern Africa	41
5.1	Years that the Kuiseb River reached the Atlantic Ocean (1837-1996)	86
5.2	Estimated house-hold costs spent annually by residents of Walvis Bay to control and clear sand from their properties	109
5.3	Annual income of black, coloured and white population groups in Walvis Bay (1991)	109
6.1	Plant species evaluated for dune stabilisation at Walvis Bay by the Department of Forestry	128

LIST OF PLATES

1.	Landsat image of the central Namib Desert	i
2.	Brown hyaena tracks on the beach south of Walvis Bay	24
3.	Walvis Bay Lagoon is regarded as the most important wetland for migratory birds in southern Africa	24
4.	Informal structures alongside formal housing at Kuisebmond, Walvis Bay	28
5.	Walvis Bay Harbour	28
6.	Small coastal hummocks between Walvis Bay and Swakopmund	49
7.	Flood-plain hummocks in the Kuiseb Delta	49
8.	Barchan dunes south of Walvis Bay Town	55
9.	Large transverse barchanoid dunes in the Swakopmund/Walvis Bay Dune Field	55
10.	Linear dunes in the Swakopmund/Walvis Bay Dune Field	59
11.	Vegetated linear dunes south-east of the study area	59
12.	Off-road vehicle damage on coastal hummock dunes	92
13.	Sand accumulation in residential gardens in Narraville	104
14.	Collapse of garden walls in Kuisebmond as a result of sand accumulation	104
15.	An example of a wind-break erected at a private home in Walvis Bay Town	105
16.	Salt Works south of Walvis Bay Lagoon	105
17.	Municipal clearing of sand at Kuisebmond	106
18.	A sand-storm on the outskirts of Walvis Bay	106
19.	Sand inundation of a road outside of Walvis Bay	107
20.	Dune stabilisation south of Walvis Bay Town undertaken by the Directorate of Forestry	130
21.	A sluice that controls the movement of water into dune areas, with the Walvis Bay Lagoon in background	130
22.	Green belt of bamboo and Dead Sea tamarix south of Walvis Bay ..	131
23.	Slatted wooden fences erected south of Narraville to control driftsand movement	131

LIST OF APPENDICES

1. Plant communities of the lower Kuiseb River 157
2. Historical changes in the surface area of Geomorphic and other
Features in the Kuiseb Delta (1943-1980) 158
3. Historical changes in the surface area of the Swakopmund /
Walvis Bay Dune Field (1963-1980) 159
4. Questionnaire Survey: Wind-blown sand - issues and concern 160

LIST OF ABBREVIATIONS

CSIR	Council for Scientific and Industrial Research
CZM	Coastal Zone Management
DANCED	Danish Cooperation for Environment and Development
EEU	Environmental Evaluation Unit
EIA	Environmental Impact Assessment
EPZ	Export Processing Zone
FRD	Foundation for Research and Development
GIS	Geographical Information System
ha	hectare
ICZMP	Integrated Coastal Zone Management Plan
km	kilometre
m	metre
MET	Ministry of Environment and Tourism
NAMPORT	Namibian Port Authorities
ORV	Off-road vehicles
pers. comm.	<i>personal communication</i>
pers. obs.	<i>personal observation</i>
SARDC	Southern African Regional Development Community
UCT	University of Cape Town
UNEP	United Nations Environment Programme
UNIDO	United Nations Industrial Development Organisation

INTRODUCTION

1. INTRODUCTION

1.1 BACKGROUND TO THE PROJECT

The Walvis Bay area is currently experiencing a phenomenal rate of population growth, resulting in an increased demand for resources and housing. Coupled to this, there is an increase in the stresses caused by today's lifestyle, which results in the need for relaxation and recreation in unspoilt environments. As a consequence, much of the Walvis Bay area is currently being developed and altered for commercial, residential and recreational purposes, with very little consideration for the natural ecosystems involved. The resulting degradation of this coastal area reduces both present and future benefits which can be derived from this environment. In recent years these pressures have been recognised by the Namibian Government, who have highlighted the requirement for an integrated environmental management plan for the Walvis Bay area.

The Danish Co-operation for Environment and Development (DANCED), in accordance with the recommendations outlined in Agenda 21, aims to contribute to the restoration of the global environment. In doing so DANCED has identified Integrated Coastal Zone Management as one of its key areas of interest. Following with this commitment, and in line with the above mentioned requirement, DANCED offered assistance to the Namibian Government in the formulation of an Integrated Coastal Zone Management Plan for the Walvis Bay area of the central Namib coastline.

An Integrated Coastal Zone Management Plan can be defined as a co-ordinated management plan for the coastal zone. This plan should correlate with local, regional and national goals, with particular focus being placed on the interaction between various activities and resource demands that occur within the coastal zone and neighbouring regions (Ramboll, 1995). This plan therefore provides an integrated and holistic means of planning, involving many sectors in the facilitation of development.

The first stage of DANCED's involvement entailed a site visit to the study area (23 October 1995 - 17 November 1995), with the purpose of identifying prevalent issues that need to be addressed. Thereafter, University of Cape Town Masters students from the Environmental and Geographical Science Department were commissioned to investigate these issues further. The objective of this study was to outline the major factors which would require attention in an Integrated Coastal Zone Management Plan, and to present

baseline information on the state of the environment in Walvis Bay and surrounding areas. This baseline report was submitted to DANCED on the 31 March 1996.

In addition to the baseline report, it was also agreed that individual dissertations relating to specific aspects of the Walvis Bay environment be drawn up by each of the Masters students. These reports would provide a better understanding of environmental processes acting in the region, and would contribute towards the formulation of a comprehensive Coastal Zone Management Plan. Furthermore, it is assumed that the academic nature of these reports will provide insights that will aid relevant authorities in the planning and decision making process.

This study is one of the individual dissertation reports, and highlights the significant role dune encroachment is playing in the area of study. Even though this issue was touched upon within the baseline report, it was felt that the enormity of this problem was greatly under-emphasised and inadequately addressed. On deeper analysis and discussion with several authorities it has become apparent that the ingress of driftsands are having severe implications both ecologically and socio-economically, and in light of developmental needs ought to be seriously considered in the future planning of land-use and resource utilisation. It has been noted by the Council for the Environment (1991) that in order for coastal zone planning and management to be effective, a thorough knowledge of the ecological and geomorphological processes is vital. This report, therefore, attempts to provide a better understanding of the dominant role dunes and sand drift play in the Walvis Bay area, and provide considerations for future management and planning in the region.

1.2 AIMS AND OBJECTIVES

As discussed in the previous section, dunes are an integral part of the Walvis Bay environment. Their dynamics significantly influence the functioning of the coastal system and pose a major threat to present and future residential and industrial development. Much of the research on dunes in the Walvis Bay area, however, has been uncoordinated, haphazard and focused on specific aspects of the dune environment. Furthermore, large gaps concerning the historical dynamics of the region as well as the sociological and economic importance and value of dunes and dune processes are apparent. This has limited any holistic understanding of the functioning of the system and contributed little to effective dune management.

The overall objective of this report, therefore, will be to provide a better understanding of the functioning and dynamics of dunes in the Walvis Bay area and, in so doing, contribute to more judicious development, management and conservation of the region.

Specific aims to this study are as follows:

- * To identify all dune types occurring in the study area, and discuss the geomorphological and ecological characteristics of each.
- * To provide an analysis of the long-term stability of dunes in the Walvis Bay area by means of aerial photograph interpretation.
- * To analyse all factors that are contributing to dune migration and highlight the ramifications of this movement upon the ecological and socio-economic environments. Also, emphasise elements that need to be considered with any future planning of land-use and development.
- * To review dune management practices in the Walvis Bay area and highlight considerations for the more effective management of the system in the future.

It is hoped that the information and results obtained from this study will help in the formulation of an effective Integrated Coastal Zone Management Plan for the Walvis Bay area, so that this coastal system can be managed in a sustainable manner.

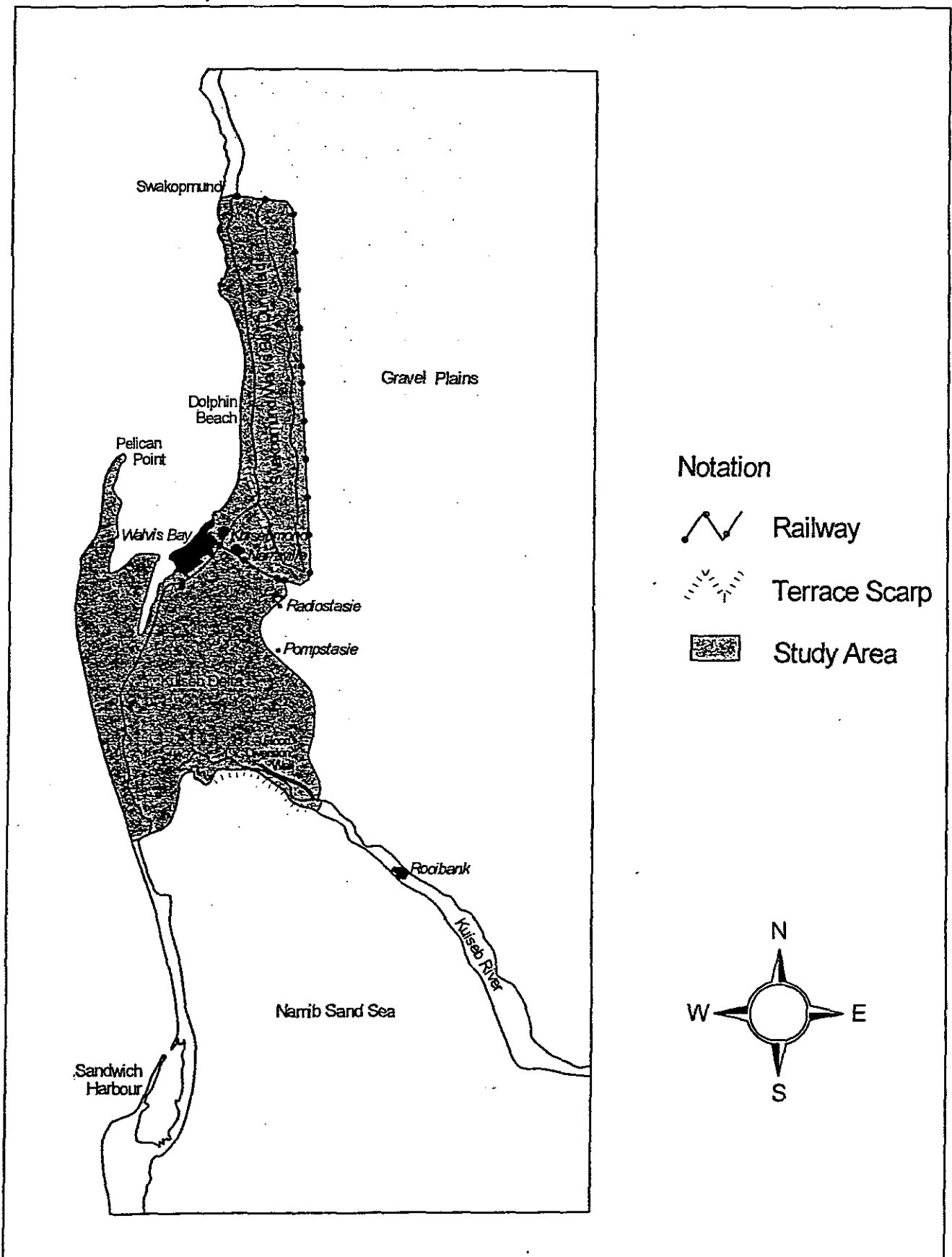


Figure 1: Key Features of the Study Area

1.3 BOUNDARIES OF THE STUDY AREA

The study region is situated on the north-western edge of the Namib Sand Sea (approximately 23°00'S; 14°30'E), in the central Namib Desert, and includes the coastal town of Walvis Bay (see Figure 1). The study area is bounded to the west by the Atlantic Ocean, to the south-east by the dunes of the sand sea and the north-east by the extensive gravel plains of the Central Namib Desert. The northern boundary is set by the leading edge of the Swakopmund/Walvis Bay Dune Field, which is periodically kept in check by the westward flowing Swakop River.

The principle motivation for the delineation of these boundaries was to include all features that were directly influenced by the northward movement of aeolian sand from the main Namib Sand Sea. These features primarily included the lower Kuiseb River and Delta, the Walvis Bay Lagoon, Walvis Bay Town and the coastal tract immediately north of the town. For future dune management it should be noted that these boundaries are not static, but are instead part of a dynamic process, and should reflect changing environmental conditions.

1.4 METHODOLOGY OF STUDY

Due to the range of topics addressed within this report, several methods were employed to obtain and analyse information. These methods are briefly outlined in this section, although they are discussed in more detail in the appropriate chapters.

1.4.1 Information Gathering

In order to obtain the wide range of information required for this study both descriptive and quantitative techniques have been utilised. These are as follows:

- * review of relevant literature;
- * personal observations and ground truthing;
- * aerial photograph interpretation;

- * interviews;
- * questionnaire survey.

Literature Review

A wide range of appropriate literature was reviewed for the purpose of this report so as to provide an efficient background knowledge of the subject and identify any gaps in the information. It should be noted that even though much of the literature gathered is available as published scientific papers, reports, books and conference proceedings, a large proportion of the information obtained exists as unpublished internal documents and notes of various parastatal and private companies, and government departments.

Personal Observations and Ground Truthing

Two site visits (26/11/1995 - 13/12/1995 and 04/02/1996 - 17/02/1996) enabled direct observations to be made concerning various aspects of the Walvis Bay environment. Much of the locality was ground truthed to confirm the assertions made from the aerial photographs and to obtain a 'genius loci' of the study area. In addition, numerous field notes and photographs were taken of important features relevant to the study.

Aerial Photograph Interpretation

Five sets of aerial photographs for the years 1943 (Task 37), 1963 (Task 507), 1969 (Task 662), 1976 (Task 706) and 1980 (Task 498) were obtained in order to ascertain the dynamic status and general stability of the dunes in the Walvis Bay area. This method of multi-temporal analysis is discussed in more detail in Chapter 4.

Interviews

A series of informal interviews were undertaken in Cape Town, Windhoek and Walvis Bay with representatives from governmental, parastatal and private organisations. The information collected during interview sessions was compiled, and is quoted extensively in the document.

Questionnaire Survey

In order to obtain a preliminary perception of the driftsand problems faced by the local population, as part of this study a questionnaire survey was undertaken in the Walvis Bay suburbs of Kuisebmond (a lower income black residential area), Narraville (a lower to middle income coloured residential area) and Meersig (a middle to upper income white residential area). Further information concerning this survey is discussed in Chapter 5.

1.5 ASSUMPTIONS AND LIMITATIONS

1.5.1 Assumptions

The assumptions made at the outset of this study are listed below:

- * This study would contribute to the more effective management of dunes in the Walvis Bay area, and in so doing aid in the planning of future land-use and resource utilisation in the region.
- * Information gathered during interviews with various authorities is correct, and the opinions and views recorded mirrors those of the organisations which they represent.
- * Information obtained through the questionnaire surveys is accurate and reliable.
- * The literature collected for the purposes of this study is correct and complete.

1.5.2 Limitations

The limitations which influenced this study are listed below:

- * Comprehensive studies require the participation of all the stakeholders. While efforts were made to solicit opinions from a broad base of interested and affected parties, the public participation process was curtailed due to time and budgetary constraints.

- * The process of note taking during interview sessions may have resulted in a certain amount of distortion. Personal biases may also have been conveyed by those interviewed, which may possibly not represent the opinions of their affiliated organisations.
- * Due to time constraints the questionnaire survey was not expected to be statistically representative and was undertaken with the simple objective of obtaining a further understanding of socio-economic impacts of driftsands in the study area.
- * The historical record of dune distribution in the Walvis Bay area begins with the 1943 series of aerial photographs. This limits any earlier understanding of dune dynamics and coastal stability in the study area.
- * The mapping and digitising from the aerial photographs may have resulted in inaccuracies. In addition, due to often hazy boundaries between landforms, any measurements should be considered approximate and seen as being of a preliminary nature for detecting gross geomorphic changes.
- * Several additional limitations regarding the use of aerial photographs are discussed in Section 4.3.

1.6 STRUCTURAL OUTLINE

The report consists of seven chapters, each divided up into numerous sections and, where necessary, sub-sections.

Chapter 1, the Introduction, provides a general overview of the report. This chapter deals with the background, outlines the aims and objectives, and gives an indication of the assumptions and limitations of the study. It also gives a brief overview of the methodology used in the study. Following the Introduction, the next two chapters of the report are primarily descriptive and provide in-depth information on environmental characteristics of the study area (Chapter 2), and more specifically, the characteristics of particular dune types identified in the study area (Chapter 3).

Chapter 4 attempts to determine the historical stability of the Walvis Bay area by looking at changes in the distribution and surface area of various dune types. In so doing the coastal processes and dynamics of the region can be better understood. Chapter 5 highlights factors that have influenced these changes and identifies and describes all impacts that have resulted, both biophysical and socio-economic. In addition, Chapter 5 provides considerations for future land-use planning and development.

Chapter 6 deals with the management of dunes in the study area, and reviews all strategies that have been used in the past to stabilise dunes and combat driftsand encroachment. Considerations for the better management of the system in the future are also provided. Chapter 7 concludes the study by drawing together all arguments and findings from the various chapters.

**ENVIRONMENTAL
CHARACTERISTICS OF THE STUDY
AREA**

2. ENVIRONMENTAL CHARACTERISTICS OF THE STUDY AREA

2.1 INTRODUCTION

The Walvis Bay area has been the focus of much scientific research for many years, particularly over the last few decades as human developments increasingly impact upon the desert system. Recent studies that pertain to the Walvis Bay environment include a multi-disciplinary report of the lower Kuiseb River (Huntley, 1985), a Coherent Development Strategy for Walvis Bay (Dennis Moss Partnership, 1994) and a Baseline Report on the Coastal Zone of the Erongo Region (UCT, 1996). Each of these studies have indicated the unique and complex nature of this environment and pointed out the important bio-physical and socio-economic characteristics that ought to be considered with any future planning and management of the region.

These unique and complex conditions are primarily a result of Walvis Bay being situated at the confluence of several significant environmental features, including the Atlantic Ocean, the Namib Sand Sea, the gravel plains of the central Namib and the delta of the Kuiseb River. As a result this area is highly dynamic, provides a wide range of habitats that supports a rich and diverse flora and fauna, and offers a multi-functional system that is attractive to human settlement. This chapter, therefore, intends to briefly outline the environmental features of the study area, and in so doing highlight any trends, both natural and anthropogenic, that may significantly threaten the present and future functioning of the system.

2.2 BIOPHYSICAL ENVIRONMENT

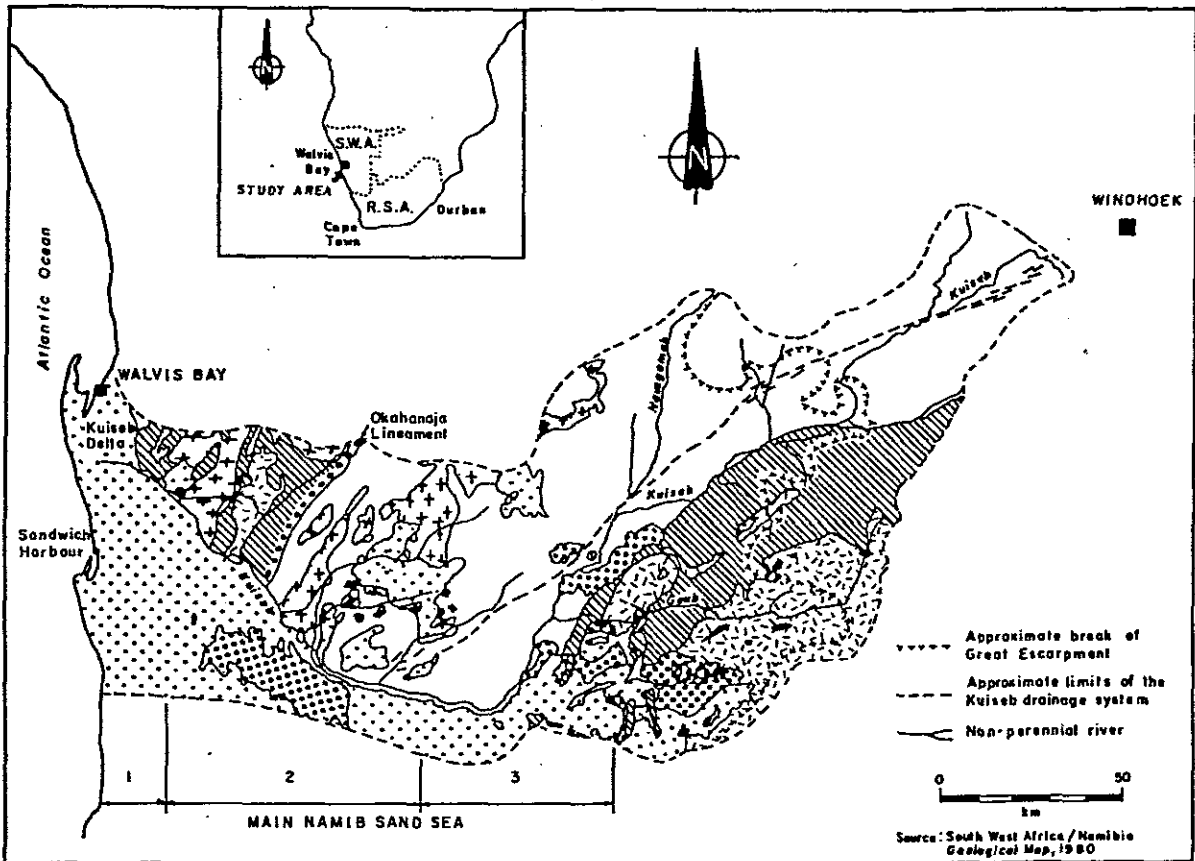
2.2.1 Geological Origin of Study Area

An analysis of the functioning and dynamics of the study area needs to be made within the context of the long-term geological changes in the region. These changes are summarised in the following outline and are illustrated in Figure 2.1, a regional geology map of the Kuiseb drainage system.

The central Namib desert tract developed in response to the formation of the Great Escarpment, following the break-up of Gondwanaland in the Early Cretaceous period, approximately 130-135 million years (Ma) ago (Ward and von Brunn, 1985a). This desert was formed primarily across rocks of the Damara Orogenic Belt that occupies much of northern Namibia (Schreiber, 1995). Marine conditions predominated around 80 Ma ago, resulting in the formation of a relatively level surface. This surface acted as a platform for the accumulation of Cenozoic sediments (Ward and von Brunn, 1985a).

Arenaceous sediments of the Tsondab Sandstone Formation dominate the sedimentary record in the region between 60 Ma to 20 Ma ago (Schreiber, 1995). These sediments are 45 - 90 m thick (Lancaster, 1989), and are indicative of arid/desertic conditions (Ward and von Brunn, 1985a). The Tsondab Sandstones are overlain by the gravels of the Karpfenkliff Conglomerate Formation, that have been tentatively assigned a Middle Miocene age by Ward and von Brunn (1985a). Marking the end of the Middle Miocene are the Kamberg Calcretes, which have been interpreted by Yaalon and Ward (1982) as pedogenic calcretes which were developed under semi-arid conditions approximately 500 000 years ago.

During the late Tertiary, all major rivers in the Namib underwent extensive incision as a result of continental uplift (Lancaster, 1989). Quaternary fluvial deposits are evident in the valleys cut at this time, and provide a record of incision and aggradation events of the period (Lancaster, 1989). During the early to Mid-Pleistocene, quartzose gravels, identified as the Oswater Conglomerate Formation were deposited. These show that the Kuiseb was characterised by streams of a greater competence than today and flowed in a general north-westerly direction (Ward and von Brunn, 1985a).



LEGEND

- QUATERNARY** sediments, including alluvium, river terraces, calcrete and **MAIN NAMIB SAND SEA** :
 - 1 Coastal salt flats, compound transverse and barchanoid dunes
 - 2 Complex linear dunes
 - 3 Star dunes and 'multicyclic' dunes

- TERTIARY** sediments - calcrete conglomerate terraces along Kuiseb and Gaub Valleys
 - red, partially consolidated dune deposits of the Namib Desert

- JURASSIC - ETJO FORMATION** of **KAROO SEQUENCE** -
 Dolerite dykes in western region

- NAMIBIAN**
 - syn- to post-tectonic granites, mostly **SALEM** and **DONKERHUK**
 - KUISEB FORMATION**, with Matchless Member
 - PRE-KUISEB FORMATION**
 - DAMARAN ROCK TYPES**

- MOKOLIAN**
 - comprises: **SINCLAIR SEQUENCE**
 - REHOBOTH SEQUENCE**
 - Middle to upper Mokolian
 - ELIM, ABBABIS, MOOIRIVIER FORMATIONS** - Lower Mokolian

Figure 2.1 Simplified Geological Map of the Kuiseb Drainage System
 (Source: Ward and von Brunn, 1985b)

The Homeb Silt Formation, of at least 30 m thickness, provides information of floodplain overbank deposits from an aggrading Kuiseb River. These silts, deposited 19 000 - 23 000 years ago, testify to the importance of the Kuiseb River as a barrier to the generally northerly migration of the main Namib Sand Sea throughout the Pleistocene (ca 1800 000 - 10 000 years before present) (Ward and von Brunn, 1985a). During the last 6000 years the Kuiseb has maintained itself as an effective northern boundary to the encroachment of the Namib Sand Sea, except along the coastal tract where high energy, south - south westerly winds have transported sands across the Kuiseb Delta to form the narrow Walvis Bay/Swakopmund Dune Field (Ward and von Brunn, 1985a).

2.2.2. Climate

The Walvis Bay area falls within the cool desert climatic region of Namibia and is characterised by mild summers and cool winters. On the basis of the Köppen system it can be classified as a west coast desert climate, with fog being the principle form of precipitation along the coastal strip. These arid conditions are a result of the influence of several dominant climatic factors. These are as follows (Seely and Ward, 1989):

- * the sub-tropical South Atlantic Anticyclone;
- * the absence of convection with temperature inversion in the lower atmosphere;
- * the divergence of the South East Trade Winds;
- * the cool north-flowing Benguela Current with its associated cold water upwelling system.

The main climatic components that influence the topography and ecology of the study area includes precipitation (rainfall and fog), temperature and wind. Each of these components are discussed in more detail below.

Precipitation

The rainfall in the study area is low, seasonal and highly variable. Showers that give measurable amounts of rain occur mainly at the beginning and the end of summer, with a maximum in March, and originate from convective thunderstorms of high intensity and

short duration. In general less than 15 mm of rain falls per annum in the Walvis Bay area (see Figure 2.2).

Adventive sea fog is a characteristic feature and the dominant form of precipitation along the Walvis Bay coast. Here an average of 146 fog days per annum have been recorded over the long term (Tinley, 1985). The greatest fog frequency occurs in spring and autumn (see Figure 2.3), and the heaviest fogs are associated with coastal low conditions and south-westerly winds. This fog results from the upwelling of cool water along the Namibian coast, leading to sea temperatures that are on average 7°C colder than those further offshore. As warmer air passes over these cold waters it forms a layer of stratus and strato-cumulus clouds at fairly low levels. This cloud is generally described as fog, and often results in heavy drizzle along the coast (UCT, 1996).

Adventive fog can extend inland for about 110 km (Scheepers, 1990), and provides an important source of moisture to plants and animals in the Namib Desert (Louw and Seely, 1982). It has been noted that the resultant precipitation from fog along this stretch of coast amounts to approximately 35 - 45 mm per annum (Nieman *et al.*, 1978), and decreases further inland where an average of less than 35 mm is recorded annually at Gobabeb (Scheepers, 1990).

Temperature

The Walvis Bay area is characterised by mild summers and cool winters, with average minimum and maximum temperatures ranging between 10°C and 24°C (UNIDO, 1992). The area experiences little seasonal fluctuation in temperature compared to areas further inland, due to the moderating maritime effect of the Benguela Current and the associated fog conditions.

A temperature inversion typically occurs between 600m and 1800m above ground. This is a result of variable upper air temperatures, and subsidence which occurs as a result (Jackson, 1941). These inversions have serious implications for air pollution dispersal, as pollution is trapped and concentrated beneath the inversion layer (UCT, 1996).

Wind

With the relatively large amount of unconsolidated sands in both the Kuiseb Channel and Delta, and the adjacent Namib Sand Sea, wind is an important environmental factor in

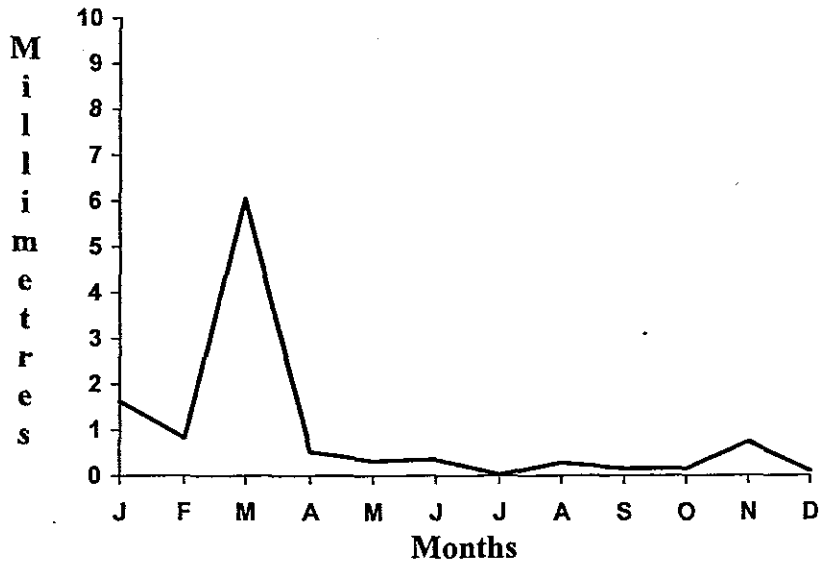


Figure 2.2 Mean monthly rainfall at Walvis Bay (1958-1978)

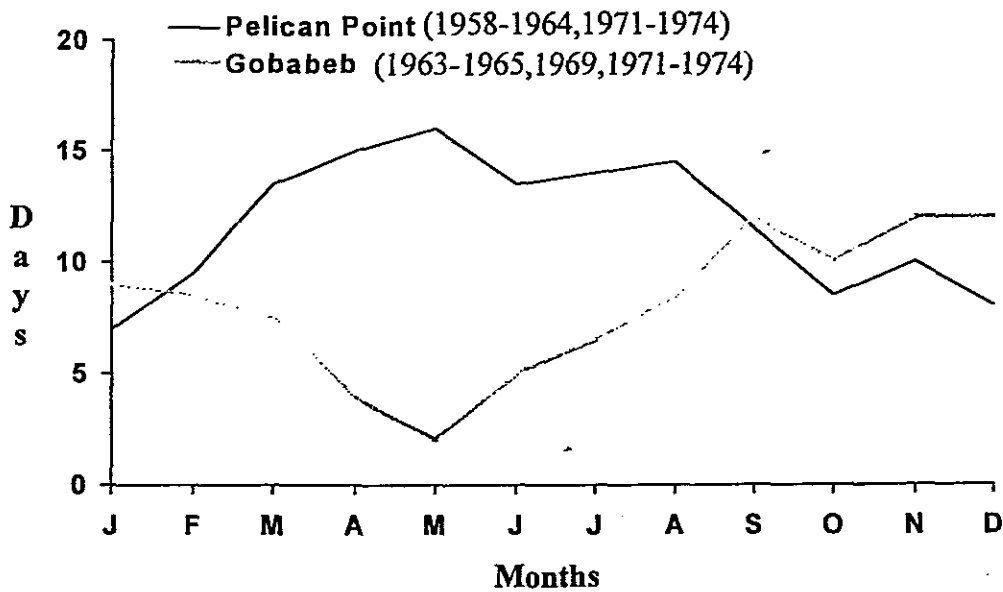


Figure 2.3 Mean monthly fog frequency at Walvis Bay and Gobabeb

sand transportation and dune development. From Figure 2.4 it is evident that the winds in the study area display two main trends. These are as follows:

- * the dominance of south to south-westerly winds throughout the Walvis Bay area in summer;
- * high velocity, low frequency east to north-easterly winds during winter.

These trends in the wind regime have long been recognised and their potential to effect northward migration of the sand dunes from the main Namib Sand Sea across the Kuiseb River was even appreciated last century (Wilmer, 1893). Observations by Ward and von Brunn (1985b) have shown that maximum rates of sand movement are in a north to north-easterly direction, indicating the geomorphic importance of the south and south-westerly winds. The role these winds play in the study area are discussed in more detail in Section 3.4.3.

2.2.3 Geomorphology

The landscapes in the Walvis Bay area are the result of a complex geomorphic interplay between fluvial, marine and aeolian processes. These processes are further complicated by the influence of sea-level fluctuation. The prominent landform features of the region include the Kuiseb Valley and Delta, the various dunes of the Namib Sand Sea (including the dune field between Walvis Bay and Swakopmund), and the extensive gravel plains and exposed bedrock surfaces that extend north. The physical characteristics of hummock, crescentic and linear dune forms identified in the study area are discussed in Sections 3.6.1, 3.7.1 and 3.8.1 respectively.

Wind is the most important geomorphological agent in the region due to its influence on wave generation, the associated transport of sediment onto the shore-line, the transportation of sand inland from the beach, and control of the patterns and forms of sand dunes. As mentioned in the previous section, prevailing south-westerly winds blow with great intensity, picking up loose sands and contribute to driftsand encroachment in the study area. An analysis and discussion of driftsand problems are presented in Section 5.3.

The Kuiseb River, the main river in the study area, is ephemeral and has its source in the Great Escarpment. The influence this river has had on the landscape of the study area,

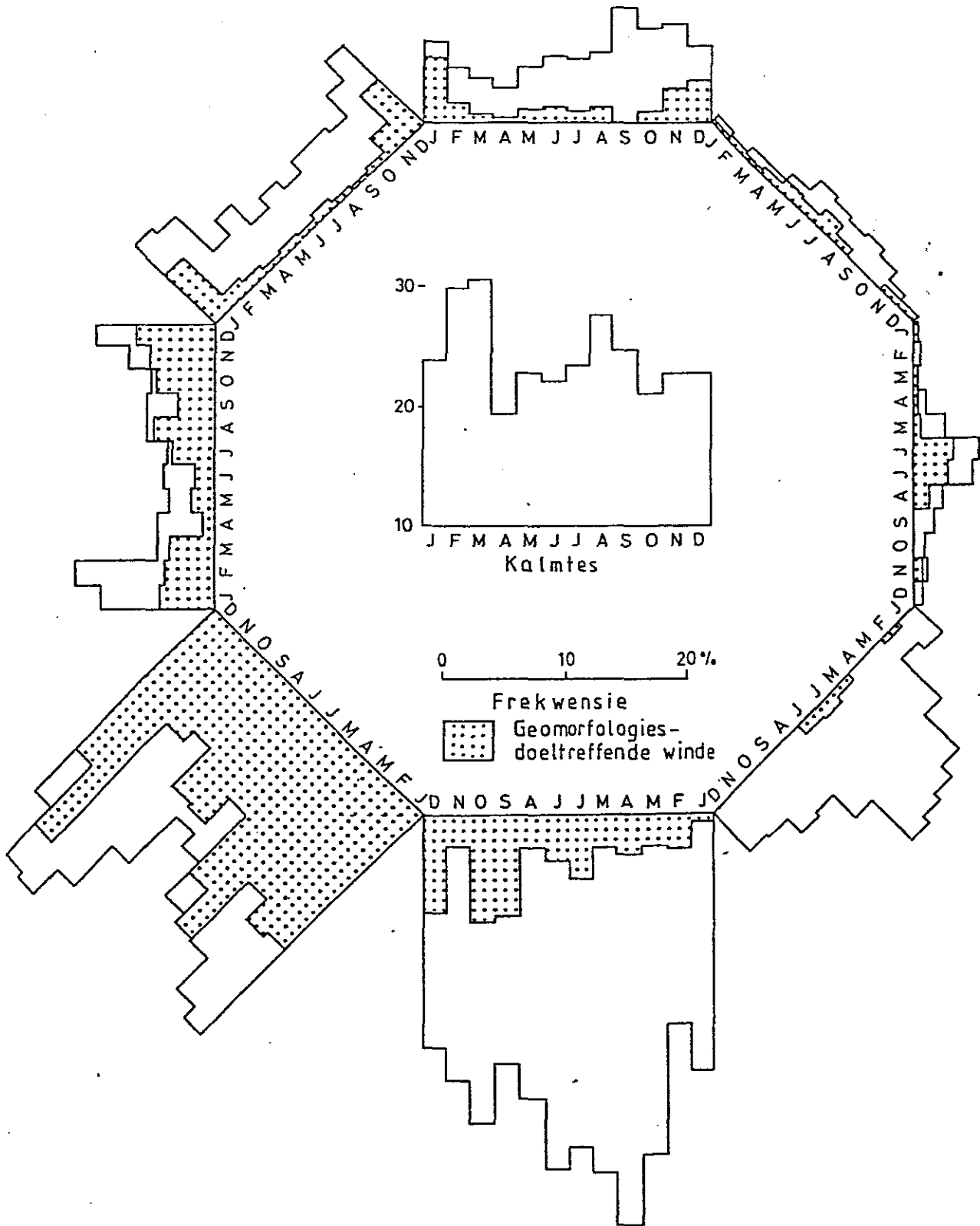


Figure 2.4 Average monthly variation in wind direction and frequency at Pelican Point (Source: Scheepers, 1990)

even though it flows over periods of only hours or a few days every several years, is significant. The geomorphic importance of this running water is primarily related to its sediment carrying capability. Even relatively minor floods transport many millions of metres cubed of sediment to the ocean. This sediment is subsequent removed by coastal erosion processes. Of particular importance is the ability of the Kuiseb River to keep northward moving sands in check. In addition, the dense vegetation of the lower Kuiseb River was is seen as a potent physical barrier to dune migration (Huntley, 1985). The apparent encroachment of dunes in recent years is analysed in Chapter 4, and possible factors responsible for this movement outlined in Chapter 5.

2.2.4 Soils

The extreme arid climate, scant rainfall and strong winds preclude the formation of any but the most immature of desert soils in the Walvis Bay area (Jacobson *et al.*, 1995). These poorly developed soils are usually thin, less than 10 cm thick, and are most pronounced on stony plains where gravels impart some geomorphic stability to these surfaces. The abundant wind-blown sand cover, mobile to some degree, over much of the study area does not develop any distinctive soil horizons. In the study area, colluvial and alluvial deposits occur at the base of hills and in the Kuiseb Valley, whereas more calcareous gypsum soils are found along the coast.

The coastal belt of the Walvis Bay area is characterised by halomorphic soils often associated with gypsum or salt deposits (Jacobson *et al.*, 1995). Miller (1980) notes that these soils have become cemented together in many areas forming a gypcrete layer. Halomorphic soils are rich in salts as a result of evaporation, and the deposition of wind-blown salt of marine origin. This high salt content tends to decrease the mechanical stability of these soils, resulting in a high erodibility and hence a particular vulnerability to physical disturbance. It has been noted that these soils support unique and sensitive plant communities (Daneel, 1992).

Alluvial deposits are evident in the Kuiseb Valley and Delta. These soils are primarily sandy loams to sandy clay loams, with the percentage of silt and clay being highly variable (CSIR, 1991a). Even though these soils support relatively dense stands of vegetation, they have a very poor structure (little ped development), are extremely friable, are prone to erosion and are subject to saline accumulation (Environmental Information Services and Inter Consult Namibia, 1991). Colluvial soils have been deposited on the shallower slopes of some hills and at the base of steeper hills in the

region. The colluvium slope wash varies in thickness, up to a maximum of about 1,5m. These colluvial deposits are discontinuous, variable in colour, and support unique assemblages of plants and animals (CSIR, 1991a).

The sand dunes in the study area are generally characterised by either little or no soil layer. According to Louw and Seely (1982) this is because the dune sands are very dry and do not support bacteria that can breakdown organic material, resulting in very slow rates of decomposition. Therefore, the growth of many dune plants is limited by an unavailability of nutrients - making them particularly sensitive to disturbance and characterised by slow rates of recovery.

2.2.5 Vegetation

Nel and Opperman (1985) briefly described the vegetation types of the central Namib (See Figure 2.5). They identified three main veld types in the vicinity of Walvis Bay, these being the southern Namib dunes, the dry Namib gravel plains and the vegetation of the lower Kuiseb Valley. It was noted that these main types could be further subdivided into different subtypes on the basis of variations in vegetation composition, soil type, geological formation and topography.

The broad range of habitats that interface in the vicinity of Walvis Bay, according to Giess (1971), has resulted in the area being characterised by a richness of plant species that is typically unusual for such an arid environment. These plants provide an important source of food and refuge for many animals in this otherwise barren landscape. The study area, therefore, is an ecotone area and of particular conservation importance. In addition, vegetation plays a significant role in the study area by trapping mobile sands and limiting the northward migration of dunes across the lower Kuiseb River and Delta. This section will briefly outline the broad vegetation types that are found in the Walvis Bay area.

Sand Dunes

The dunes south of the Kuiseb River are primarily characterised by grasses of the genus *Stipagrostis* and small shrubs such as *Trianthema hereroensis*. More stable sand dunes further inland are typified by a wider variety of plant types, including *Monsonia ignorata*, *Limeum fenestratum* and *Hermannia mimifolia*. An important plant also growing in dune areas across the delta is the !nara (*Acanthosicyos horrida*). These plants

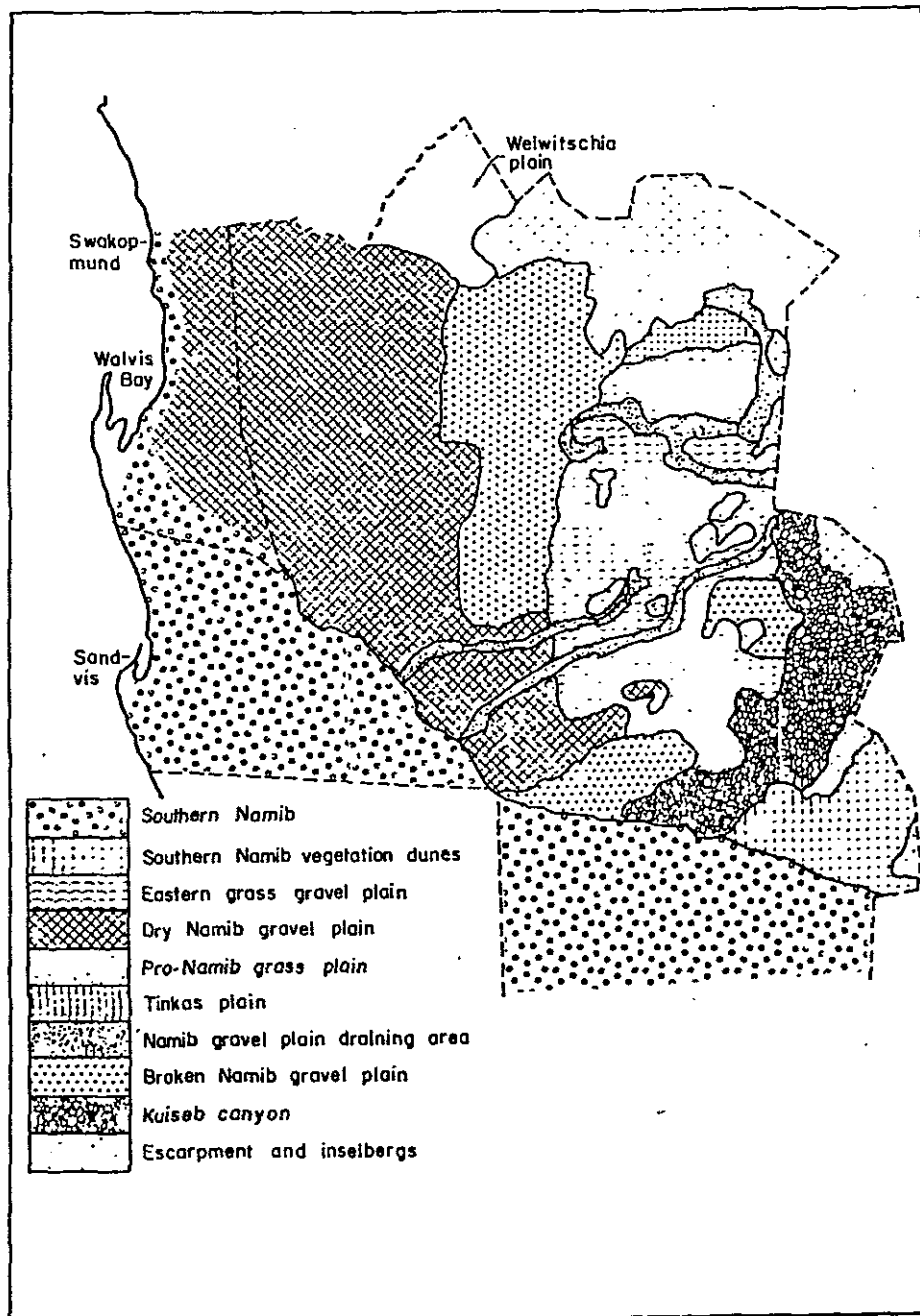


Figure 2.5

Veld Types of the central Namib Desert
 (Source: Nel and Opperman, 1985)

are traditionally used by the Topnaar people as a source of food and for medicinal purposes.

Dune vegetation plays an important role in stabilising mobile sands, and providing refuge and a food source for many desert organisms. Sections 3.6.2, 3.7.2 and 3.8.2 provide a detailed description of the vegetation characterising hummock, linear and crescentic dunes in the study area.

Kuiseb River Bed

The vegetation of the lower Kuiseb River has been extensively researched by Theron et al (1985). Various communities are identified, dominated by the trees *Acacia albida* and *Acacia erioloba*, as well as *Tamarix usneoides*, *Eragrostis spinosa*, and *Stipagrostis sabulicola*. Several species of plants, whose seeds have been washed down from the escarpment by floods, also colonise the river beds. These are mostly short-lived species, and are only plentiful after flood or rainfall events. Appendix 1 provides a list of plant communities that occur in the lower Kuiseb River.

The significance of riparian and river bed vegetation has been noted by Ward and von Brunn (1985b). Their study indicated that vegetation in the Kuiseb plays an important role in stopping the northward movement of dune sand from the Namib Sand Sea. Furthermore, this vegetation provides a refuge and source of food for many animals that seasonally migrate up this linear oasis. It has been noted by Gabriel (undated), however, that in certain areas much of the vegetation in the lower Kuiseb River is being overgrazed by domestic stock. In addition, it has been noted by Huntley (1985) that the over-abstraction of groundwater from the lower Kuiseb River has placed increased stress on the vegetation of this area, and has contributed to the die-off of trees and shrubs. The ramifications of this are discussed in Chapter 5.

Gravel Plains north of the Kuiseb River

Even though the gravel plains are generally barren, various plant communities have been recorded in these areas (Nel and Opperman, 1985). Sparsely scattered clumps of *Zygophyllum stapfii* and *Arthroaerua leubnitziae* are the dominant shrubby inhabitants of the gravel plains north of the lower Kuiseb River. Further inland grasslands dominated by

various *Stipagrostis* species, *Enneapogon brachystachyus* and *Zygophyllum cylindrifolium* occur. The well known *Welwitschia bainesii*, is endemic to this area, and is protected under the Nature Conservation Ordinance 4 of 1975. Lichen fields in the central Namib are the most extensive in the world, and are characterised by over 85 different species (UCT, 1996).

2.2.6 Fauna

The variety of habitats and diversity of vegetation in the region supports a wealth of animal life. Unlike many other wildlife areas, however, it is the smaller animals such as insects, reptiles, rodents and birds that characterise much of the region (UCT, 1996). These animals manage to survive in the desert environment by displaying a variety of behavioural, morphological and physiological adaptations (Smuts, 1989). The declaration of the Walvis Bay Lagoon as a Ramsar site, and the presence of the Namib Naukluft Park to the south of the study area, highlights the importance of this area as a relatively unspoilt natural environment.

Mammals

The majority of large mammals in the region have a wide southern African distribution, with many species only entering the study area along the Kuiseb River, or temporarily during good rainfall periods when food is plentiful. As a result of this nomadism, the study area generally supports few large mammal populations. Species recorded in the area include Hartman's zebra (*Equus zebra hartmannae*), Chacma baboon (*Papio ursinus*), gemsbok (*Oryx gazella*) and springbok (*Antidorcus marsupialis*). Black-backed jackal (*Canis mesomelas*) and Brown hyaena (*Hyaena brunnea*) have also been observed scavenging off dead seals, nesting birds, small rodents and reptiles along the coast (see Plate 2). Unlike larger species, smaller mammals are found in a variety of habitats, including dune areas, gravel plains and the river valley. Various species of shrew, gerbils, hares and moles have been identified in and around Walvis Bay (Griffin, 1994).

The destruction of natural vegetation in the study area is major threat to several mammal species, which rely on plant growth for refuge and forage. Due to the arid conditions and low levels of primary production, the abundance of mammals is already marginal and with a decrease in habitat and food supply the disappearance of several species from the study area is highly probable.

Reptiles

Reptiles are common and conspicuous in the study area. Many reptiles are substrate dependent and often only inhabit specific areas, for example, sand dunes, gravel plains and river beds. The greatest variety of reptiles in the region are lizards and geckos. These include the endemic Web-footed gecko (*Palmatogecko rangei*) which prefers sandy substrates and *Kaokogecko vanzyli* which inhabits gravel plains and sand flats (Griffin, 1994). Snakes recorded include the endemic Side-winding adder (*Bitis peringueyi*), the Horned adder (*Bitis caudalis*) and the Namib sand snake (*Psammophis leightoni namibensis*). Due to the specific habitat requirements of many reptiles, any decrease in habitat diversity could result in the local extinction of several species.

Birds

A wide variety of birds are found in the study area, particularly marine and wetland species that utilise the coastal belt and lagoon for breeding and feeding purposes. Both pelagic and resident seabirds are recorded along the Walvis Bay coastline. White-fronted plovers (*Charadrius marginatus*), Damara terns (*Sterna balaenarum*) and African black oystercatchers (*Haematopus moquini*), for example, regularly breed on the beaches in the study area (Williams, 1987). The Bird Rock guano platform in Walvis Bay also provides an important breeding site for many resident sea birds, supporting rare populations of both the Great white pelican (*Pelecanus onocrotalus*) and the Crowned cormorant (*Phalacrocorax neglectus*) (Williams, 1993).

The Walvis Bay Lagoon is recognised by authorities in the field as the most important wetland in southern Africa for migratory birds, and as such has been registered under the Ramsar Convention as an internationally important wetland (see Plate 3). The lagoon annually supports significant numbers of European and Pan-African migrants. For example, over 60% of the world population of Chestnutbanded plover (*Charadrius pallidus*), and between 50 - 70% of the world population of the Black-necked grebe (*Podiceps nigricollis*) (Southern African sub-species) rest and feed here during the non-breeding season (Williams, 1993).

Most of the terrestrial birds found inland from the coast either occur in the vegetated valley of the Kuiseb River and Delta, or around the Walvis Bay sewerage works. Two bird species that are endemic to the Namib Desert are found in the study area. These are the Dune lark (*Mirafra erythroclamys*), which lives in sand dune habitats and regularly

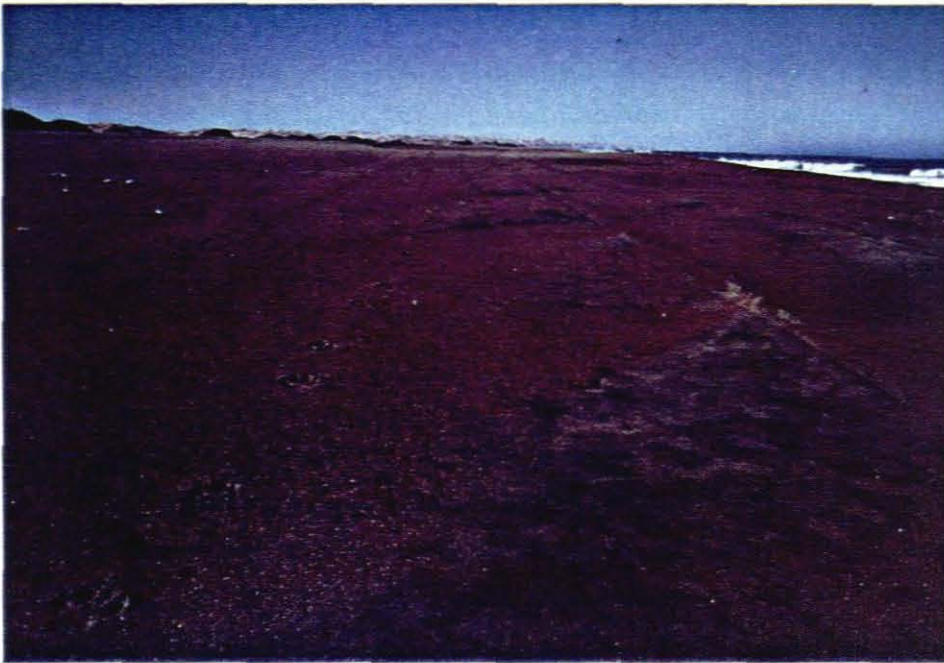


Plate 2 Brown hyaena tracks on the beach south of Walvis Bay, with coastal hummock dunes in the background.



Plate 3 Walvis Bay Lagoon - the most important wetland for migratory birds in southern Africa.

breeds in the delta, and the Grays lark (*Ammomanes grayi*) which inhabits the gravel plains north of the lower Kuiseb River (Colahan, 1987). Several raptor species, including the Pale chanting goshawk (*Melierax canorus*), the Yellow-billed kite (*Milvus migrans*) and the Augur buzzard (*Buteo augur*) have also been recorded in the Walvis Bay area. The significant threat the reduction of bird breeding and feeding habitat, resulting from a die-back of vegetation and the resultant of dunes across the delta and into the lagoon, is discussed in Section 5.3.1.

Invertebrates

Due to the flightlessness and relative immobility of many invertebrates in the study area, a great deal of speciation has occurred resulting in many species becoming highly adapted to specific niches. The variety of invertebrates in the region is highlighted by a survey near Rossing Mine, where some 5000 specimens of spiders, scorpions and other arachnids were recorded (CSIR, 1991a). It has been noted by Jacobson *et al.* (1995) that the important role insects play in this desert environment, particularly in the breakdown of organic matter, is a vital aspect of the ecology of the area. The relative immobility of many invertebrate species, and their unique adaptations to this environment, makes them highly sensitive to any environmental perturbations.

Estuarine Fauna

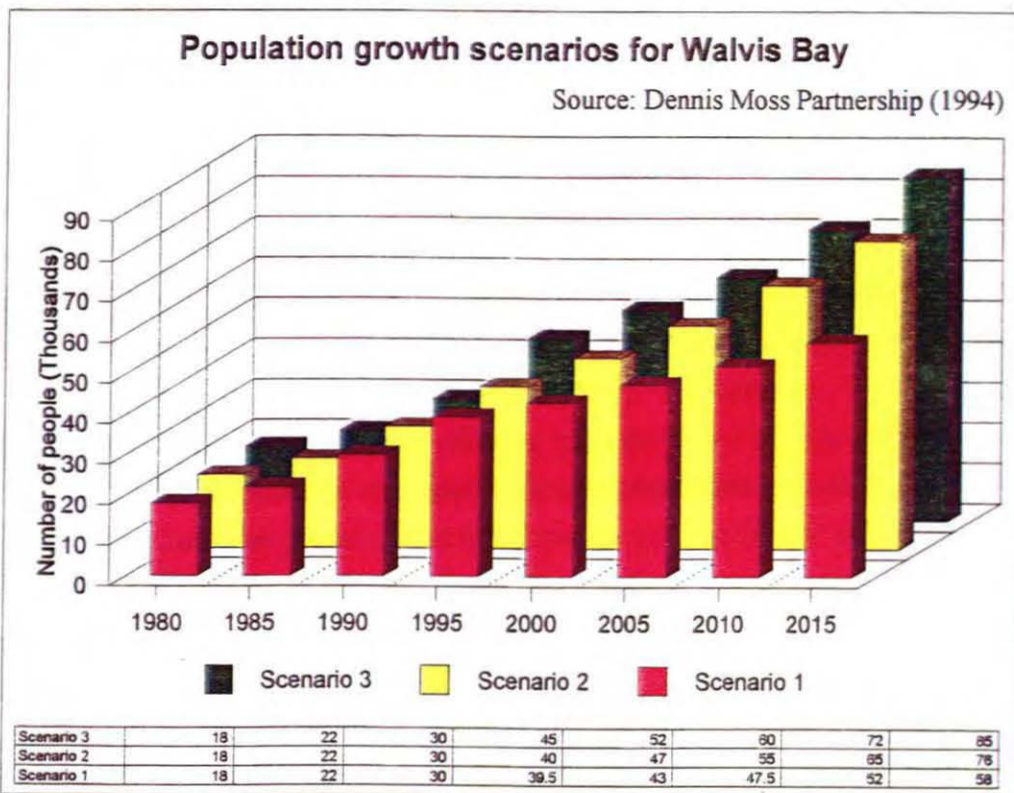
The relatively uninterrupted Namibian coastline offers few suitable habitats for marine organisms that require a sheltered environment. Where such areas do occur, for example at Walvis Bay, a rich estuarine fauna exists, characterised by numerous macro-benthic invertebrate, fish and bird species. The diversity and abundance of organisms in the lagoon is being threatened by both natural and human induced disturbances, including sulphur eruptions, siltation and pollution (CSIR, 1989). As mentioned, this wetland is a registered Ramsar site and of international conservation significance.

2.3 SOCIO-ECONOMIC ENVIRONMENT

2.3.1 Population

In order to predict the demands which will be placed on Walvis Bay's resources and to plan effectively for the future development of the town, it is essential to analyse the relevant population projections. It has been estimated by the Dennis Moss Partnership

Figure 2.6



(1994) that the population of Walvis Bay rose from only 18 000 in 1981 to about 30 000 in 1990, and presently has a population of between 40 000 - 44 000. These figures indicate a sharp annual population growth rate of 3 - 4%. Population growth scenarios set out in the Coherent Development Strategy (Dennis Moss Partnership, 1994) show that if this rate of 3- 4% continues, Walvis Bay can expect to have a population of over 85 000 by the year 2015 (see Figure 2.6).

The rapid growth of Walvis Bay has been attributed, in part, to rural-urban migration in the Erongo Region. However, the most significant migration patterns occur from the northern regions to the Walvis Bay area (UCT, 1996). It has also been noted that the majority of those entering Walvis Bay are of an economically active age, indicating an influx of people seeking employment in the study area (UCT, 1996).

The reason for this rapid migration to Walvis Bay Town is primarily a result of the handing of this port over to the Namibian government and the subsequent downfall of the Apartheid regime. This has allowed freedom of movement in Namibia, particularly from the impoverished northern regions (UCT, 1996). Furthermore, Walvis Bay, as an industrial town, is expected to grow with the implementation of Export Processing Zones (EPZs). The ramifications of this unprecedented population growth in the Walvis Bay area on future land-use planning and development are significant, and will be discussed in Sections 2.3.2 and 5.4.

2.3.2. Housing

As a result of South African rule in Namibia, Walvis Bay has a settlement pattern typical of an Apartheid city. This is characterised by a well serviced modern part for the minority and inadequate houses and shacks for the majority (Anon, 1995) (see Plate 4). Furthermore, a restriction of the black population to rural areas meant that they migrated to urban centres only to fulfil labour contracts. This meant that the only housing provided were hostels and single quarters accommodation, which is now unsuitable for permanent family residence (Anon, 1995).

As discussed in the previous section, Walvis Bay is experiencing an enormous population growth primarily as a result of migrants seeking employment in the area. If the growth rate of 3 - 4 % presented in the Coherent Development Strategy (Dennis Moss Partnership, 1994) is to be assumed, about 11 000 dwelling units will be required in Walvis Bay by the year 2015. This is due not only to the increase in population numbers,

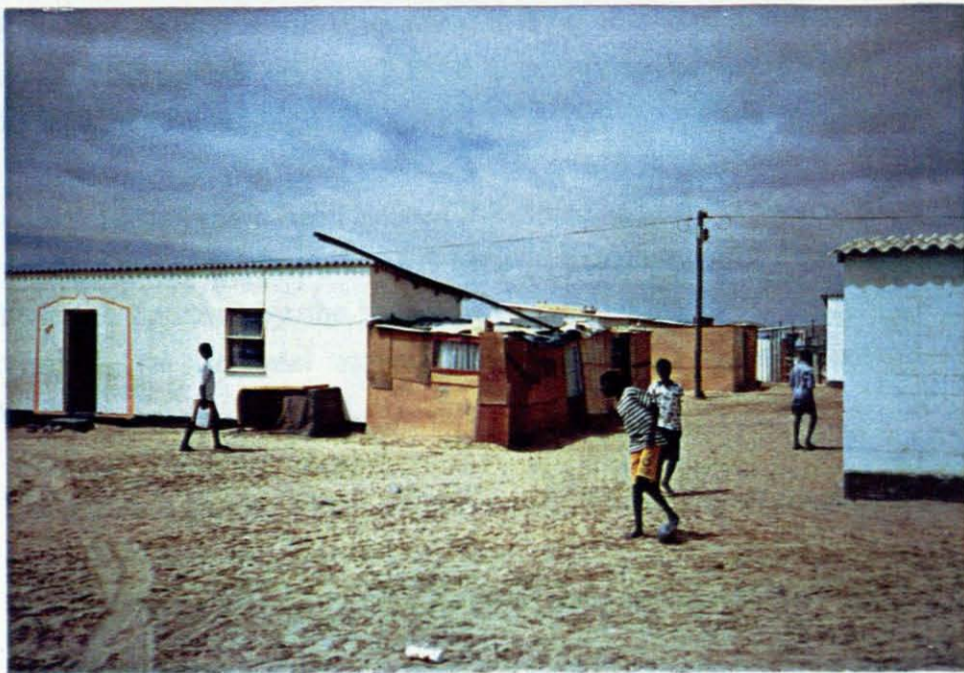


Plate 4 Informal structures alongside formal housing at Kuisebmond, Walvis Bay.



Plate 5 Walvis Bay harbour

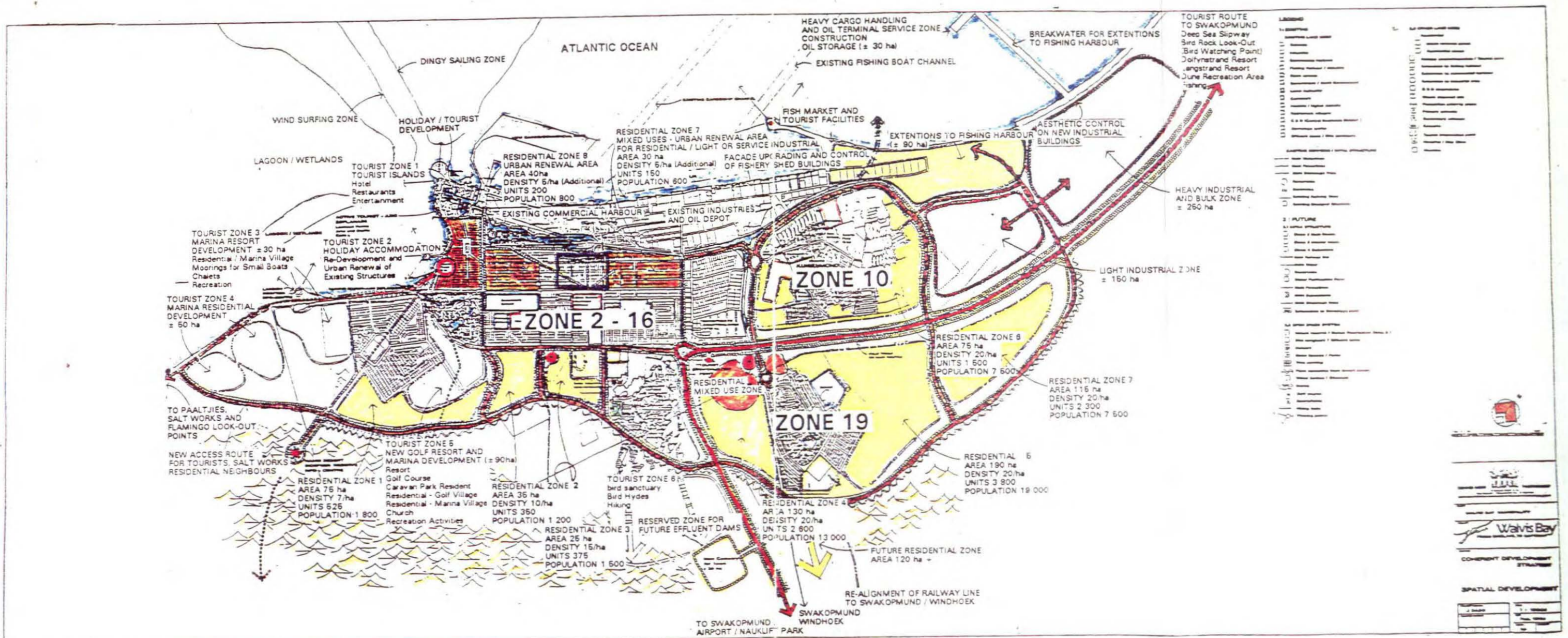
but also the current housing backlog - the waiting list for housing in Kuisebmond alone is about 2000. Furthermore, if squatting is to be controlled and overcrowding alleviated, between 500 and 800 erven will have to be serviced per annum for the next five years (Dennis Moss Partnership, 1994).

Various measures have been initiated in order to address the housing issue at all levels of planning. One of these measures has been the development of a National Housing Policy, which was approved by the Namibian Government in 1991. This policy places certain obligations on the local authority of Walvis Bay, so as to ensure (Walvis Bay Municipality, 1994):

- * that adequate provision of land is zoned for housing development;
- * that utility services (water, electricity and sewerage) be provided;
- * that it be involved in housing project planning and implementation;
- * that site and service schemes for self-help and self-build be set up and managed.

In addition to the obligations prescribed above, the Walvis Bay Municipality has established a Housing Policy in terms of Section 30 (1) and Section 57 (1) of the Local Authorities Act 23 (1992). These sections allow Walvis Bay Municipality to establish a housing scheme and to acquire, maintain, let or sell dwellings (Walvis Bay Municipality, 1994). Another mechanism, developed by the Walvis Bay Municipality, to accommodate the need for shelter and to respond to the increasing cost of land and services, is the Residential Densities Policy (1995). The primary objective of this policy is to properly control and manage the development of residential areas within Walvis Bay (Walvis Bay Municipality, 1994).

Of significance, particularly regarding urban expansion, is that Walvis Bay does not exhibit the typical density characteristics of an urban residential area. Where a high density residential development is usually located near the CBD, with a decrease in densities towards the outer suburbs, Walvis Bay displays the opposite. Here, the highest density areas are found in the outer suburban areas of Kuisebmond and Narraville, with the lowest being adjacent to the town centre (UCT, 1996). Large tracts of existing vacant and underdeveloped land are therefore scattered throughout Walvis Bay, and pose opportunities for residential development and densification.



- LEGEND**
- 1: EXISTING**
- EXISTING LAND USES**
- Schools
 - Industrial
 - Commercial Harbour
 - Fishing Harbour / Industry
 - Open spaces
 - Government / Semi-Government
 - Local Authority
 - Cemetery
 - Higher Density Housing
 - Retirement villages
 - CBD (Central Business District)
 - Sewerage works
 - Effluent dams / Bird sanctuary
- EXISTING SERVICES / INFRA STRUCTURE**
- Main Waterlines
 - Main Powerlines
 - Main Sewerage lines
 - Reservoirs
 - Boreholes
 - Existing Railway lines
 - Existing Dropped Channels
- 2: FUTURE**
- 2.1 INFRA STRUCTURE**
- Class 2 Main Roads
 - Class 3 interior roads
 - New Railway line
 - Main Water
 - Reservoirs
 - Water Purification Plant
 - Main Powerlines
 - Main Substations
 - Main Sewerage lines
 - Extensions to Sewerage plant
- 2.2 OPEN SPACE SYSTEM**
- Nature reserve / Dunes (Recreation Zone 3)
 - Bird sanctuary / Effluent dams
 - Nursery
 - Open Spaces / Parks
 - Tree planting
 - Plant screening from desert dunes
 - Water bodies / Channels
 - Berms
 - Golf course
 - Sportsfields
 - Hiking trails
 - Viewing points
- 2.3 OTHER LAND USES**
- Residential
 - Urban renewal zones
 - Residential zones
 - Holiday accommodation / Tourist zone
 - Extension to fishing harbour
 - Extension to commercial harbour
 - Extension to industrial area
 - CBD extensions
 - Waste disposal site
 - Pedestrian priority areas
 - Primary schools
 - Secondary schools
 - Creche
 - Tourist information point
 - Hospital / Day Clinic
 - Chimes

FIGURE 2.7
Future Spatial Requirements
 (SOURCE: DENAJIS MOSS PARTNERSHIP, 1994)

In terms of the Coherent Development Strategy (Dennis Moss Partnership, 1994), areas that have been identified for future residential development include over 400 ha north-east of Narraville and 225 ha east of Walvis Bay Central (see Figure 2.7). These areas are trending primarily onto lands that are presently covered by mobile sands and are expanding the urban/dune interface. The engineering implications concerning drift-sands, and the long-term ramifications of permanent structures being built in this mobile-dune environment will be discussed in Sections 5.3.2 and 5.4 .

2.3.3 Economic Trends and Industrial Development

The fishing industry forms the back-bone of economic activities in Walvis Bay. The commercial fishing industry creates employment for approximately 10 000 people, and it is estimated that 70% of all the 600 industries in Walvis Bay are either directly or indirectly dependent upon it (Ramboll, 1995). Employment in the industry has grown by about 15 000 jobs per year, and the current labour force is expected to double by the year 2000. Furthermore, the contribution of fisheries to Namibia's Gross Domestic Product (GDP) has grown by 35% per annum, with the total fish exports peaking around N\$ 1,3 billion in 1994 (Anon, 1994). Even though this industry is expanding it is entirely dependent on fish-stocks and is hence variable from year to year (see Plate 5).

Another key employer in Walvis Bay is the mining industry, and presently operational mines in the study area include Damara Granite and Walvis Bay Salt and Chemical Company. Walvis Bay also provides a base for several regional mining operations, and is a centre for numerous secondary and tertiary industries associated with mining. Of particular importance to the study area at present is the prospecting for heavy minerals in the Walvis Bay/Swakopmund Dune Field by Caledonia Mining Corporation, and the exploration for off-shore oil and gas by several international oil companies including Ranger Oil, Shell, Chevron, Sasol and Norsk Hydro. The dune mining is expected to be a significant new supplier of heavy minerals internationally, and will benefit both the local and national economy. However, these benefits will need to be considered with regard to the provision of water and various other potential ecological impacts (Walmsley Environmental Consultants, 1995a). In terms of exploration for oil and gas, Walvis Bay has been identified as the main supply base for all off-shore drilling. If deposits were to be discovered, this operation would provide employment, set up infrastructure and result in the development of several associated industries (UCT, 1996).

Even though possibilities for expansion of both the fishing and mining industries do exist, Namibia has realised that it cannot continue to rely on natural resource intensive activities in the medium to long term. It has been noted in the National Development Plan (Anon, 1995) that Namibia will attempt to stimulate the manufacturing and tourism industries, so as to increase their contribution to the GDP, while at the same time decreasing the country's dependency on primary goods. This trend from primary to tertiary industries is evident in Table 2.1, which compares the contribution of various activities to the GDP from 1987 - 1994. As this table indicates, a degree of economic diversification has occurred since independence, with increasing contributions from the secondary and tertiary industries.

In order to enhance these sectors, and to attract foreign investment, the Namibian Government has adopted an Export Processing Zone (EPZ) policy. In terms of this policy, Walvis Bay is the only area where the implementation of such a regime has been planned (UCT, 1996).

Export Processing Zones (EPZ)

An EPZ has been defined as a geographically zoned area within which fiscal incentives apply (De Loen, 1995). The Export Processing Zone Act of 1995 in Namibia recognises both industrial parks and single enterprise EPZs. EPZ industrial parks usually contain a variety of different enterprises, each independently performing diverse operations. Single enterprise EPZ is an individually situated industry, the location of which depends on the economic viability of the area (De Loen, 1995). In Walvis Bay, only industrial park EPZs have been allocated, and will be sited in areas that were previously zoned for industrial use (see Figure 2.7) (UCT, 1996).

Although Namibia's EPZ scheme is still in its infancy, several incentives, including tax exemptions and recent political stability, have resulted in over forty applications for EPZ status having been received (De Loen, 1995). The majority of these companies are labour intensive and include operations relating to mineral processing, automobiles, textiles, and domestic appliances (UCT, 1996). The main benefits accrued by both Walvis Bay and Namibia will be foreign currency earnings, employment opportunities, technology and skills transfer, industrial development, and the promotion of the manufacturing industry (Sherbourne, 1993). This being in line with the goals of the National Development Plan (Anon, 1995) - to reduce Namibia's dependency on primary goods and to diversify the economy.

TABLE 2.1 CONTRIBUTION OF VARIOUS ACTIVITIES TO THE GDP (PERCENTAGE)

INDUSTRY	1987	1988	1989	1990	1991	1992	1993	1994
Agriculture	11.9	11.8	10.7	10.1	10.4	7.4	7.8	10.4
Fishing	1.6	1.7	1.5	1.7	2	2.8	3.3	3.5
Mining & quarrying	23.1	26.8	28	21	19	16.5	12.1	15.9
PRIMARY INDUSTRY	36,6	40,3	40,2	32,8	31,4	26,8	23,2	30,3
Manufacturing	6.6	6	5.9	7.2	6.3	7.4	9.2	9.3
Elec. & water	1.6	1.9	1.8	2	1.8	2.4	1.4	1.4
Construction	2.4	2.8	2.3	2.7	2.3	2.9	3.1	2.7
SECONDARY INDUSTRY	10,6	10,7	10,6	11,9	10,4	12,7	13,7	13,4
Wholesale & retail	7.7	7.2	7.5	8.1	8.1	8.5	9	8.1
Hotels & restaurants	1.6	1.7	1.8	1.5	1.7	1.8	1.8	2
Transport & Comm.	5.6	5.1	5	5.5	5.3	5.2	5.6	4.6
Finance & real est.	9.8	9.7	10.1	11.5	11.5	12.1	12.8	11.6
Community, soc services	1.2	1.1	1.1	1.3	1.3	1.2	1.4	1.2
Govt. services	24.4	21.8	21.3	24.7	27.3	29	29.5	26.1
Other producers	2.5	2.4	2.4	2.7	2.7	2.8	3	2.7
TERTIARY INDUSTRY	52,8	49	49,2	55,3	58,2	60,6	63,1	56,3
Industries at basic Prices	100	100	100	100	100	100	100	100

(Source: National Accounts, CSO, 1995)

Due to the potential environmental degradation posed by the introduction of industrial zones, each EPZ applicant will be evaluated in terms of its environmental performance, and if necessary an environmental impact assessment (EIA) will be undertaken. It has been noted by UCT (1996), however, that no guidelines exist for this environmental evaluation, thus undermining the EPZ Act. The main impacts of an EPZ in Walvis Bay are likely to be the increased demand placed on social services and physical infrastructure, which in turn has ramifications upon the natural environment. Of particular concern, at the present EPZ site, is the shortage of water and lack of sewerage facilities (UCT, 1996). Furthermore, Walvis Bay does not have waste disposal facilities capable of handling hazardous waste substances (Ramboll, 1995).

In terms of the economy, Walvis Bay is presently underpinned by primary sector industries, namely fishing and mining. In the short term this sector is expected to grow, particularly in light of heavy mineral sands and off-shore fuel prospects. In an attempt to create a more stable economy in the medium to long term, Export Processing Zones have been designated for the Walvis Bay area. Due to the nature of the EPZ industries, and the sensitivity of the Walvis Bay environment, careful consideration needs to be given to the siting and type of industry introduced. The importance siting of industry with due consideration to zones of driftsands encroachment is discussed in Section 5.4.

2.4 CONCLUSION

The area of study is a unique and complex environment, that for the last several thousand years has maintained itself as a dynamically stable system. This complexity is primarily due to the interplay of geological, climatic and marine processes, and the resultant landscape features, which continually interact and influence each other. Regionally, these features include the extensive gravel plains, the dunes of the Namib Sand Sea, the Kuiseb River and Delta, and the coastal tract including the Walvis Bay Lagoon. The study site forms the confluence of these features and is consequently regarded as an ecotone area, displaying a wide variety of habitats and a wealth of animal and plant species, which is generally unusual for desert biomes. The declaration of the Walvis Bay Lagoon as a Ramsar site and the presence of the Namib Naukluft National Park to the south of the Kuiseb River, highlights the importance of this area as a natural environment.

Due to its interface between land and sea, and the presence of a natural harbour, freshwater and recreational utilities, the study area is typically seen as a multi-functional system of great importance to society. In recent years Walvis Bay has experienced a rate

of population growth that supersedes any other urban area in Namibia. In addition, with the hand over of the Walvis Bay enclave to Namibian authorities in May 1994 new policies for industrial expansion have been established. The increasing development of the industrial, commercial and residential sectors is placing an enormous pressure on the natural environment, and with rates of growth envisioned it is likely that these pressures will escalate in the future. Several researchers in the field (eg. Barnard, 1975; Huntley, 1985; Ward, 1987) have acknowledged accelerated dune movement across the Kuiseb Delta as a ramification of developmental pressures in the region.

**CHARACTERISTICS OF DUNES
IDENTIFIED IN THE STUDY AREA**

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**CHARACTERISTICS OF DUNES
IDENTIFIED IN THE STUDY AREA**

3. CHARACTERISTICS OF DUNES IDENTIFIED IN THE STUDY AREA

3.1 INTRODUCTION

The Namib Sand Sea occupies an area of approximately 34 000 km² and stretches for over 300 km between the towns of Luderitz in the south and Walvis Bay in the north. Dunes are found over its entire 100 - 120 km width from sea-level to the Great Escarpment. The wide variety of dune forms that occur in such a small area has attracted the attention of several previous investigators. Barnard (1973) analysed dune formations in the Central Namib and divided the northern part of the sand sea into three zones: a coastal belt of transverse dunes, an interior zone of longitudinal dunes and an eastern zone of multi-cyclic dunes. Studies by Lancaster (1983) assessed both dune morphology and morphometry and related the spatial variation in these properties to changes in the grain size and sorting characteristics of the sands in the various wind regimes. From this study he produced a complex map of dune types in the Namib Sand Sea (see Figure 3.1).

In more recent times several researchers have focused specifically on the Kuiseb River environment, which forms the northern boundary of the sand sea, identifying key features and determining rates of change (Huntley, 1985; Ward, 1987; Scheepers, 1990). These studies have all recognised the dominant role dunes play in this area, and have pointed out that with any future management a knowledge of dune functioning is imperative. They have also noted the wide variety of dune types in the study area, and how each of these forms has relatively distinctive geomorphological and ecological characteristics. This chapter, therefore, attempts to provide an outline of the origins and development of dunes in the study area, as well as their respective geomorphological and ecological features. In doing so, this chapter presents a preliminary understanding of the functioning and dynamics of the dune system, and provides a basis for further analysis in the following sections of the study.

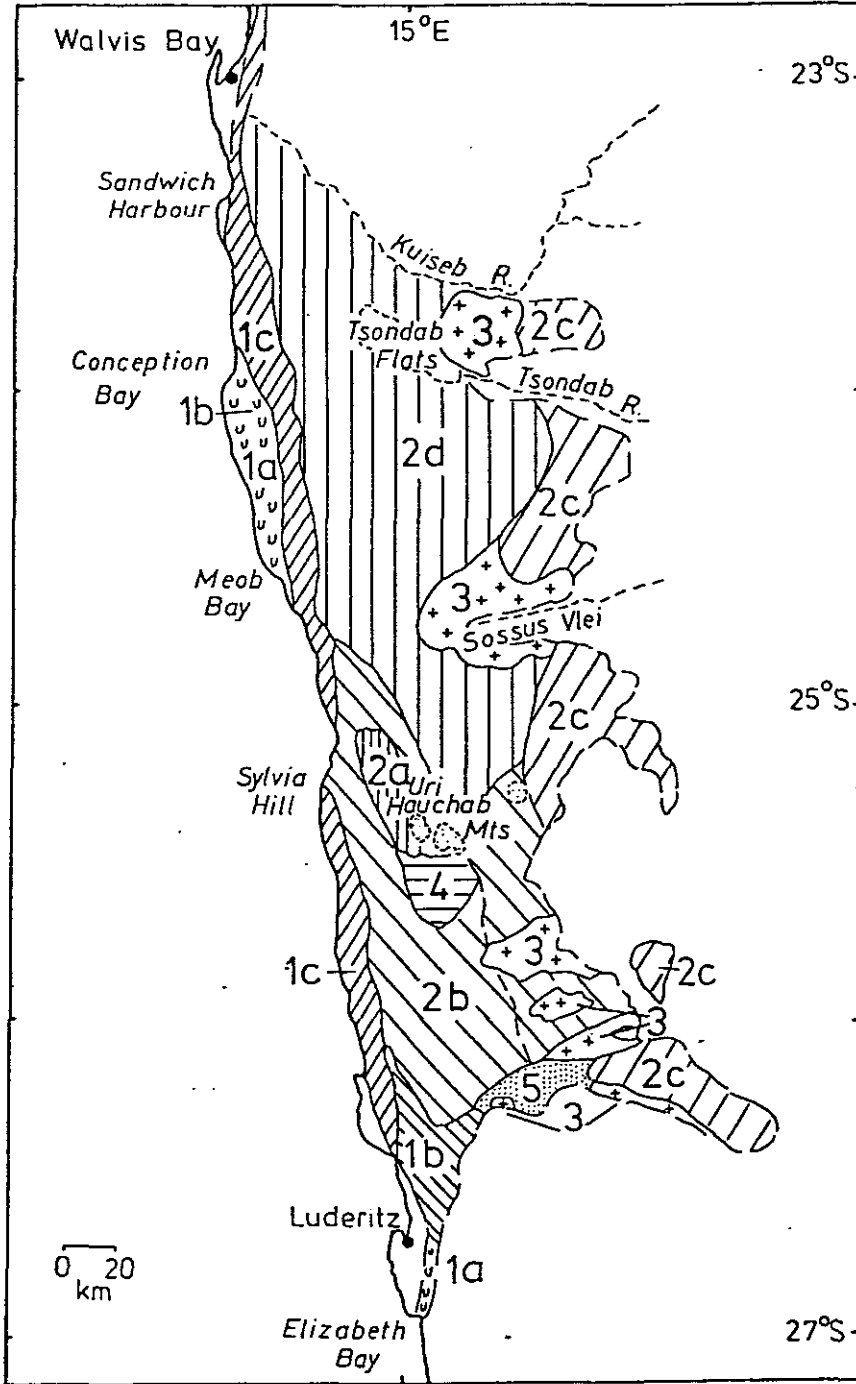


Figure 3.1 Distribution of different dune types in the Namib Sand Sea. Areas of shrub coppice dunes along coast not shown. 1: Crescentic dunes; a) Barchans; b) Simple crescentic dunes; c) Compound crescentic dunes; 2: Linear dunes; a) Linear dunes; a) Simple; b) Compound, straight; c) Compound, anastomosing; d) Complex; 3: Star dunes and chains of star dunes; 4: Large zibar; 5: Sand sheets (SOURCE: LANCASTER, 1973).

3.2 DETERMINANTS OF DUNE DEVELOPMENT

It has been noted by Lancaster (1989) that there are six main determinants of dune morphology in desert areas:

- * the nature of dune sands (especially grain size and sorting characteristics);
- * sand supply;
- * wind regime (particularly directional variability);
- * wind strength;
- * vegetation cover;
- * time.

In the coastal environment, however, many more variables are at play than in continental desert areas. Therefore, with the study area fronting onto the Atlantic Ocean, additional determinants of dune development need to be considered. Tinley (1985) has recognised several of these factors:

- * coast trend and configuration of shorelines (the degree of exposure and deflection of effective winds);
- * rainfall regime;
- * sea (wave action and longshore drift);
- * river mouth dynamics (change of flow and sand input)

The study area is therefore a unique environment, having characteristics of, and being influenced by, both continental desert and coastal environmental conditions.

3.3 CLASSIFICATION OF DUNES

Dunes have been simply defined by Strahler (1975) as any hill or accumulation of sand shaped by the wind. Dunes can be active or inactive depending on the intensity of the wind and the degree of vegetation cover, and can be up to 150 metres high and several kilometres long. As has been discussed by Wilson (1972), dunes are not the only aeolian sand accumulation bedforms. He recognised a hierarchy of aeolian bedforms consisting of four main components: impact ripples, aerodynamic ripples, dunes and draas (see Table 3.1). Wilson based his research on the granulometric control hypothesis and

suggested that there is a relationship between bedform spacing and grain size, with the larger, more widely spaced bedforms consisting of coarser sand particles. This work, however, has not been readily supported by other researchers in the field (McKee, 1979; Pye and Tsoar, 1990), as draas cannot always be distinguished from dunes on the basis of grain size alone, and because there is a continuum of scale between these two bedforms. Pye and Tsoar (1990) proposed that draas are typically large dunes (megadunes) and can be simple, compound or complex in nature.

Although there are relatively few simple or basic dune forms, many combinations of dune type exist and an almost endless number of varieties. According to McKee (1979) dune combinations can be divided into three main categories, namely simple, compound and complex dunes. Simple dunes consist of individual dune forms which are spatially separate from their neighbours. Compound dunes, however, consist of two or more dunes of the same type which have coalesced or are superimposed, whereas complex dunes consist of two or more different types of dunes which have coalesced or have superimposed. It has been noted by Pye and Tsoar (1990) that many attempts have been made to classify dunes based on a combination of shape, number and orientation of slip-faces relative to the prevailing wind (or resultant sand-drift direction) and degree of form mobility. However, the relationship between these factors is highly complex and has led to many problems in classifying dunes types. Many aeolian landforms display a dynamic behaviour typical of different dunes that also complicates this classification. Furthermore, this confusion has been compounded by the use of various generic and local names in different parts of the world.

Several authors have compiled dune classification systems, such as Mabbutt (1977), McKee (1979) and Tinley (1985). These classification systems are represented in Tables 3.2, 3.3 and 3.4 respectively. Tinley's classification was selected above the other systems for the purposes of this study as it was developed specifically for use in southern Africa, and is appropriate for application in both continental desert and coastal dune environments. In this classification system Tinley (1985) divides dunes into four basic groups (Figure 3.2 displays all dune types classified by Tinley):

- * bare or free dunes (wind formed);
- * vegetated dunes (wind and plant formed);
- * dunes related to topographic barriers;
- * dunes related to wetlands.

TABLE 3.1 WILSON'S HIERARCHY OF AEOLIAN BEDFORMS (SOURCE: WILSON 1972)

ORDER	NAME	WAVELENGTH (m)	HEIGHT (m)	ORIGIN
1	draas	300-5500	20-450	aerodynamic instability
2	dunes	3-600	0.1-100	aerodynamic instability
3	aerodynamic ripples	0.015-0.25	0.002-0.05	aerodynamic instability
4	impact ripples	0.05-2.0	0.0005-0.1	impact mechanism

TABLE 3.2 MABBUTT'S CLASSIFICATION OF AEOLIAN SAND FORMS (SOURCE: MABBUTT 1977)

SAND SHEETS	
MINOR FORMS	Sand Ripples Granule ripples
FREE DUNES	Simple dunes Crescentic dune or barchan Longitudinal dunes Transverse dunes
COMPOUND DUNES	Linked barchans Linked longitudinal ridges Reticulate dunes
COMPLEX DUNES	Barachnoid forms Longitudinal forms Transverse forms Peaked forms
DUNES RELATED TO OBSTACLES	Topographic barriers Leeward accumulations Sand shadow Sand drift Lee dune Windward accumulations Climbing and falling dunes Anchorage by vegetation Isolated mounds Transverse ridges Parabolic dunes Longitudinal ridges

TABLE 3.3 McKEE'S, CLASSIFICATION OF AEOLIAN SAND FORMS (SOURCE: McKEE 1979)

TERM	FORM	NUMBER OF SLIPFACES
SHEET	sheetlike with broad, flat surface	none
STRINGER	thin, elongate strip	none
DOME	circular or elliptical mound	none
BARCHAN	crescent in plan view	1
BARCHANOID RIDGE	row of connected crescents in plan view	1
TRANSVERSE RIDGE	asymmetrical ridge	1
BLOWOUT	circular rim or depression	1 or more
PARABOLIC	"U" shaped in plan view	1 or more
LINEAR	symmetrical ridge	2
REVERSING	asymmetrical ridge	2
STAR	central peak with 3 or more arms	3 or more

TABLE 3.4: TINLEY'S CLASSIFICATION OF DUNES IN SOUTHERN AFRICA (SOURCE: TINLEY 1985)

BARE OR FREE DUNES (wind formed)	Mobile sand sheets and mounds Crescentic or transverse dune types Barchan Barchanoid Transverse Reversing Buttress barchanoid Linear Star
VEGETATED DUNES (wind and plant formed)	Strand plant hummock dunes Driftline embryo dunes Hummock or hillock dunes Parallel beach ridge Precipitation dune or retention ridge Parabolic dune types Blowout Accretion ascending parabolic Deflation hairpin parabolic Parallel wind-rift ridges
DUNES RELATED TO TOPOGRAPHIC BARRIERS	Climbing-falling dunes Headland bypass dune Windward diverging dunes
DUNES RELATED TO WETLANDS	Hummock dunes of slacks, washes and river flats Playa lunette dunes Lagoon-shore dunes

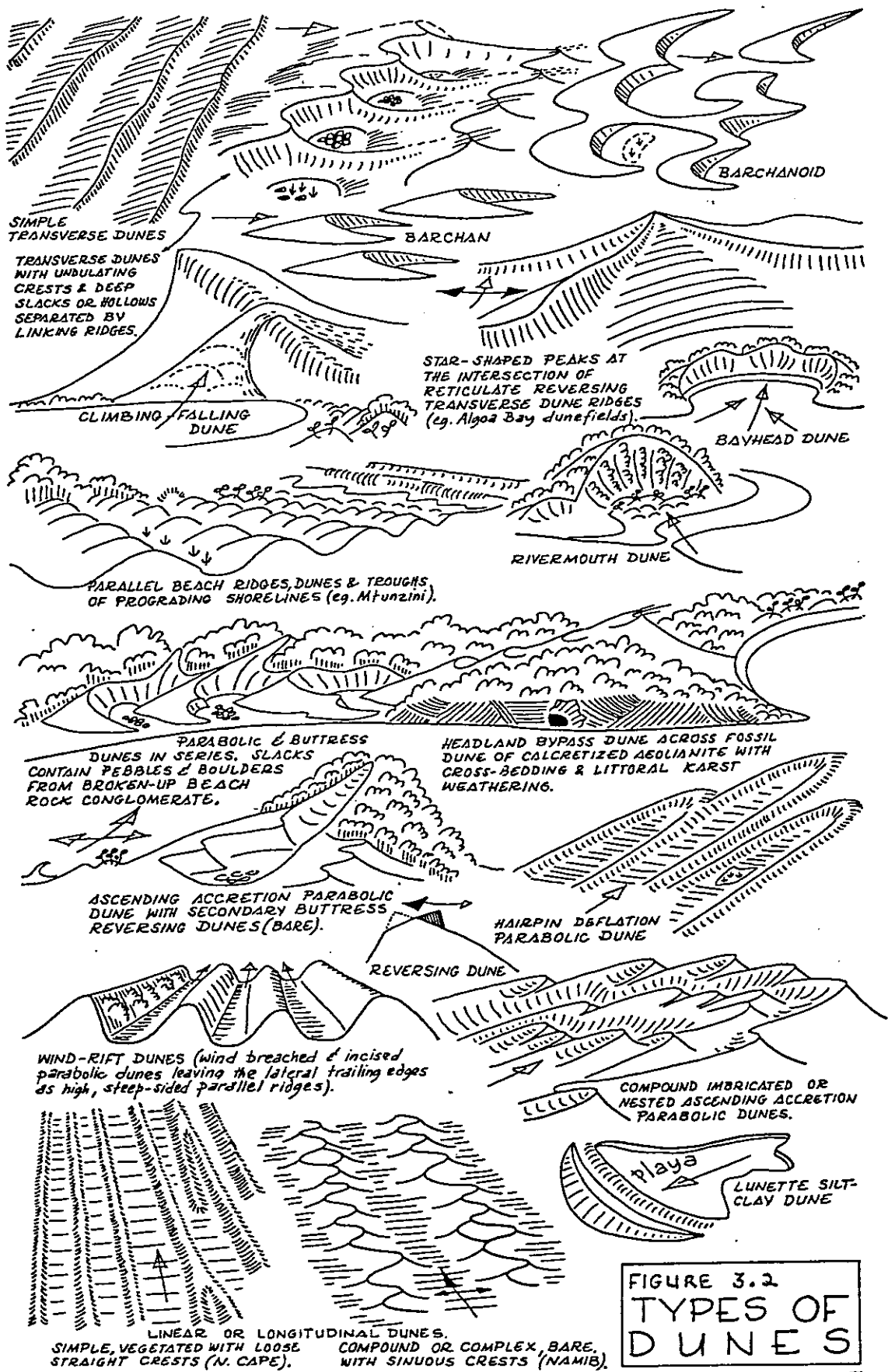


FIGURE 3.2
TYPES OF
DUNES

SOURCE: TINLEY (1985)

The first major category, thus, consists of bare or free dunes which include mobile sand sheets and mounds, crescentic/transverse types, linear dunes and star dunes. Mobile sand sheets and mounds display a rippled surface with few to no low transverse slipfaces. These sand bodies feed climbing dunes, windward dunes, parabolic dunes and precipitation ridges. Crescentic/transverse dunes have their crests and slipfaces orientated transversely to the wind direction. This group includes barchan, barchanoid, transverse, reversing and buttress barchanoid dunes. Linear dunes, characteristic in the Namib Sand Sea, form long elongated ridges parallel to the formative winds. Star dunes, the last type in this category, form sinuous radiating arms that result from effective winds blowing from several directions (Tinley, 1985).

The second major category according to Tinley's (1985) classification are vegetated dunes, which include strand hummocks, precipitation ridges and parabolic dunes. Strand hummock dunes can be divided into driftline embryo dunes, hummock dunes and parallel beach ridges. Precipitation dunes or retention ridges result when sand carrying winds meet a vegetated front, lose velocity and drop their sand load. Parabolic dune types are u- or v- shaped blowouts which have developed as a result of a gap in the plant cover which enables breaching by the wind to occur.

Dunes related to topographic barriers are common in both desert and coastal areas throughout southern Africa. The commonest of the large obstacle-related types along the coastline of the sub-continent is the headland bypass dune. Minor obstacle-related dunes are prevalent in sandy areas wherever rock outcrops or clumps of vegetation occur and Tinley (1985) also identifies several dunes that are associated with wetlands. Examples of these dunes include hummocks of slacks, washes and river flats, playa lunette dunes and lagoon-shore dunes.

3.4 SEDIMENT SOURCES AND COASTAL PROCESSES

3.4.1 Sand Sources

Several theories have been put forward concerning the sources of sand in the Namib Desert. Early this century investigators concluded that the Namib dune sands were derived from the extensive deflated plains of the Sperrgebiet in southern Namibia (Lancaster, 1989). More recently, however, it has been suggested that the fluvial

sediments washed down to the Atlantic Ocean by the Orange River, are responsible for a large proportion of the sands in the Namib Sand Sea (Logan, 1960; Rogers, 1979). Other studies suggest that the Tsondab Sandstone Formation and ephemeral rivers that flow to the east of the sand sea, are also a source of desert sand (Lancaster, 1989; Scheepers, 1990).

The Tsondab Sandstones are widespread along the eastern margins of the sand sea and weather rapidly to produce sand that is easily transported by wind. This sand has a mineralogy that is very similar that of the dune sands, and it has been argued that this formation is a significant sand source. Lancaster (1989), however, has indicated that even though these sandstones do provide a source of desert sand, they are limited to the eastern edges of the sand sea and their contribution is limited. Another source of sand are the ephemeral rivers that flow to the east of the sand sea. However, the importance of these rivers is small, as they drain only small catchments and are characterised by infrequent flood events (Lancaster, 1989). The deposits of the Kuseb River provide a significant source of dune sand in the northwestern sectors of the Namib Sand Sea and hence play an important geomorphic role in the study area (Scheepers, 1990).

It is generally agreed (Logan, 1960; Rogers, 1979; Lancaster, 1989), that the bulk of the sand in the Namib Sand Sea had its origins in the interior of southern Africa, and was deposited by the Orange River into the Atlantic Ocean. Dingle et al. (1983) showed the transport potential of the Orange River and estimated that this river and its tributaries are responsible for at least 27% of the total sediment discharge of the sub-continent. It was noted that even though the majority of this sediment is fine grained and derived from Karoo shales, at least 25-55 million tons of sand sized sediment is also discharged from the Orange River every year (Rogers, 1979). This sand is transported up the coast and inland primarily by longshore drift and aeolian processes.

3.4.2 Ocean Currents and Longshore Sediment Movement

Rogers (1979), in a study on the dispersal of sediment up the Namibian coast, indicated that the sediment of the Orange River on reaching the Atlantic Ocean, is dispersed in a variety of ways. Finer materials are moved southwards by nearshore/rip currents, whereas coarser sands are moved northwards by longshore drift. The rate of transport of sands by longshore drift was measured at Pelican Point near Walvis Bay (CSIR, 1984), and it was

concluded that a net movement of sediment of about 1,0 to 1,4 million cubic metres takes place each year.

Lancaster (1989) documented that this northward moving sediment is in time redirected towards the coast and into shallower water. From here it is cast onto the beach and moved inland by the dominant south and south-westerly winds.

3.4.3 Aeolian Sand Movement

As noted in Section 2.2.2 wind is an important environmental factor in sand transportation and deposition in the study area. The main trends of movement are directly related to the dominant wind directions. Ward and von Brunn (1985b) in their study on the sand dynamics of the lower Kuiseb River recognised two main trends in regional airflow patterns. These patterns are displayed in Figure 3.3, and are summarised as follows:

- * a coastal, high energy, dominantly south to south-westerly unimodal regime west of Rooibank as opposed to a low to intermediate energy, complex bimodal regime inland of Rooibank;
- * the dominance of south to south-westerly wind at all stations in summer compared with the general lower occurrence of those winds in winter, when high velocity, low frequency easterly quadrant berg winds are experienced.

Along the coast, therefore, sand drift shows a marked north to north-easterly trend. However, in the vicinity of Rooibank, just inland of the study area, a south to south-westerly movement predominates. These patterns are roughly compatible with the observed dune types in the Walvis Bay area. The rapid decrease in wind energy inland from the coast, suggests the presence of less active linear dunes in the interior and more active crescentic dunes along the coast.

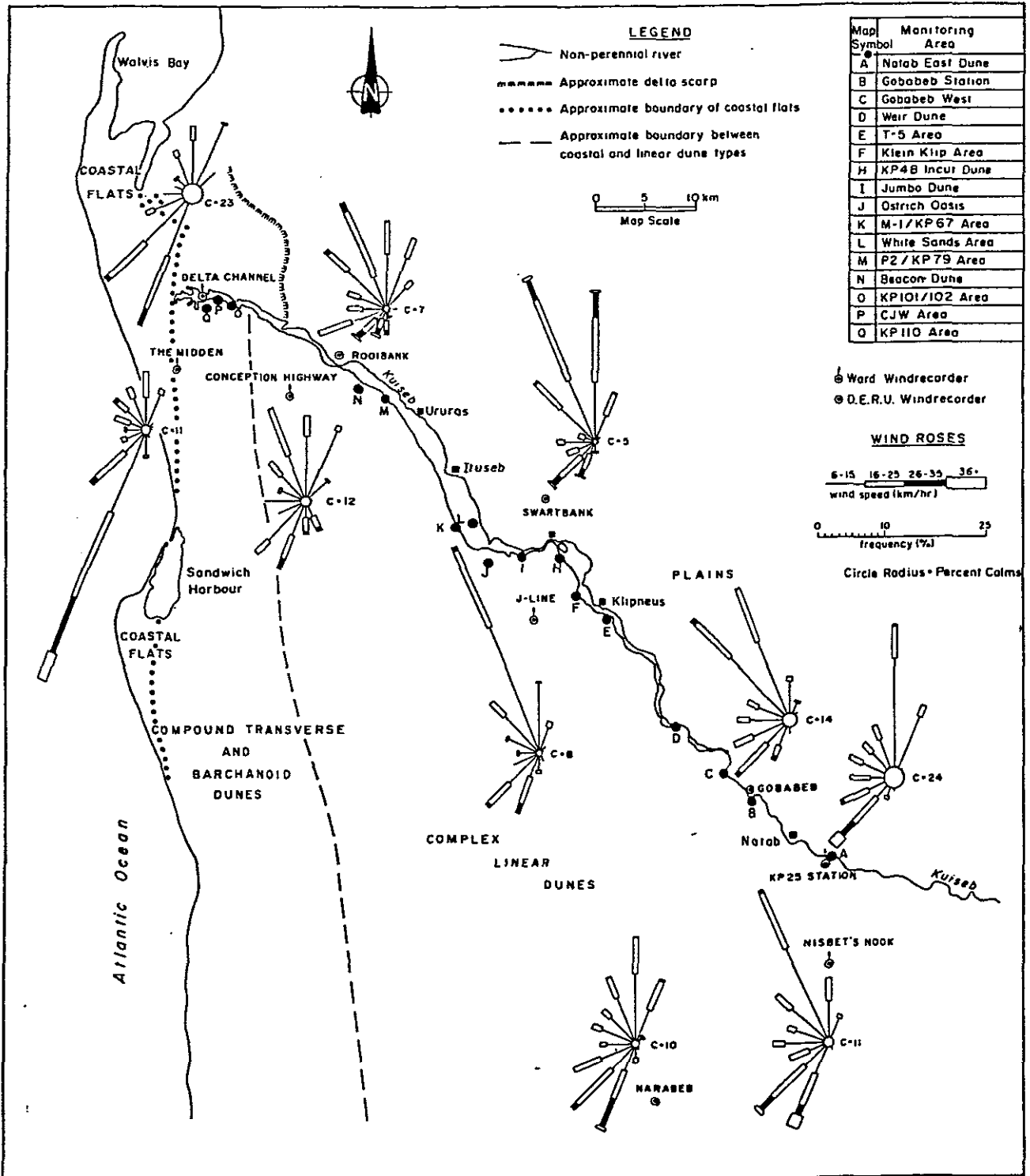


Figure 3.3 Regional airflow patterns in the central Namib Desert (Source: Ward and von Bruun, 1985b)

3.5 DUNES IDENTIFIED IN THE STUDY AREA

Following Tinley's classification (see Table 3.4) as close as possible, three main dune types have been identified in the study area, which have been sub-divided into seven dune forms. These are as follows:

- * hummock dunes (coastal, river delta and flood-plain);
- * crescentic dunes (barchan, small and large transverse barchanoid);
- * linear dunes (complex linear).

3.6 HUMMOCK DUNES

The term hummock dune has been defined as any irregularly shaped mound of sand whose surface is wholly or partially vegetated (Pye and Tsoar, 1990). These features have previously been referred to as knob dunes (Barnard, 1975), coppice dunes (McKee, 1982; Lancaster, 1989), nebkhas (Cooke and Warren, 1973), and hillocks (Tinley, 1985). Hummock dunes are widely distributed in the Walvis Bay Region, particularly in the river mouth flats and coastal foreshore areas. Three hummock dune forms have been identified in this study, these being flood-plain hummocks, river delta hummocks and coastal hummocks. The identification of each of these forms is based on the dominant vegetation type characteristic of each and their distribution across the study area.

3.6.1 Distribution (refer to Figure 4.5)

Coastal hummocks occur primarily along the coastal tract south of Walvis Bay, stretching from 2 km south of the lagoon to approximately 12 km north of Sandwich Harbour. These dunes form a belt at least 2.5 km wide in places. North of Walvis Bay, along the coast towards Swakopmund, patches of coastal hummocks are also evident as a series of discontinuous chains (see Plate 6). River delta hummocks are situated centrally in the Kuiseb Delta, just north of the salt marsh areas. Flood-plain hummock dunes are characteristic in the old northern arm of the lower Kuiseb River, within the terrace created by the 1963 flood event.

3.6.2 Physical Characteristics

Coastal and river delta hummock dunes in the study site are primarily formed and maintained by wind and plant growth in areas where the water table comes near enough to the surface to create a relatively moist sub-soil. Due to the depth of the water table in the more northern sectors of the delta, however, it is unlikely that flood-plain hummocks are maintained in this manner. It has been noted by Ward and von Brunn (1985b) that these dunes are maintained by the perennial grass *Stipagrostis sabulicola* which is able to trap fog water (see Plate 7) (for further detail see Section 3.6.3).

Apart from the continued addition of wind-driven sand, the shape, density and growth characteristics of the associated vegetation strongly determines the morphology of hummock dunes in desert areas (Cooke and Warren, 1973). The hummocks of the study area range in size from about one to five metres in height with diameters of up to fifteen metres. These dunes also vary considerably in plan profile and cross-section, depending on the colonising vegetation and form modification due to wind scouring. The following section briefly outlines the vegetation and fauna characteristic of hummock dunes in the study area.

3.6.3 Flora and Fauna

Dune Vegetation

Research on plant communities in the Lower Kuiseb Valley and Delta by Giess (1971), Theron *et al.* (1980), Ward and van Brunn (1985b), and Van Wyk *et al.* (1985) have shown that the various types of hummock dune occurring in the area all have relatively characteristic plant communities. It has been noted by Theron *et al.* (1980) that flood-plain hummocks are characterised by the plants *Stipagrostis sabulicola*, *Acanthosicyos horrida*, *Acacia erioloba*, *Adenolobus gariensis* and *Lycium tetrandrum*. These communities were recorded both sides of the Kuiseb River, with plants occurring individually or in groups on a hummock dune. It was also observed that *Stipagrostis sabulicola* and *Eragrostis spinosa* commonly occur in areas between the hummock dunes. *Tamarix usneoides* communities were found on flood-plain hummocks at the base of large sand-dunes along the Kuiseb Valley.

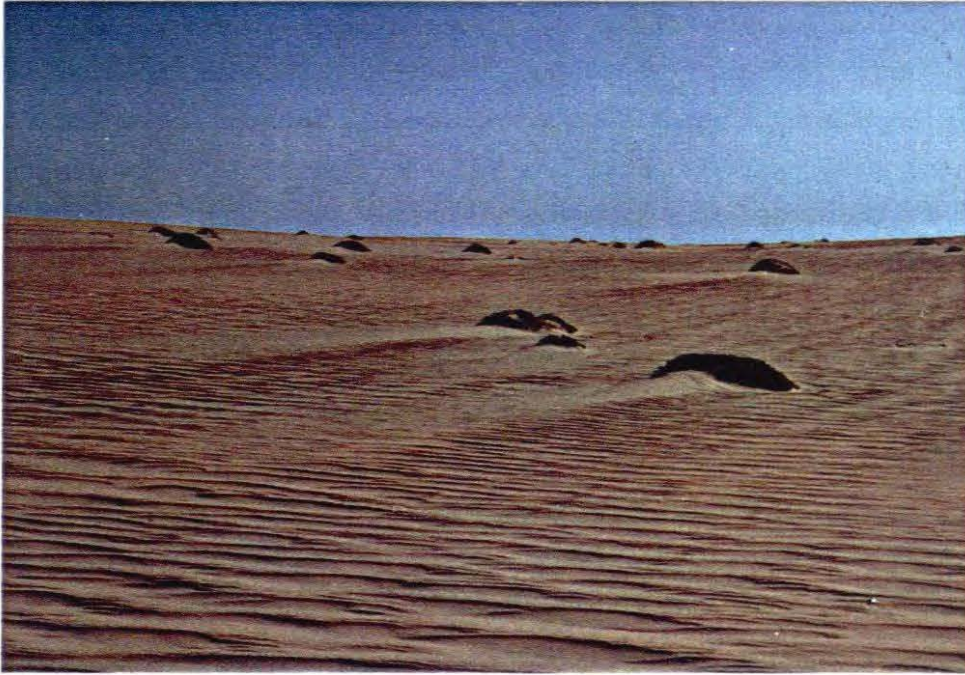


Plate 6 Small coastal hummocks between Walvis Bay and Swakopmund characterised by the shrub *Salsola nollothensis*.

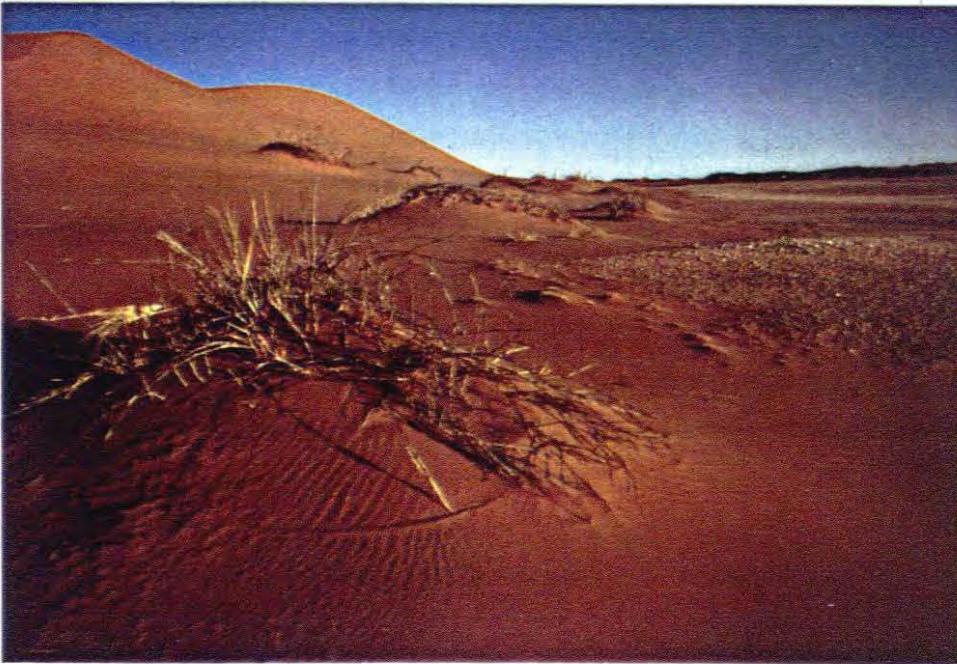


Plate 7 Flood-plain hummocks in the Kuiseb Delta characterised by the grass *Stipagrostis sabulicola*.

Ward and van Brunn (1985b), in their study of the sand dynamics of the lower Kuiseb River, indicated the importance of *Stipagrostis sabulicola* in stabilising dune sand. It was shown that clumps of this perennial grass trap sand, thereby limiting the northward movement of shifting dunes. Louw and Seely (1982) recorded the ability of *S. sabulicola* to trap fog water, use it highly efficiently, and thus survive many years with little or no rain. It is for this reason that Ward and von Brunn (1985b) recognised that this grass is probably independent of the Kuiseb River groundwater for its survival. Giess (1971) and Theron *et al.* (1980) also recorded the sand-holding capability of the Inara, *Acanthosicyos horrida*, and *Tamarix usneoides* in the northern sectors of the study area. Unlike *Stipagrostis sabulicola*, *Tamarix usneoides* appears dependant on moist conditions for its establishment, and hence older individuals and thickets of this plant occupying the floodplains possibly indicate earlier courses of the river (Theron *et al.*, 1980).

The hummocks of the central delta are formed and maintained principally by *Salsola nollothensis*, and to a lesser extent *Lycium tetrandum*, *Stipagrostis sabulicola* and *Tamarix usneoides* (Seely and Ward, 1989). These plants are supported by the high water table in the area. It has been noted by Scheepers (1990) that this area is characterised by the particularly large size of the *Tamarix* trees. Along the coastal strip between Walvis Bay and Swakopmund, and south of Walvis Bay, hummock dunes have formed over and around specimens of *Zygophyllum clavatum*, *Psilocaulon salicornioides*, *Salsola nollothensis*, and *Salsola aphylla* (Giess, 1971). Other mound-forming coastal dune plants occurring in the study area include *Arctotheca populifolia*, *Merremia multisecta*, *Arthraerua leubnitziae* and the rhizomatous grass *Eragrostis cyperoides* (Tinley, 1985). Important features which enable these plants to contend with the harsh conditions of this stretch of coast have been noted by Tinley (1985), and are as follows:

- * the ability to grow sufficiently rapidly to keep ahead of accumulating sand;
- * being succulent or having other water adaptations to prevent water loss;
- * being resistant to high salt concentrations.

Dune Fauna

Few faunal studies have been done specifically on the hummock dunes in the Walvis Bay area, however, research has been undertaken extensively across the delta which includes many of these dune areas (eg. Seely and Griffin, 1986; Fielden, 1989; Seely, 1990).

These studies have shown that vegetated hummock dunes supply a necessary refuge for many species that do not burrow beneath the sand. In addition, vegetation of these dunes is a vital food source for many desert animals.

The invertebrate fauna specific to coastal, river delta and flood-plain hummocks is poorly known. Seely and Griffin (1986) do outline insect fauna for vegetated dunes in the region, but this also includes linear dune forms. Hummocks within the channel of the Kuiseb River, outside of the study area, have been investigated to a greater degree (eg. Whanton and Seely, 1982; Van Wyk *et al.*, 1985; Jacobson *et al.*, 1995). Whanton and Seely (1982) recorded eight species of tenebrionid beetle along the sandy washes and dune bases of the Kuiseb River valley and noted the high concentration of heteropodid spiders in the hummock dune areas. Jacobson *et al.* (1995) noted the many species of millipedes and isopods, which have only recently been identified, that inhabit the lower Kuiseb River. It is possible that a high degree of endemism occurs in the hummock dunes of the study area, although, considerably more research is required to substantiate this.

Vertebrate fauna that inhabit hummock dunes along the coast and river flats of the Kuiseb Delta include several reptile and small mammal species that take refuge in the dune vegetation, and larger mammals that pass through these areas in search of food. The common mole-rat (*Cryptomys hottentotus*) is found in the region and probably occurs in the Walvis Bay area, as well as several species of gerbil, including the Dune hairy-footed gerbil (*Gerbillus tytonis*), Setzer's hairy-footed gerbil (*Gerbillus setzeri*), the Pygmy gerbil (*Gerbillus paeba*) and the Short-tailed gerbil (*Desmodillus auriculairs*) (Seely and Griffin, 1986). Several species of mouse, four species of shrew, and two species of hare have been recorded in the Namib Naukluft Park, and may also occur in the study area (CSIR, 1991a).

Larger mammals such as the Brown hyaena (*Hyaena brunnea*) and the Black-backed jackal (*Canis mesomelas*) are also found scavenging through these dunes, particularly south of Walvis Bay, for nesting birds, smaller rodents and reptiles (see Plate 2). Studies on the foraging behaviour of the Black-backed jackal along the Namibian coast has shown that these jackals drag their prey carcasses onto the summits of hummock dunes. Favoured hummocks become middens comprising many years of accumulated prey remains and windblown sand. It is argued that these hummock dunes are important for thermo-regulation, as they reduce windspeeds in their lee by at least four-fold and have

air temperatures about seven degrees higher than the beach (Lovegrove, 1993). Vegetation of dune hummocks in the Kuiseb Valley and Delta also provides forage for several larger nomadic species including Hartman's zebra (*Equus zebra hartmannae*), gemsbok (*Oryx gazella*) and springbok (*Antidorcas marsupialis*) (UCT, 1996).

In addition, vegetated hummock dunes supply refuge to several lizards and snakes, such as the endemic Side-winding adder (*Bitis peringueyi*), Puff adder (*Bitis arietans*), Horned adder (*Bitis caudalis*) and various species of sand-snake (*Psammophis* spp.) (UCT, 1996). The insectivorous Namaqua chameleon (*Chameleo namaquensis*) also frequents these areas in search of prey. Vegetated dune and inter-dune areas provide important nesting and breeding sites for several resident birds. Along the coast African black oystercatchers (*Haematopus moquini*), White-fronted plovers (*Charadrius marginatus*) and Damara terns (*Sterna balaenarum*), all of which are threatened species, utilise hummock dunes and inter-dune areas for nesting purposes. Flood-plain and river delta hummocks provide important feeding and nesting habitat for the endemic Dune lark (*Mirafra erythroclamys*) and the Pale chanting goshawk (*Melierax canorus*).

3.6.4. Conservation significance

Hummock dunes in the Walvis Bay area play an important role in the physical dynamics of the area, by trapping and storing large volumes of unconsolidated sands. These dunes therefore act as a reservoir for sand that is constantly exchanged between different areas (eg. between dunes and beach). This function is significant in the Kuiseb Delta as it limits the northward advance of dunes from the Namib Sand Sea, and hence reduces potential driftsand problems. Hummocks are also important in that they provide a discrete ecological environment that supports numerous endemic and specialised plants and animals. The vegetation on these dunes not only provides a source of food for many organisms, but also is a vital source of shade and cover in this otherwise barren environment.

A significant concern in the Kuiseb Delta has been the noticeable die-back of vegetation, particularly the dominant shrub *Salsola nollothensis*, an important hummock forming plant (Walvis Bay Municipality, 1985). These plants were apparently established when the last flood occurred in 1963 and the area was inundated with freshwater. Even though *Salsola nollothensis* has a high salt resistance, the absence of floods has resulted in a salinity that exceeds the tolerance levels of this species. In certain areas this has led to

their death, and consequently the movement of large volumes of sand to the dune area situated to the east, south and west of the lagoon (Walvis Bay Municipality, 1985). On a more local scale, damage to dune vegetation by off-road vehicles has also resulted in instability.

The destruction of dune vegetation, not only alters the sand budget of the area, but also poses a threat to many indigenous invertebrates, reptiles, birds and mammals that inhabit these areas. A loss and fragmentation of habitat could result in the local disappearance of several species and possibly even extinctions. Chapters 4 and 5 provide an in-depth analysis of the factors contributing to the die-back of vegetation and point out all the ramifications that result, both ecological and socio-economic.

3.7 CRESCENTIC OR TRANSVERSE DUNES

Crescentic dunes in the study area are represented by both barchans and transverse barchanoid dunes. Barchans are unvegetated and typically recognised by their steep lee face and leading horns. Transverse barchanoid dunes are either sparsely vegetated or unvegetated, and were divided into large and small forms because of their size and interdune spacing. Based on measurements by Scheepers (1990), large transverse barchanoids were estimated to be 20 - 40 metres in height, and small transverse barchanoids 5 - 20 metres in height. Throughout the central Namib Desert crescentic dunes generally do not occur more than twenty kilometres inland from the coast (Lancaster, 1989).

3.7.1 Distribution (refer to Figure 4.5)

Barchans are typically rare in the Namib Desert, however, in the study area are evidenced in two main areas: south of Walvis Bay Town, and on the leading edge of the Swakopmund/Walvis Bay Dune Field. Small transverse barchanoids are recorded widely across the Kuiseb Delta, forming a link with the Namib Sand Sea to the south. A small patch of these dunes is also apparent at the north-western edge of the Swakopmund/Walvis Bay Dune Field. The distribution of large transverse barchanoids are extensive south of the Kuiseb River, however, in the study area only occur along the western edge of the Swakopmund/Walvis Bay Dune Field.

3.7.2 Physical characteristics

Barchans are isolated, crescent-shaped dunes that typically occur in groups on firm desert floors, with their axes at right angles to the wind (see Plate 8). These dunes are formed where there is a steady though sparse sand supply carried by moderate sand-moving winds which are persistent from one direction (Tinley, 1985). Barchan dunes have a leeward avalanching slipface that tapers towards the sides, forming horns that advance downwind faster than the higher central body of the crescent. The barchan therefore advances downwind by movement of sand over the gentler windward slope, avalanching down the steeper slipface and along the horns by creep. Barchans in the Kuiseb Delta are generally not less than five metres high (Scheepers, 1990). According to Lancaster (1989) most barchans occur on the downwind margins of sand seas or dune fields, and as such, barchans in the study area are no exception to this.

Large transverse barchanoids are typically compound in form and consist of parallel rows of linked or coalesced barchans and transverse dune ridges (see Plate 9). These dunes usually consist of a main dune ridge 20 - 40 m high with a spacing of over 100m. On the upper stoss slopes and crests there are often several small barchanoid ridges 2 - 5 m high. These dunes occur where sand cover is complete or near complete, and rarely has true interdune areas (Lancaster, 1989). Small transverse barchanoids are similar in shape to the former but have a dune ridge that is not more than 5 - 20 m high and a far smaller dune spacing.

Rates of movement of 10-13m high barchan dunes were measured by Barnard (1975) in the Kuiseb Delta region, who calculated advance rates of 6.8 - 13.7 m. yr⁻¹. More recent studies suggest, however, that in some areas dunes are migrating at rates of up to 20 m. yr⁻¹ (Walvis Bay Municipality, 1985). Ward and von Brunn (1985b) showed rates of dune movement for crescentic dunes up to 30m high (ie. large transverse barchanoid dunes) on the southern bank of Kuiseb River west of Rooibank. This study showed advance rates of 0.80 - 6.40 m.yr⁻¹.

3.7.3 Plate 8 & 9

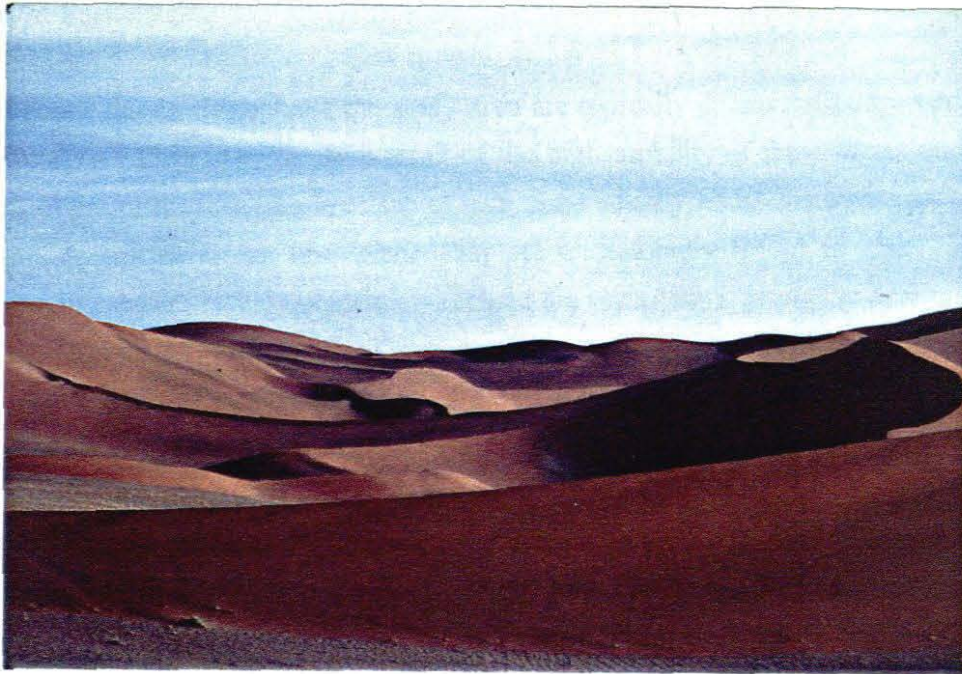


Plate 8 Barchan dunes south of Walvis Bay Town.

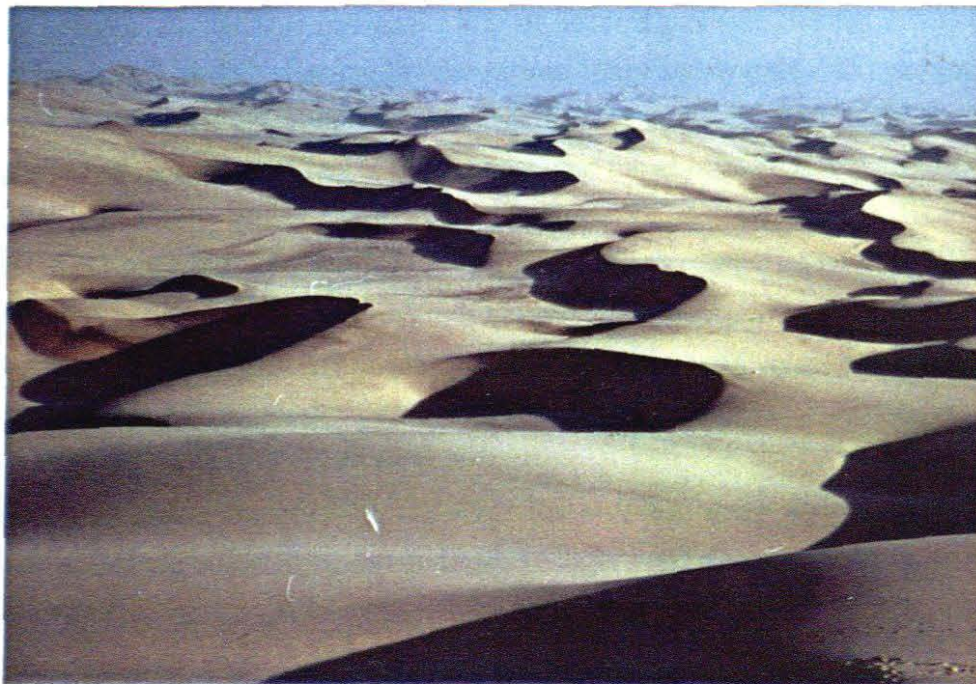


Plate 9 Large transverse barchanoid dunes in the Swakopmund/Walvis Bay Dune Field.

3.7.3 Flora and fauna

Dune Vegetation

Crescentic dunes throughout the study area are typically characterised by very little or no vegetation. This is primarily a result of the high mobility of these dunes and the lack of true inter-dune areas (the lee face of one dune usually abuts the stoss slope of the next dune downwind). The few plants that are occasionally found in areas dominated by crescentic dunes include perennials such as the succulent *Trianthema hereroensis* and the grass *Stipagrostis sabulicola*. These species generally occur at the base of slip faces and the lower parts of stoss slopes.

Dune Fauna

Since these dunes are characterised by very little or no vegetation their fauna is primarily restricted to invertebrates and small mammals which feed off wind-blown detritus that concentrates on the dune slip faces. Therefore detritus, which may include seeds and other reproductive parts of the plant and organic material of animal origin, forms the basis of the food webs on these dunes.

The invertebrate fauna is not unlike that of linear dunes (see Section 3.8.3) except there are fewer herbivorous species. In reference to Seely and Ward (1989) tenebrionid beetles and fishmoths are the dominant detritivores of these dunes. Due to the relatively close distribution of crescentic dunes to the coast, and the extremely infrequent rainfall events, many fog-basking insects are found collecting water on the dune slips. Examples include the head-standing tenebrionid *Onymacris unguicularis* and *Zophosis fairmairei*. Predatory solifugids (sun spiders), and several families of arachnida such as Nemiesiidae, Eresidae, Occobiidae, Aranneidae and Zodariidae, can also be found (Walmsley Environmental Consultants, 1995b).

Vertebrate fauna recorded in crescentic dunes of the study area is confined to a few species that are suited to an environment of highly mobile sand. Such species include the Side-winding adder (*Bitis peringueyi*), Sand-diving lizard (*Aporosaura anchietae*) and Grant's golden mole (*Erimitalpa granti namibensis*). It has been noted that larger mammals such as Black-backed jackal (*Canis mesomelas*) and Brown hyaena (*Hyaena brunnea*) have been reported in the transverse/barchanoid dunes between Walvis Bay and

Swakopmund (Walmsley Environmental Consultants, 1995b). However, it is unlikely that they live in these areas, and probably only pass through these dunes on their way to the coast. Several bird species, including the rare Dune Lark (*Mirafra erythroclamys*), inhabit the small transverse barchanoid dunes across the Kuiseb Delta in search of food.

3.7.4 Conservation significance

Even though the encroachment of crescentic dunes are a severe threat to the Walvis Bay environment (see Chapter 5), they do support several species that are specifically adapted to a system of shifting sands, and are hence of conservation significance. Such species include the endemic Side-winding adder (*Bitis peringueyi*) and the Shovel-snouted lizard (*Aporosaura anchietae*). It has been noted by Louw and Seely (1982) that due to the low primary production and biomass supported by these dunes, large areas need to be conserved in order to adequately support minimum viable populations.

Crescentic dunes in the study area are of great scenic beauty and are important tourist attractions, particularly the larger transverse barchanoids of the Swakopmund/Walvis Bay Dune Field. These dunes are extensively used for motor-cross driving, paragliding, dune-boarding and sight-seeing trips. Being unvegetated and fairly mobile, these activities generally have little impact on the dune system.

Recent archeological research has revealed several stone-age sites in the Kuiseb Delta that are considered to be of particular scientific, historic and cultural value. Many of these sites lie beneath the shifting barchan dunes south of Walvis Bay and are periodically exposed. These sites are vulnerable to disturbance and important material could be destroyed through vehicular traffic and other recreational activities. As such, these areas should be delineated and access controlled (for further discussion see Section 6.3.4).

3.8 LINEAR DUNES

Linear or longitudinal (Barnard, 1973) dunes on N-S to NW-SE alignments are the dominant form in the Namib Sand Sea and cover 74% of its area. These dunes occur inland of the crescentic dunes along the coast and extend inland where they become vegetated and more stable. As with other dune types, simple, compound and complex

varieties can be recognised (Lancaster, 1983), with complex linear dunes being the only variety found in the study area.

3.8.1 Distribution (refer to Figure 4.5)

Linear dunes in the study area are limited to the eastern inland sector of the Swakopmund/Walvis Bay Dune Field. Linear dunes of the main Namib Sand Sea verge onto the south-eastern boundary of the study area and their gradual northward advance results in their leading edge collapsing into the lower Kuiseb River channel.

3.8.2 Physical characteristics

Linear dunes are characterised by their considerable length, relative straightness, parallelism, regular spacing, and low ratio of dune to interdune areas (Pye and Tsoar, 1990). The complex linear dunes in the study area consist typically of a single main dune ridge which rises to 50-170m above adjacent interdune areas (see Plate 10). Dune spacing is generally between 400-800m. Secondary or superimposed crescentic dunes, usually oblique or transverse to the main trend, are often developed on their surfaces and can reach heights of up to 10m (Lancaster, 1989).

Rates of movement and extension of linear dunes have not been measured systematically in the study area, however, Ward and von Brunn (1985b) observed dune advance at the northern end of the sand sea, and noted minimal rates (mostly less than 0.04 m yr^{-1}) in the Swartbank and Rooibank areas, with net movement in a north north-west or east north-east direction. Lancaster (1989) recorded slightly higher rates of up to 1.85 m yr^{-1} in the vicinity of Gobabeb. It can be inferred, therefore, that similar rates of advance are experienced in the study area.

3.8.3 Flora and flora

Dune Vegetation

Linear dunes in the Namib Desert are either partly vegetated or unvegetated, with the more vegetated forms occurring towards the east of the sand sea (see Plate 11). In the study area linear dunes are generally unvegetated, although it has been noted that in wetter years sparse vegetation is evident (Walmsley Environmental Consultants, 1995b).



Plate 10 Linear dunes in the Swakopmund/Walvis Bay Dune Field.

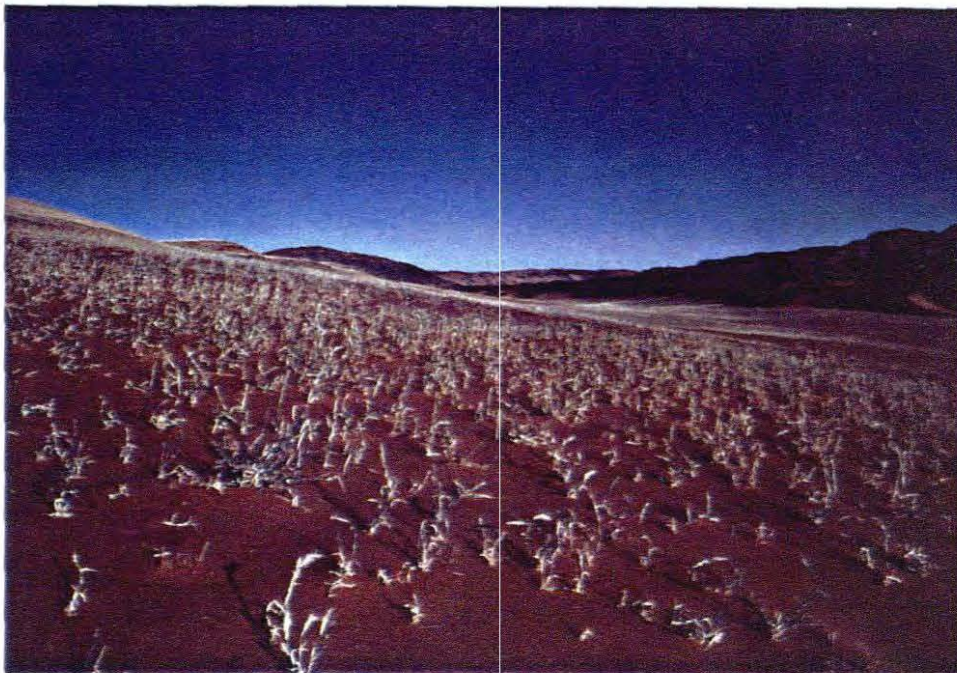


Plate 11 Vegetated linear dunes south-east of the study area.

According to Louw and Seely (1982) up to ten species of plant occur in the linear dunes south of the Kuiseb River, and it is likely that several of these species are found in the linear dunes of the study area. This vegetation occurs mainly on the dune slopes as a result of the water-storing characteristics of dune sand and the instability of dune crests. Species recorded include *Stipagrostis sabulicola*, *Eragrostis spinosa* and *Trianthema hereroensis*. These plants are often clumped on the eastern slip-faces of these dunes in order to trap fog water, and as a result have a partly stabilising effect (Louw and Seely, 1982). Various other plants, including *Monsonia ignorata*, *Hexacyrtis dickiana*, *Stipagrostis gonatostachys* and *Stipagrostis lutescens*, have also been recorded (Giess, 1971).

Linear dunes in the study area are mobile and are characterised by unconsolidated sands. Due to this instability of the sand surface plants have developed a variety of adaptations to cope with periods of inundation. For example, grass species of the genus *Stipagrostis* are stimulated to grow by sand smothering. Roots of plants on these dunes are also adapted to living in mobile sands by having either long tap roots, or a profuse growth of lateral and adventitious roots that do not penetrate the dune further than a few metres. Furthermore, the lateral surface roots of *Stipagrostis* sp. have the ability to uptake fog water (Louw and Seely, 1982). The response of plants to mobile dunes concerns not only the plasticity of growth patterns, above and below sand, but also germination, establishment and reproduction (Seely, 1990). It should be noted, however, that a rapid rate of dune advance, such as that displayed by barchan dunes, may smother and destroy even well adapted species. Many of the plants in these dunes (particularly grasses) have relatively short life-spans, opportunistically germinating during brief rainfall periods. Much of the vegetation observed on these dunes, therefore, is in fact dead and represents past rainfall events. This detritus, however, plays an important role in these systems by supplying organic matter and provides a semi-stabilising effect to the dunes.

Dune Fauna

Numerous studies (eg. Koch, 1961; Holm and Scholtz, 1980; Louw and Seely, 1982; Seely and Griffin, 1986) have indicated a wide variety of organisms inhabit linear dunes of the central Namib Desert. This research has compared dune fauna over various spatial and temporal scales, from across the entire sand sea to micro-habitats on individual dunes. Seely (1990) noted that mobile sand dunes in the Namib host a fauna that is characterised by at least 128 invertebrate species, 10 reptile species, 5 mammal species

and 1 resident bird species. It is likely that many of these species are represented in the linear dunes in the Walvis Bay area.

Due to the relative immobility of many insects, particularly the flightless species such as the tenebrionids, a high degree of speciation has occurred. These endemics are characterised by herbivores, detritivores, predators and parasitoids, with their distributions being influenced by several factors, viz: dune height, ratio of vegetated to unvegetated surface, quantity of detritus on slip faces, and amount of fog (Seely, 1990). Holm and Scholtz (1980) list 29 phytophagous insects living among sparsely vegetated linear dunes of the central Namib. These include members of the Orthoptera (Tettigoniidae, Acrididae), Hemiptera (Dictyopharidae, Cynidae, Coreidae), Hymenoptera, Diptera and Coleoptera (Medoidae, Buprestidae, Histeridae, Curculionidae).

Due to the fact that rain almost never occurs and fog is only present for a few hours, if it occurs at all, fungi and bacteria, which need a perpetually moist environment, are probably of no importance in the decomposition and mineralisation of plant detritus in the dunes of the Namib (Seely and Griffin, 1986). For this reason, larger invertebrates such as thysanurans and tenebrionids, play an important role as decomposers of surface litter. Holm and Scholtz (1980) list 36 species of detritivores/omnivores living in the linear dunes of the central Namib, 15 of which live only on the dunes and avoid nearby interdunes. These include species within the orders Thysanura (Lepismatidae), Isoptera (Hodotermitidae, Rhinotermitidae) and Coleoptera (Tenebrionidae). The Namib fauna at the higher trophic levels is little known with the exception of the sun-spiders (Solifugae) (Holm and Scholtz, 1980). Other arthropod predators and parasitoids recorded in linear dune habitats include species belonging to the groups Aranea, Acari (Anystidae), Scorpions (Buthidae, Scorpionidae), Hemiptera (Cydnidae), Neuroptera (Myrmeleontidae), Dectyoptera (Mantidae), Hymenoptera, Diptera (Asilidae) and Coleoptera (Carabidae, Histeridae) (Holm and Scholtz, 1980).

The vertebrate fauna in the linear dunes south of the Kuiseb River is primarily characterised by reptiles, small mammals and a single endemic bird species. Certain reptiles are specifically adapted to the dune environment. These include the sand-diving Shovel-snouted lizard (*Aporosaura anchietae*), and the insectivorous Web-footed gecko (*Palmatogecko rangei*) which burrows into compacted sand on dune slopes (Louw and Seely, 1982). Snakes are poorly represented in the dune areas and only two species have been recorded here, namely the Namib sand snake (*Psammophis leightoni namibensis*)

and the endemic Side-winding adder (*Bitis peringueyi*). The endemic Dune lark (*Mirafraga erythroclamys*) is the only bird that resides in the sand sea south of the Kuiseb (Lovegrove, 1993).

Several mammals have been recorded in the linear dunes, but few are restricted to these areas. Studies on the distribution of Grant's golden mole (*Eremitalpa granti namibensis*) have shown that it occurs widely in the dunes south of the Kuiseb River, and probably is found in the Swakopmund/Walvis Bay Dune Field (Fielden, 1989). Other rodents that occur in these dunes include the Dune hairy-footed gerbil (*Gerbillurus tytonis*), Pygmy gerbil (*Gerbillurus paeba*) and the Round-eared elephant shrew (*Macroscelides proboscideus*). The Cape hare (*Lepus capensis*) may also be present (Seely and Griffin, 1986).

3.8.4 Conservation significance

Even though linear dunes are only evident in the north-east of the study area, they are a characteristic and significant landform in the Namib Sand Sea, covering three-quarters of its area. As a consequence, much of the research that has been undertaken in the Namib has focussed on these dunes and provided a great deal of information on the ecology and geomorphology of desert systems.

The mobile linear dunes in the study area, as in the main sand sea, are typified by very distinctive assemblages of organisms. Several plant and animal species are endemic and specifically adapted to this unique desert dune habitat. Due to the relatively low levels of primary production in these dunes, very large areas are required to preserve these habitats adequately.

Linear dunes are important tourist attractions, particularly in the Erongo Region where more and more recreational activities are being undertaken annually. It is apparent that increased human activities in desert areas have a detrimental influence on vegetation growth, and negatively affect anthropod, reptile and mammal components of the ecosystem (see Section 5.2.4). The impact of these activities on mobile sands, however, is probably less than other desert areas, but will need to be considered in assessing the carrying capacity of the area.

3.8 CONCLUSION

The study site occurs along the north-western edge of the Namib Sand Sea at the delta of the Kuiseb River. Studies have indicated that the main source of sands in the area are of marine origin, however, fluvial and aeolian processes also play a significant role. Due to the arid conditions and limited vegetation much of these sands are unconsolidated and have been shaped into several forms primarily by the dominant wind regimes. It is also apparent that several other factors, characteristic of both continental desert and coastal environmental conditions, influence the dune morphology in the Walvis Bay area.

Three main categories of dunes, namely hummock dunes, crescentic dunes and linear dunes, have been identified in this study. These categories have been sub-divided into specific dune types, based on morphology, vegetation cover and distribution in the study area. Hummock dunes have been split into coastal, river delta and flood-plain hummocks. Crescentic dunes have been separated into barchans, small transverse barchanoids and large transverse barchanoids. Whereas linear dunes in the study area are represented only by complex linear forms.

Hummock dunes are formed primarily by wind and plant growth, are relatively stable and play an important role in the region by trapping the movement of driftsands. The vegetation of these dunes is hardy and typically characterised by resilient pioneer communities. The vegetation of these dunes provides an important source of food and critical refuge for many animals in this otherwise barren landscape. Crescentic dunes are the more mobile of the dune forms occurring in the study area, and barchans have been observed south of Walvis Bay moving at rates of up to 20 myr^{-1} . Barchans are generally unvegetated, however, transverse barchanoids are often characterised by a few species of grasses and shrubs. Complex linear dunes are the predominant dune form in the Namib Sand Sea, but in the area of study are limited to the dune field north of Walvis Bay. Much research has been undertaken on linear dunes in the Namib, and has shown that even though these forms are usually barren or sparsely vegetated they support a wide variety of organisms that are highly adapted to the sandy desert environment.

In conclusion, therefore, several dune types occur in the vicinity of Walvis Bay, each characterised by a relatively distinctive morphology, fauna and flora. The variety of dune types contributes to the diversity of habitat in the area, and ensures the maintenance of an unusually high species richness in the region. The predominance of different dune types

in the study area are maintained by certain environmental conditions. Any alteration of these conditions, therefore, whether human or naturally induced, may result in a change in the abundance of certain dune types - which could have serious ecological and socio-economic ramifications. The following chapter will attempt to determine the degree of environmental change in the study area between 1943 and 1980, by analysing the dynamics of dune distribution and extent through aerial photograph interpretation.

**HISTORICAL CHANGES AND
STABILITY OF DUNES IN THE
STUDY AREA**

4. HISTORICAL CHANGES AND STABILITY OF DUNES IN THE WALVIS BAY AREA

4.1 INTRODUCTION

It has been widely believed that the scouring action of floods in the Kuiseb River, even at the infrequent intervals at which they occur, is sufficient to hold back the northward advance of dunes from the Namib Sand Sea (see Plate 1). Furthermore, the dense vegetation of the lower Kuiseb River and Delta was seen, by several researchers in the field, as a potent physical barrier to dune migration (Barnard, 1975; Scheepers, 1990). Observations over the last few decades suggest that a great deal of stress is being placed on these systems by an unsustainable use of resources, in particular water resources (Huntley, 1985; Jacobson *et al.*, 1995). These stresses are being reflected by the noticeable die-back of vegetation across the Kuiseb Delta (Ward and von Brunn, 1985b) and the significant drift of sand into Walvis Bay Town (Walvis Bay Municipality, 1995). In order to understand the implications of these processes, both on the sensitive desert ecology and on future land-use patterns, it is essential that the long-term dynamics and stability of the area is effectively considered.

As noted, much literature is available highlighting the significance of these issues. Extraordinarily, however, no attempts have been made to analyse the recent historical record and describe the changes that have occurred. The broad aim of this chapter, therefore, is to provide an historical perspective of sand dunes in the Walvis Bay area through the interpretation of aerial photographs (1943-1980), and specifically to answer the following questions:

- * What is the distribution and extent of various dune types, as well as other key geomorphological features, in the study area?
- * What are the dynamics of these features, in terms of distribution and extent, between 1943 and 1980?

It is intended that the results of this chapter will contribute in understanding the impacts of dune encroachment, both ecological and socio-economic, which are discussed in Chapter 5.

4.2 AERIAL PHOTOGRAPHY AS A TOOL FOR COMPARATIVE INTERPRETATION AND CHANGE

"The conquest of the air enables mankind for the first time in its history to experience (the) interaction (of man and nature shaping the face of the earth) in all its innumerable ramifications"

(Gutkind, 1956)

Multi-temporal aerial photographs provide "frozen-models" of the environment at different points along a time continuum (Bayne, 1984). The changes in elements of the environment, observed through comparative interpretation of aerial photographs, can provide valuable information on the dynamics of processes operating in a specific area. Aerial photographs not only provide information on the processes operating, but also gives indications on the rates of change at which these operate (Bayne, 1984). This information, therefore, can play an important role in environmental studies by assessing cause and effect relationships and aiding the prediction of future changes.

The usefulness of aerial photographs as a tool in environmental planning and management has been widely recognised by several investigators in southern Africa over the last two decades (eg. Bayne, 1984; Schwabe, 1992; Soboil, 1993). Of particular significance has been the value of these methods in dynamic coastal areas, where aerial photographs have been used to identify the long term stability of sandy shores and so contribute to future land-use planning and development (eg. Lord *et al.*, 1985; CSIR, 1988; Luger, 1992).

4.3 LIMITATIONS OF USING AERIAL PHOTOGRAPHY

In order to ensure the accuracy and reliability of aerial photographs used in this study, the following limitations were considered:

- * aerial photographs are at different scales (for example the 1943 series is at a scale of 1:25 000, the 1963 and 1968 series at 1:60 000, the 1976 at 1:50 000 and 1980 at 1:30 000);
- * the photographs are taken at different times of the year (therefore, seasonal variations in vegetation cover needs to be considered);

- * the photographs are taken at different times of the day (therefore, amount and length of shadow, and tidal cycles need to be considered);
- * the photographs may be distorted (due to the position of key features relative to the principal point of the photograph);
- * aerial photographs only display a single point in time (therefore, may not indicate short-term environmental changes);
- * aerial photographs are of different resolutions (therefore, variation in vegetation and dune types may not be distinct).

4.4 APPROACH USED TO IDENTIFY AND MAP DUNES FROM THE AERIAL PHOTOGRAPHS

It has been noted by Tinley (1985) that the dynamic status and general stability of sandy coasts and associated dune fields can be interpreted from the air using geomorphic features in combination with plant communities. For this reason five sets of aerial photographs for the years 1943 (Task 37), 1963 (Task 507), 1969 (Task 662), 1976 (Task 706) and 1980 (Task 498) were obtained from the Directorate of Mapping in Cape Town, and the CSIR in Stellenbosch¹. The aerial photographs were analysed stereoscopically, using a Topcon stereoscope, so that key features could be easily interpreted. Assisted by field work, various dune types were identified (see Section 3.5).

From the aerial photographs hummock dunes were characterised by darker speckled tones, with coastal forms being finer grained than the 'knob-dunes' of the river delta. Due to poor photograph resolution, and in many cases an inadequate scale, coastal hummock dunes north of Walvis Bay often could not be identified. In the old arms of the Kuiseb River lightly vegetated dunes were identified, and termed flood-plain hummocks. Crescentic dunes in the Walvis Bay area are represented by both barchans and transverse barchanoid dunes. Barchans were recognised by their steep lee face and leading horns. Transverse barchanoid dunes are generally unvegetated, and were divided into two groups because of their size and inter-dune spacing. Based on measurements by Scheepers (1990), large transverse barchanoids were estimated to be 20-40 metres in height, and small transverse barchanoids 5-20 metres in height. Complex linear dunes

1 A 1:10 000 set of aerial photographs covering part of the study area (Walvis Bay) has been undertaken by the Namibian government. Unfortunately at the outset of this study these photographs were not available, and were only released in July 1996.

were identified as long, sinuous ridges that run parallel to each other in a south-east/north-west alignment (a more in depth discussion on dune distribution and morphology is provided in Sections 3.6 - 3.8). Other features interpreted include salt marshes, that are typically a dark colour on the aerial photographs, sand plates, which form flat unvegetated surfaces, and beach areas which front onto the Atlantic Ocean.

The above mentioned features were then traced and converted to a common scale, so as to facilitate multi-temporal comparisons of the study area. The landforms delineated from the aerial photographs were then digitised into a PC ARC-VIEW geographical information package, and detailed maps of the study area produced (see Figures 4.1 - 4.5). The surface extent of the above mentioned features were then measured using this geographical information system and rounded off to the nearest kilometre squared. These results are presented as a percentage of the total study area in a series of graphs (see Figures 4.6 - 4.9). Due to often unclear boundaries between landforms, measurements are considered approximate and should be seen as being of a preliminary nature for detecting gross geomorphic changes. A summary of these results are tabulated and presented in Appendices 2 and 3.

Geomorphological Features of the Walvis Bay Area 1943

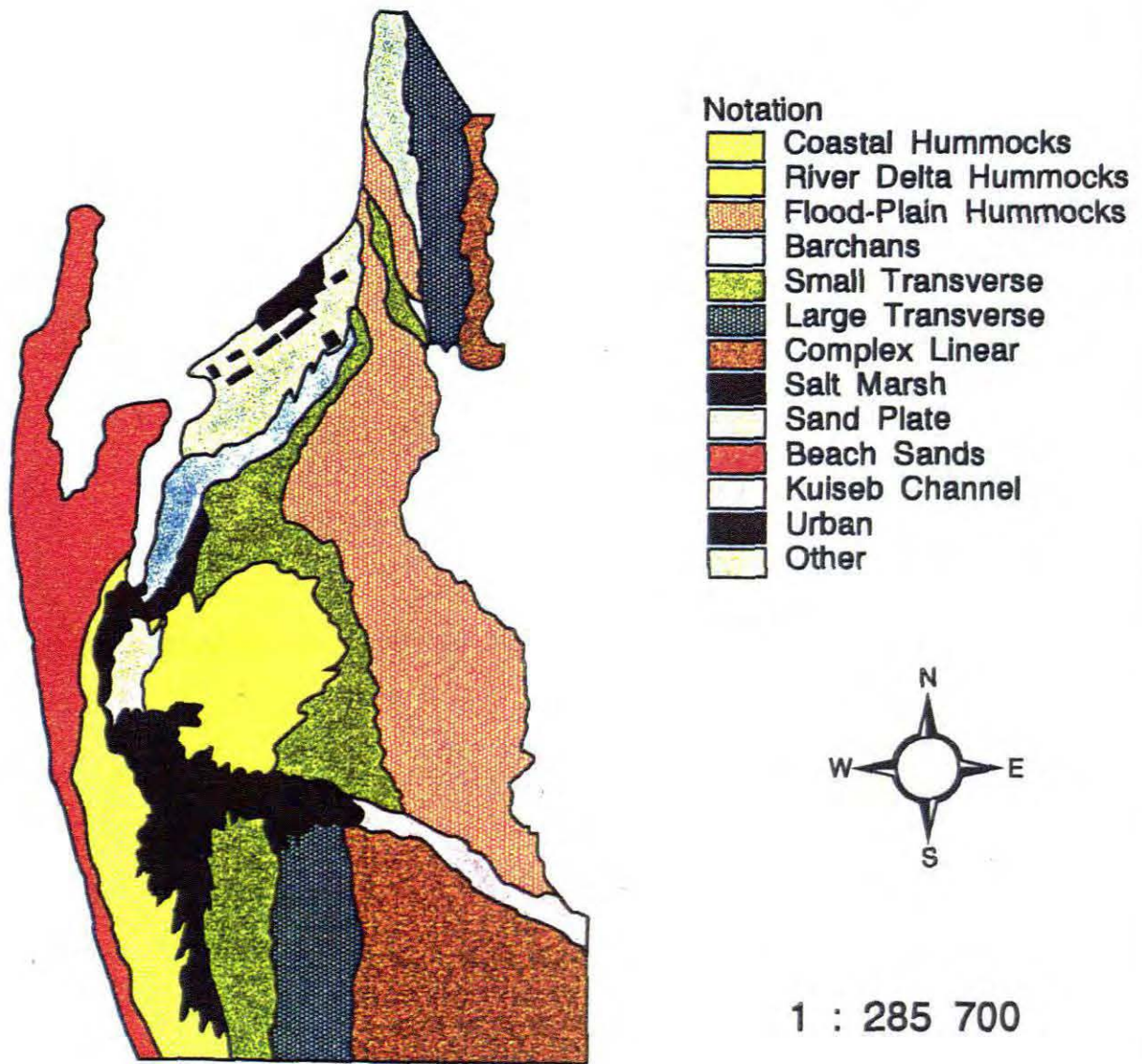


Figure 4.1

Geomorphological Features of the Walvis Bay Area 1963

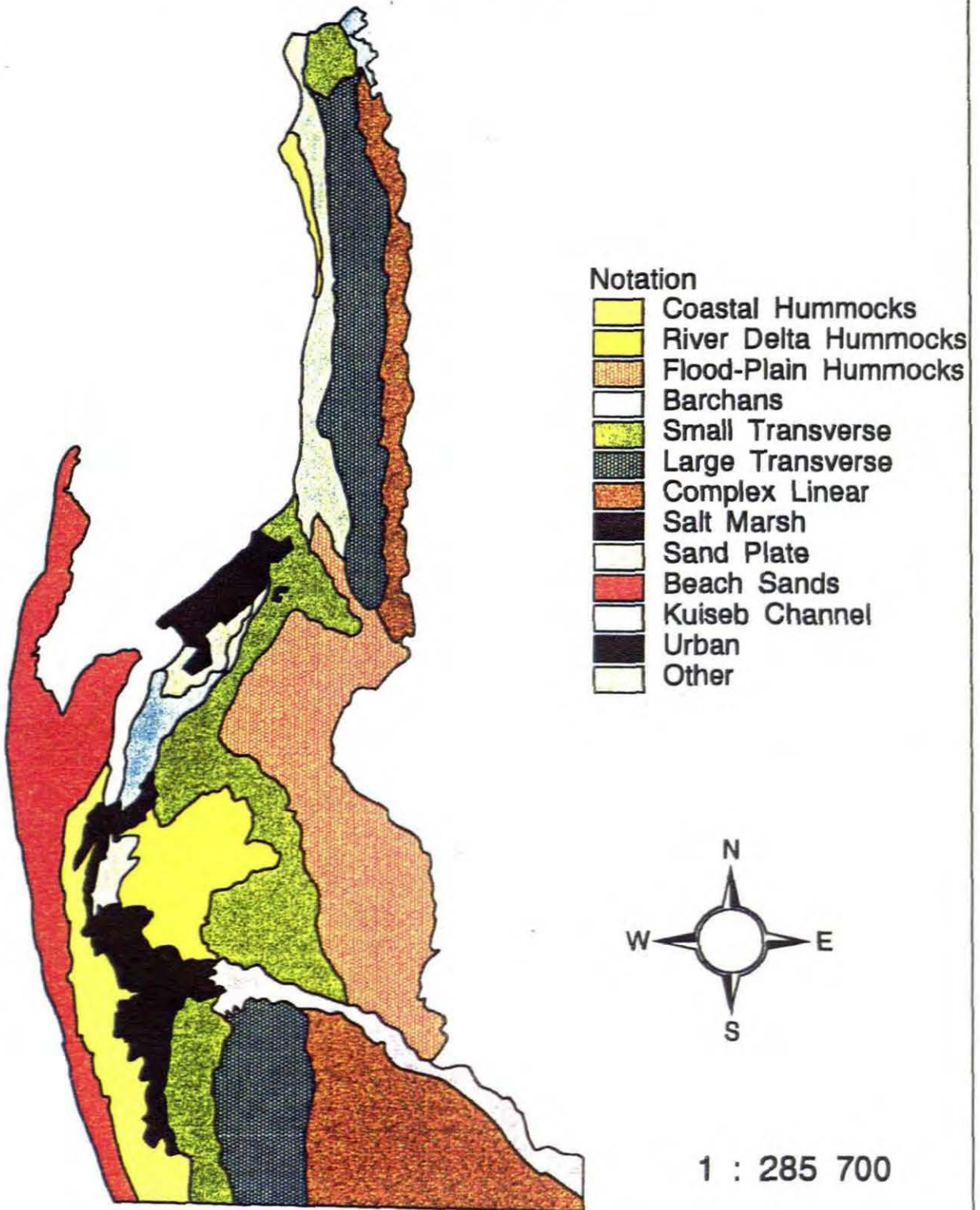


Figure 4.2

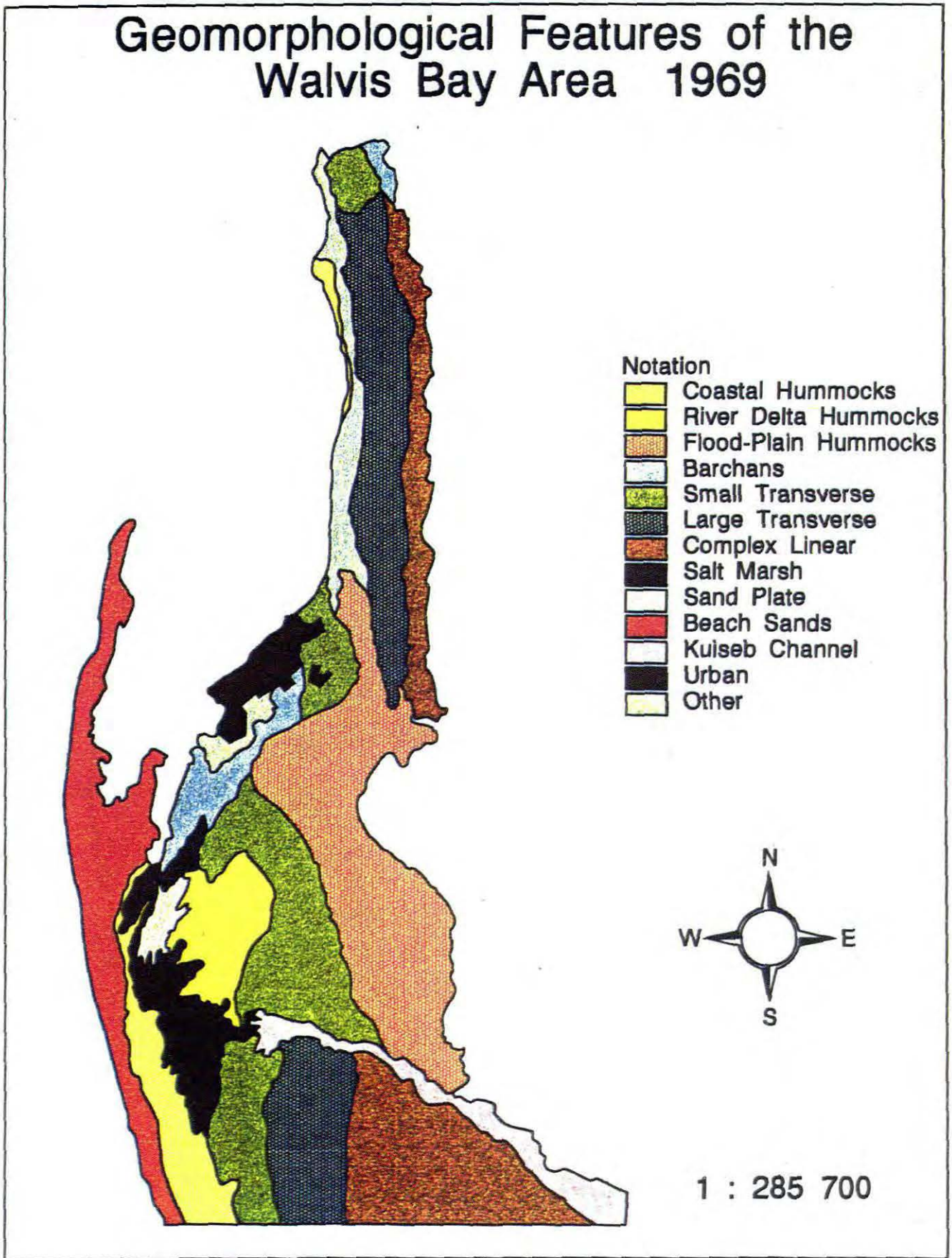


Figure 4.3

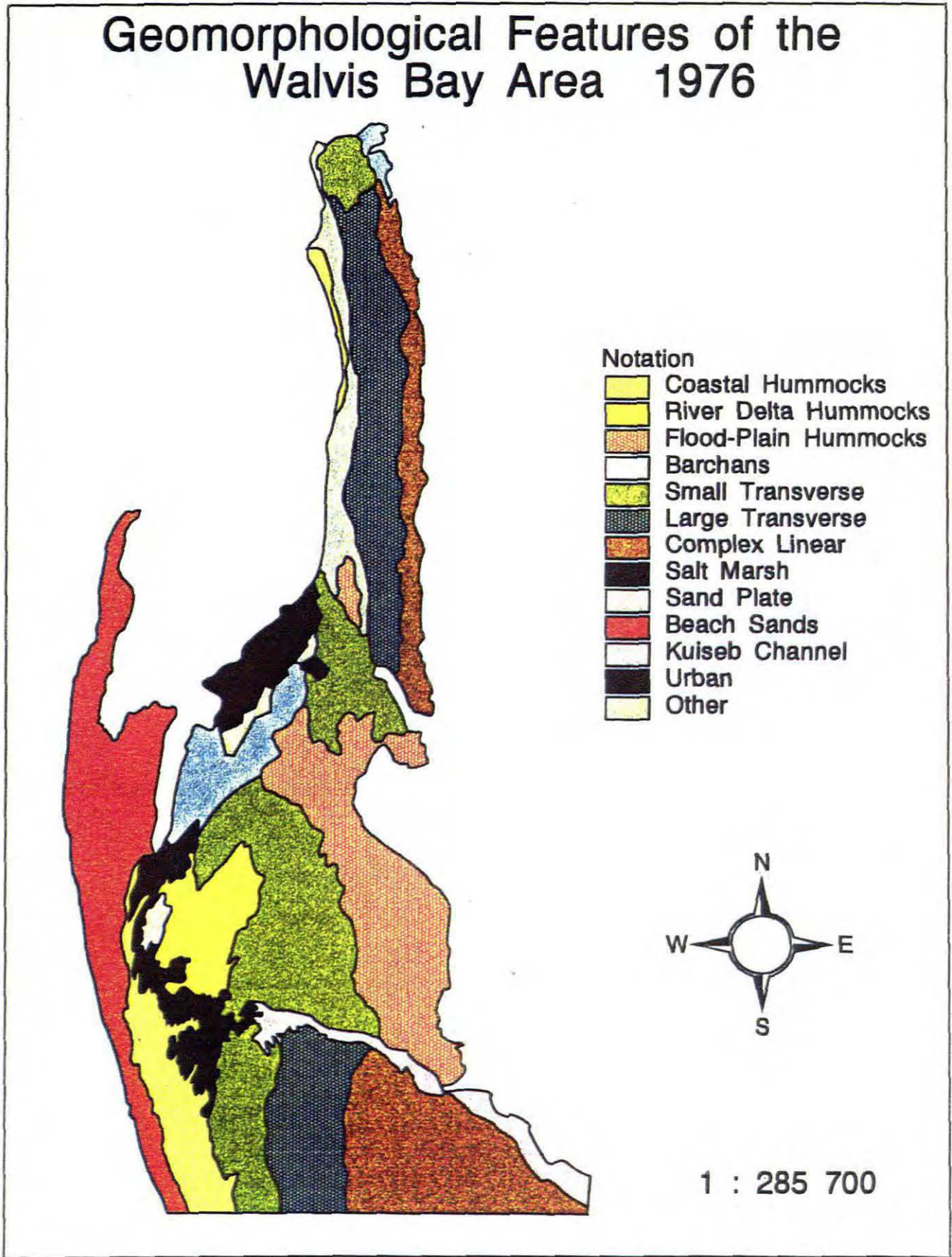


Figure 4.4

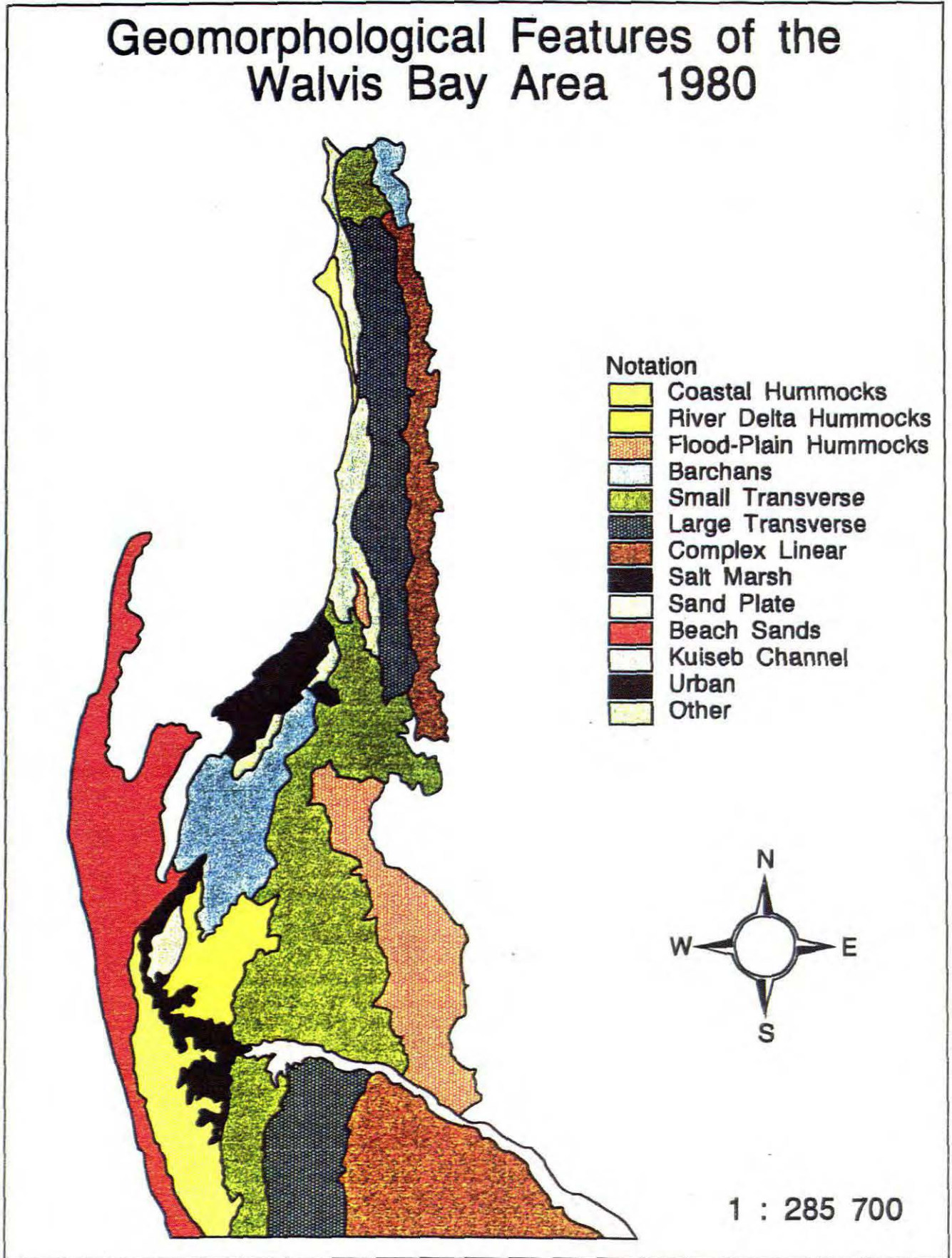


Figure 4.5

Figure 4.6

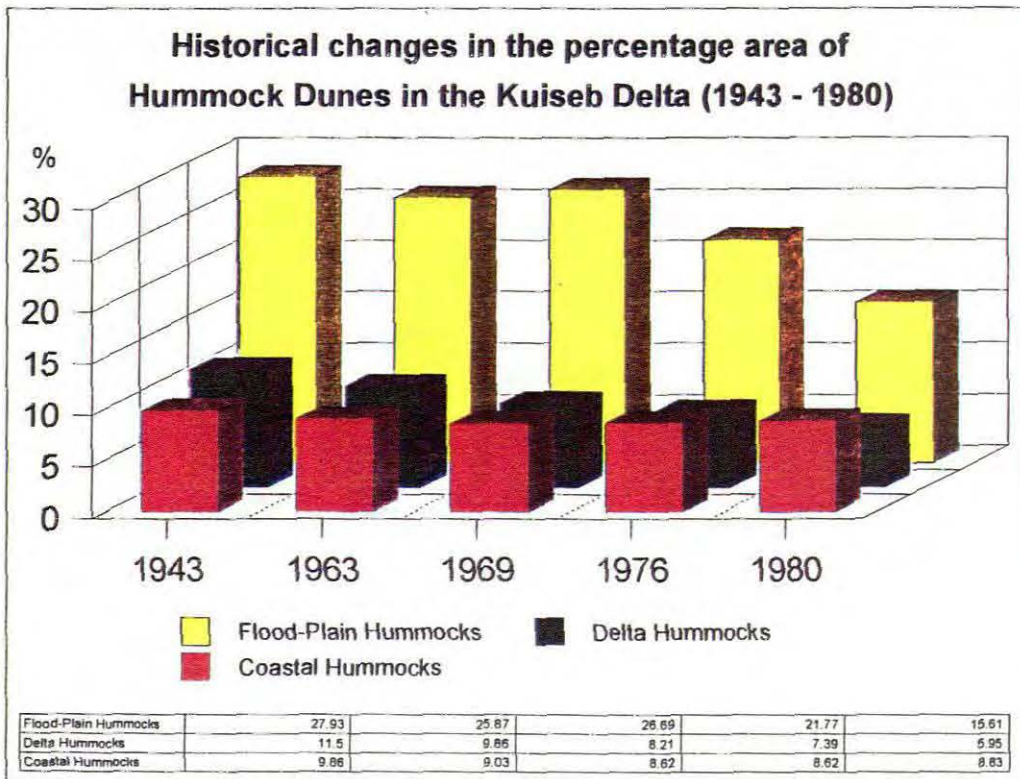


Figure 4.7

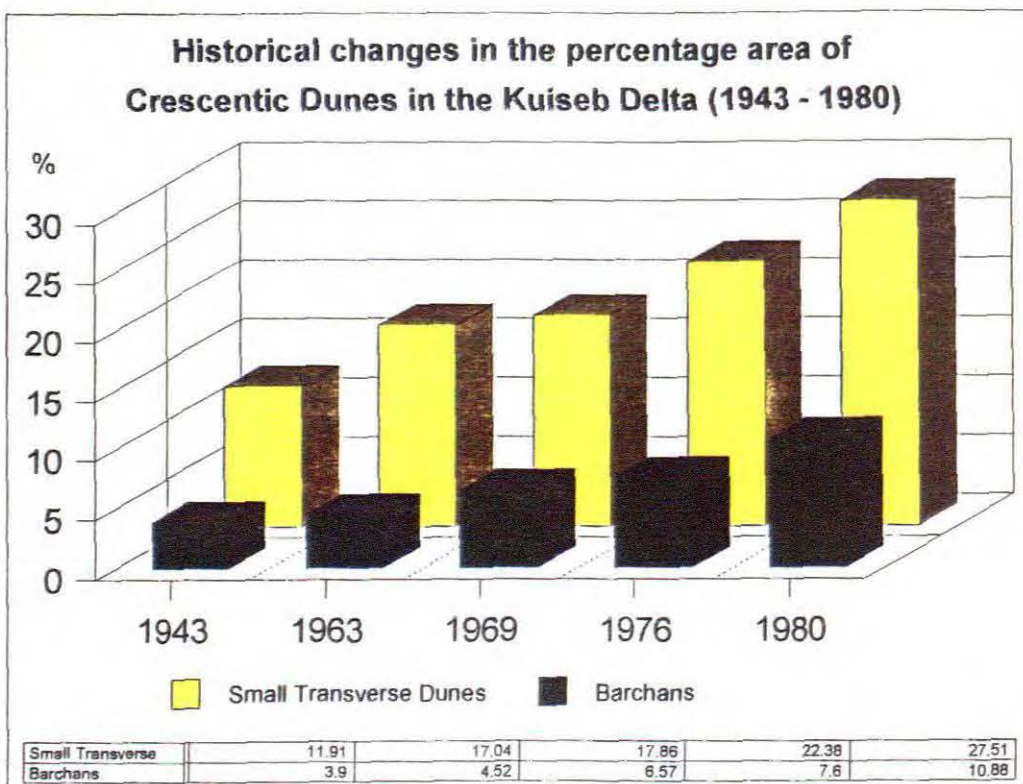


Figure 4.8

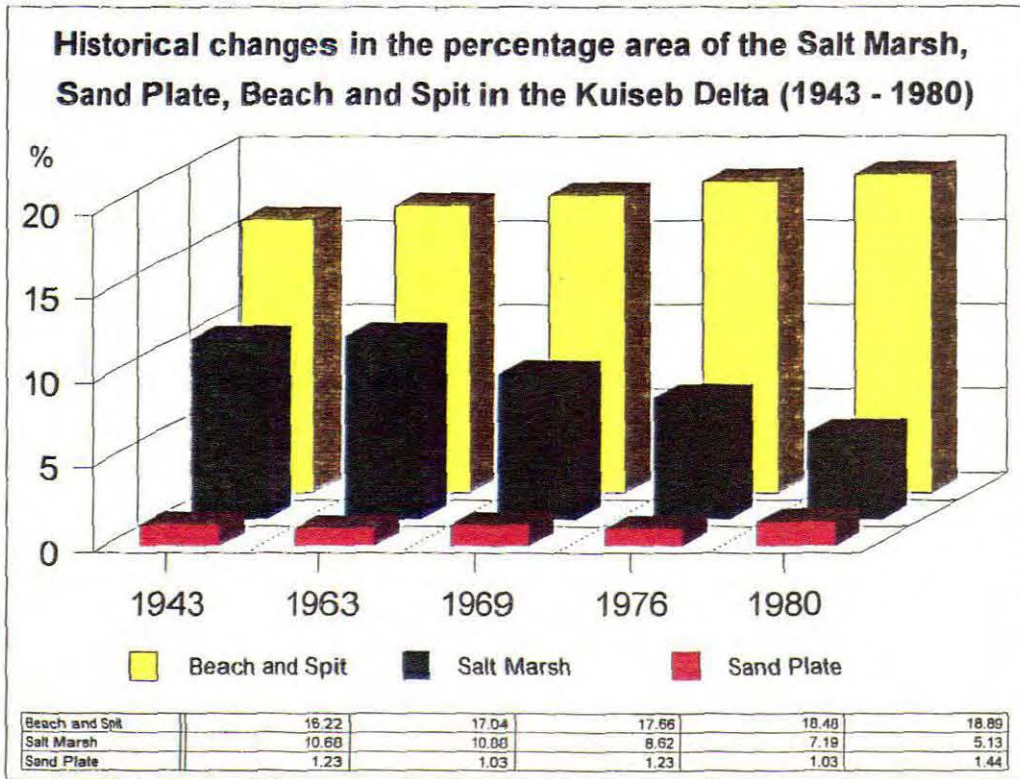
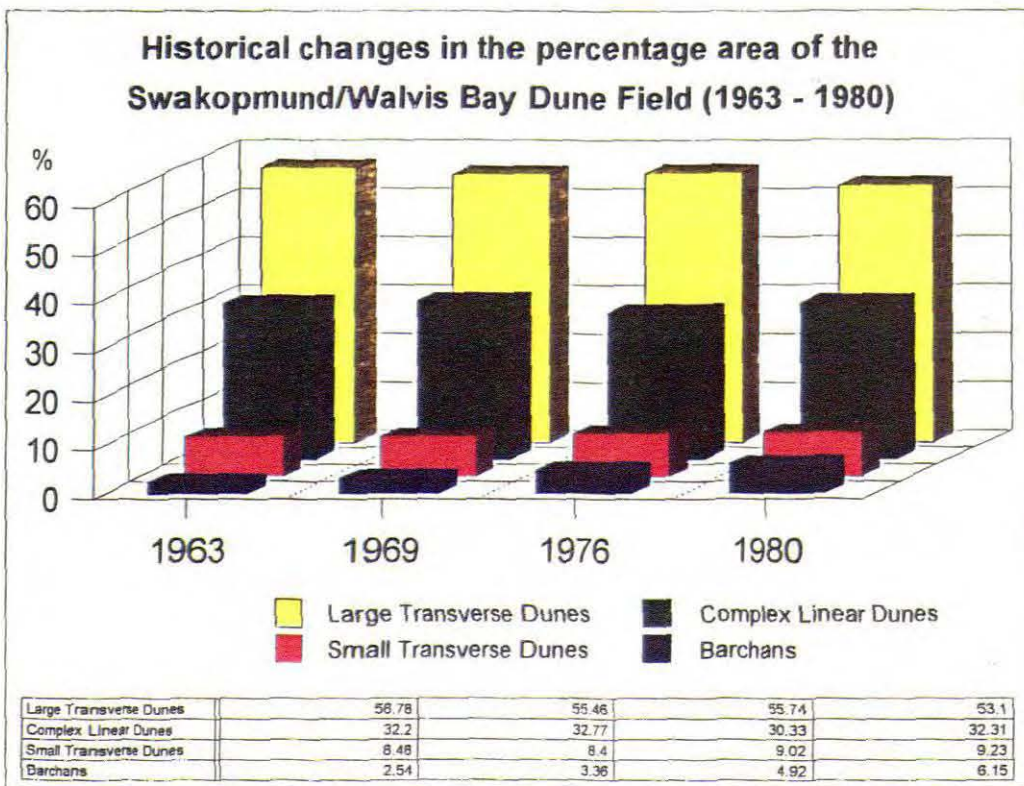


Figure 4.9



4.5 HISTORICAL CHANGES AND STABILITY OF DUNES

In order to get an understanding of the dune dynamics of the study area comparisons between the above mentioned five sets of aerial photographs are discussed below. It should be noted that even though the geomorphological features of the Kuseb Delta and those of the Swakopmund/Walvis Bay Dune Field are not mutually independent of each other, they are discussed separately to aid comparison. Frequent reference should be made to Figures 4.1 - 4.9 to facilitate these comparisons.

4.5.1. Observations 1943 - 1963

Kuseb Delta

The twenty years from 1943 to 1963 presents several changes in the features of the Kuseb Delta. These transformations are primarily linked to the area of vegetated hummock dunes and more mobile unvegetated forms. During this period it is evident that coastal, delta and flood-plain hummocks all decreased in extent. The surface area of the coastal dunes were reduced by 4 km², the delta hummocks were reduced by 8 km², and the flood-plain hummocks, occurring more in the eastern parts of the study area, decreased by 10 km².

In terms of the more mobile dune forms, both barchans and small transverse barchanoid dunes increased in size, with the former expanding from 19 km² to 22 km² and the latter from 58 km² to 83 km². These changes are significant with regards to the percentage area these mobile dunes cover on the Kuseb Delta, particularly the small transverse types which increased by 5,13%. Other features identified on the delta, including the salt marsh, sand plate and beach area, represented only minor changes in size. Of note is the decrease of flat barren land in the vicinity (particularly to the south) of Walvis Bay Town during this period.

Observations of the vegetation cover between 1943 and 1963 indicate a significant reduction in density and vitality of plants in the Kuseb Delta. These changes are most apparent in the north-eastern portion of the delta, in areas dominated by flood-plain and small transverse dune types.

Swakopmund / Walvis Bay Dune Field

Unfortunately 1943 aerial photographs of this complex were unavailable, and as a result the interpretation of change was not possible. It can be noted, however, that this dune complex is comprised of basically four dune types: complex linear dunes on the eastern side, large transverse barchanoid dunes on the western side, and at the northern leading edge both barchans and small transverse dunes.

4.5.2 Observations 1963 - 1969*Kuiseb Delta*

Two distinct changes are apparent in the Kuiseb Delta between 1963 and 1969. The first set of changes is the decrease in area covered by river delta hummock dunes and salt marsh vegetation. In 1963 these hummock dunes had an extent of approximately 48 km², however, in 1969 this area had decreased to a size of 40 km². Similarly, in 1963 the salt marsh covered an area of at least 53 km², which was reduced to a size of 42 km² in 1969. These changes are matched by the increase in area of unvegetated mobile dunes during the same period. The passage of small transverse dunes that lie to the east of the delta hummocks expanded by at least 3 km² during this time. Furthermore, the extent of the barchan dune field to the south of Walvis Bay Town also increased. This area changed from 22 km² in 1963 to 32 km² in 1969, and the increase is clearly shown by the comparison of the 1963 and 1969 maps (Figures 4.2 and 4.3).

Comparisons of the sand flats, the coastal hummocks and the flood-plain hummocks indicated negligible variations between 1963 and 1969. However, it was evident from the aerial photographs that the density and vitality of the vegetation supported by the flood-plain hummocks had reduced greatly by 1969.

Swakopmund / Walvis Bay Dune Field

Few noticeable changes are evident in the Swakopmund/Walvis Bay Dune Field between 1963 and 1969. Slight shifts in the area covered by complex linear and large transverse barchanoid dunes are apparent, but are relatively insignificant. A small increase in size of the more mobile transverse and barchan dunes at the leading northern edge of this complex have also been noted.

4.5.3 Observations 1969 - 1976

Kuiseb Delta

In the comparison of the 1969 and 1976 sets of aerial photographs distinct changes, in line with those discussed in the previous section, are visible. These observations again infer a sharp decrease in the area covered by vegetated features and an increase in more mobile dune forms. The area covered by river delta hummocks reduced by at least 4 km², an approximate reduction of 0,82% in the area of the delta previously covered by these dunes. The salt marsh also decreased further, from an approximate 42 km² in 1969 to 35 km² in 1976. The greatest changes, however, were experienced by flood-plain hummocks which displayed a reduction of 24 km² (4.93%) during this period. A notable decrease in the density of vegetation cover on flood-plain hummocks was also observed during this time.

The changes displayed by the more vegetated features of the study area were matched by a corresponding increase in the extent of the more active crescentic dunes. The passage of sparsely vegetated and unvegetated transverse dunes in the Kuiseb Delta broadened, expanding from 86 km² in 1969 to 109 km² in 1976. Of particular significance was the rise in the number of barchan dunes abutting the south and south-eastern edge of Walvis Bay Town. These dunes covered 6,57% (32 km²) of the Kuiseb Delta in 1969, and by 1976 had grown to cover 7,6% (37 km²) of this area.

Swakopmund / Walvis Bay Dune Field

Even though changes in this dune field are less extensive than those in the river delta, several shifts have been observed between 1969 and 1976. The area of the dune complex covered by linear dunes decreased by approximately 1 km², whereas that of large transverse dunes increased by 2 km². The extent of mobile dunes at the northern edge of the dune complex also increased with the percentage cover of barchans shifting from 3,36% to 4,92%, and for small transverse dunes from 8,40% to 9,02%. The overall size of the dune field increased by approximately 4 km² during this period.

Of significance in the 1976 series is the linking of small transverse barchanoids at the south-eastern edge of the Swakopmund/Walvis Bay Dune Field. In previous years this section was separated from the mobile dunes of the Kuiseb Delta by a string of vegetated flood-plain hummocks.

4.5.4 Observations 1976 - 1980

Kuiseb Delta

Comparison of the 1976 and 1980 aerial photographs continue to display the trend observed in previous sections. This being a progressive increase in the surface area covered by vegetated geomorphic features, and a relative increase in the surface area of more active unvegetated features. Figures 4.4 and 4.5 clearly illustrates these changes, with the area of river delta hummocks being reduced by 7 km² and that of the flood-plain hummocks by 30 km². This represents a 7,6% decrease in the area of the Kuiseb Delta being covered by sand-trapping hummock dunes. Another significant change has been the size of the salt marsh which was reduced by at least 10 km² during the same four year period.

The increase in area of bare sand is one of the most noticeable changes in the Kuiseb Delta. Between 1976 and 1980 the area of unvegetated barchan dunes expanded from 37km² to 53km², a change of 16km². Similarly, small transverse barchanoid dunes across the delta increased from 109km² in 1976 to 134km² in 1980, a difference in area of about 5.13%. Other geomorphic features were relatively consistent in size, however, the sand plate to the south of the Walvis Bay Lagoon did indicate a slight increase in surface area during this period. Analogous with the previous observations, a noticeable reduction in the density of the vegetation cover is evident.

Swakopmund / Walvis Bay Dune Field

The most significant trends evident between 1976 and 1980 are the relative increases in percentage cover of barchans and small transverse dunes along the leading edge of this complex. Shifts in the extent of large transverse and linear dunes are also apparent and indicate an increase in the overall size of the dune field from 123 km² (1976) to 131 km² (1980).

4.6 DISCUSSION

From the interpretations of the aerial photographs it can be inferred that several trends are evident in the study area between 1943 and 1980. These trends are as follows:

- * a decrease in the surface area covered by vegetated hummock dunes;
- * an increase in the surface area covered by mobile crescentic dunes;
- * a decrease in the extent of other vegetated features, such as the salt marsh, across the Kuiseb Delta;
- * an increase in the overall size of the Swakopmund/Walvis Bay Dune Field;
- * a broadening of the beach and a lengthening of the spit south of Walvis Bay;

It should be noted that no recent aerial photographs of the entire study area are available (see footnote 1), and hence a continuation of these trends is assumed.

4.6.1 Hummock Dunes

A significant trend, that has come to the fore in this study, is the gradual reduction in area superposed by vegetated hummock dunes. Of the three hummock dune types to have been identified in the study site, all have shown a marked decline in their distribution

The most pronounced being the flood-plain hummocks, which in 1943 were extensively vegetated and covered an area of 136km². In 1980, however, their distribution was limited to only 76km² and exhibited a sparse vegetation indicative of historical flood events. This shows a reduction of 12.32% in the area covered by these dunes in the delta.

Similarly, the area encompassed by river delta hummocks has also been greatly decreased. The 56km² extent of these dunes in 1943 was virtually halved to 29km² by 1980, representing a difference of 5.5% in the area of the Kuiseb Delta covered by these hummocks. As previously mentioned, coastal dune hummocks were often difficult to identify from the aerial photographs. However, those identified south of Walvis Bay did indicate a decrease of 5km² in their extent between 1943 to 1980.

The importance of hummock dunes as a sand trap, particularly in the high energy aeolian environment around Walvis Bay, cannot be over emphasised. The die back of vegetation and the resultant inability of these dunes to hold loose sands is undoubtedly the principle factor leading to another trend observed in the study area - a significant increase in the

occurrence of mobile dune forms. The ramifications of these changes are described in Chapter 5.

4.6.2 Unvegetated Mobile Dunes

On the Kuiseb Delta alone barchan dunes have increased in area from 19km² to 53km², growing 16km² in the four years between 1976 and 1980. In addition, an increase in the number of barchans at the northern edge of the Swakopmund/Walvis Bay Dune Field has also been noted. These changes indicate an expansion of this dune complex in a northern direction towards the Swakop River. Of particular importance is the movement of barchans into Walvis Bay Town, and their present impacts and future developmental implications (these issues are addressed in Chapter 5). Probably the most noticeable of all the geomorphic changes in the study area is the accelerated growth of small transverse dunes. The above observations suggests a north to north-easterly expansion, encroaching onto areas previously characterised by hummock dune forms. Small transverse dunes have not only increased their surface area by some 76km², but also display a marked decrease in vegetated cover (from sparsely vegetated to unvegetated), which was clearly evident in the 1943, 1963 and 1969 photographs. This is probably a key factor contributing to their increased instability and movement.

4.6.3 Larger Dunes

Larger dunes in the study area are represented by large transverse barchanoid and complex linear types, that occur in the Swakopmund/Walvis Bay Dune Field. Relative changes in the distribution of these forms are limited, however, it has been noted that these dunes have increased in size between 1963 and 1980, indicating an enhanced supply of sediment.

Sources of sediment for this complex includes sands blown across the Kuiseb Delta and marine sands pushed up from the adjacent beaches (Scheepers, 1990). The increased instability of the delta sands, therefore, is probably a key factor contributing to the growth of this complex.

4.6.4 Salt Marsh

Principally indicative of wetter periods in the Kuiseb, is the salt marsh that stretches across the delta from the mouth of the river. Comparisons of the aerial photographs

shows a sharp decrease in size from a maximum of 53km² in 1963 to less than 25km² in 1980. The salt marsh is representative of a high groundwater table (Barnard, 1975), and it can therefore be inferred that a decrease in the size of the salt marsh indicates a lowering of this table. The consequences of the reduction in salt marsh area are discussed in Section 5.3.

4.6.5 Sand Plate

The sand plate, evident on all the aerial photographs, is essentially a reliefless accumulation of sand that has been protected from deflation by an upper layer of coarse grains (Barnard, 1975). The size of this plate has been relatively consistent, ranging between 4km² and 7km² in extent. It is possible that the expansion of this feature in a north-westerly alignment over recent years, is due to an increased exposure to wind erosion resulting from a destabilisation of surrounding hummocks.

4.6.6 Beach and Spit

Detection of any change in the beach and spit is problematical and difficult to assess. This is because beaches are among the most high energy and mobile of landforms and any changes may be due to natural tidal and / or seasonal cycles. The photographs used in this study were therefore not truly representative of ongoing beach processes.

However, measurements taken do indicate an expansion of the beach westwards and a northward lengthening of Pelican Point. In 1943 the beach and spit covered an area of 77km² and by 1980 had increased to 91km². These measurements are confirmed by the CSIR (1984) who recorded that Pelican Point is lengthening in a northward direction by approximately 17m. yr⁻¹.

4.6.7 Vegetation

A final observation to be noted is the gradual reduction in vegetation density and vitality in the study area between 1943 and 1980. This trend is clearly evident from the multi-temporal comparisons, and is most apparent in the eastern sections where flood-plain hummocks are dominant. Even though the reduction in plant cover is most prevalent in the east, it must be highlighted that this trend is characteristic throughout the Kuiseb Delta. Many of the small transverse dunes, for example, were covered by stands of

vegetation up until the late 1960s. More recently, however, this vegetation has thinned and is only typified by sparse stands of more hardy species.

4.7 CONCLUSION

The interpretation of aerial photographs between 1943 and 1980, of dominant environmental features in the study area, has provided several insights into the historical stability and dynamics of the Walvis Bay area. Comparative observations between successive sets of aerial photographs indicates several distinct changes over the last 53 years. These trends are linked primarily to the important geomorphological role that vegetation plays in the dune systems of the Kuiseb Delta, with the main trends being: a decrease in the extent of vegetated hummock dunes; an increase in the surface area covered by crescentic mobile dunes; a significant decrease in the area of other vegetated features, such as the salt marsh; and an overall increase in the size of the Swakopmund/Walvis Bay Dune Field. The underlying causes for these changes, as well as ramifications of these changes upon the Walvis Bay environment, will be addressed in the following chapter.

**ENVIRONMENTAL IMPACTS AND
FUTURE LAND-USE
IMPLICATIONS OF SAND
MOVEMENT IN THE WALVIS BAY
AREA**

5. ENVIRONMENTAL IMPACTS AND FUTURE LAND-USE IMPLICATIONS OF SAND MOVEMENT IN THE WALVIS BAY AREA

5.1 INTRODUCTION

From the previous chapters it is evident that the study area is a highly dynamic environment, characterised by a rich and diverse flora and fauna, with many species being specifically adapted to the local conditions. It is also apparent that over the last fifty years, and particularly over the last twenty years, there have been considerable changes to this landscape, with a noticeable decrease in vegetation cover and a remarkable expansion of mobile dune forms. This process of land degradation has been documented globally, particularly on the edges of continental desert areas, and has been regularly referred to as desertification (eg. Dalsted and Worcester, 1979; Abu El-Ennan *et al.*, 1990; SARDC, 1994). The definition of desertification, however, has been relatively vague through the years and has been used to describe both processes of change and states of the environment (Thomas and Middleton, 1995). The most recent definition provided by UNEP (1990) specifies desertification as land degradation in arid, semi-arid and dry sub-humid areas resulting mainly from adverse human impact. The change in landscape character across the study area represents a classic example of arid zone desertification, and is resulting in widespread habitat loss and severe environmental degradation.

It is argued that, due to the dynamism and the ecological sensitivity of this region, permanent development should probably never have been initiated here. However, this is not the case, and as discussed in Section 2.3, Walvis Bay is experiencing a rate of growth that supersedes any other urban area in Namibia. The natural resource exploitation by these urban and industrial developments is the primary cause of dune movement and land degradation across the Kuiseb Delta. This dune encroachment is having considerable impacts both ecologically and, quite ironically, on the built environment of Walvis Bay itself.

This chapter, therefore, attempts to explain all the factors that are contributing to dune migration, as well as highlight the ramifications of this movement upon the ecological and socio-economic environments in the study area. Considerations for future land-use planning and development are then discussed.

5.2 FACTORS INFLUENCING SAND MOVEMENT IN THE STUDY AREA

Various studies (Huntley, 1985; Jacobson *et al.*, 1995) have identified water as the key environmental factor in the Kuiseb system. It is the infrequent flow events that flood the Kuiseb Delta and recharge groundwater sources that determine the degree of vegetation cover and sand dune migration. Therefore, in attempting to understand the rates of land degradation, as observed in Chapter 4, it is necessary to recognise the factors that are limiting the availability of water and influencing dune movement across the Kuiseb Delta. Main factors that have been identified include:

- * a decrease in the frequency of high magnitude flood events;
- * over-abstraction of groundwater;
- * the development of a flood diversion wall.

Other more localised factors that influence the migration of sand in the study area include:

- * off-road vehicles;
- * urban expansion;
- * the development of salt recovery pans;
- * dune stabilisation programmes.

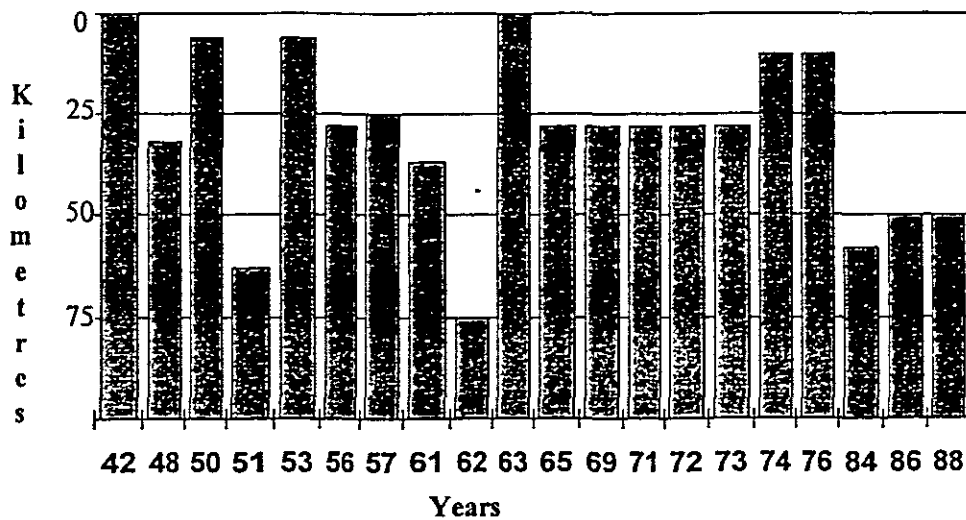
5.2.1 Decreased Flood Frequency

The recording of flood events in the Kuiseb has indicated that this ephemeral river has reached the Atlantic Ocean only 15 times since 1837 (Stengel, 1964). Table 5.1 shows that prior to the turn of the century the Kuiseb River flowed to the sea an average of once every 6,5 years. Similarly, in the first half of this century, six flows reached the sea at an average of once every 8,2 years. Since 1942, however, the Kuiseb has entered the Atlantic only on a single occasion - an average of once in 54 years.

TABLE 5.1 YEARS THAT THE KUISEB RIVER REACHED THE ATLANTIC OCEAN (1837-1996)

YEARS REACHED ATLANTIC OCEAN	DIFFERENCE IN YEARS	AVERAGE IN YEARS
1837	-	6,5
1848	11	
1949	1	
1852	3	
1864	8	
1881	17	
1885	4	
1893	8	
1904	11	8,2
1917	13	
1923	6	
1931	8	
1934	3	
1942	8	
1963	21	54
-	33 (TO DATE)	

Figure 5.1 Downstream limit of flows in the lower Kuiseb River (1942-1988) - presented as kilometres from the Atlantic Ocean



Source: Hattle (1985); Scheepers (1990); Jacobson *et al.* (1995)

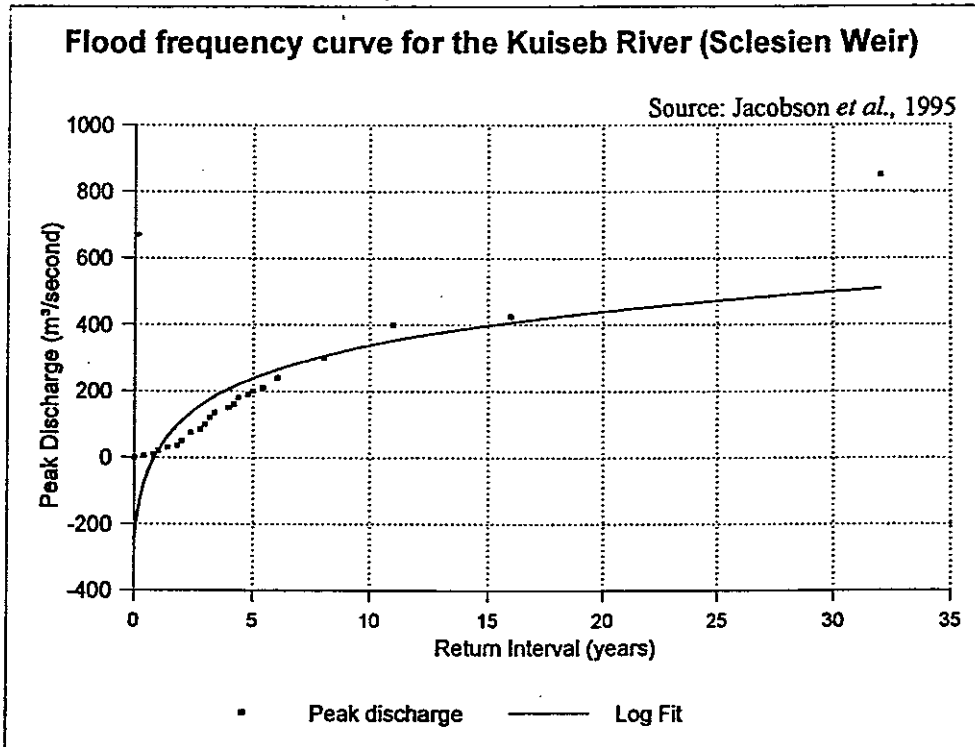


Figure 5.2

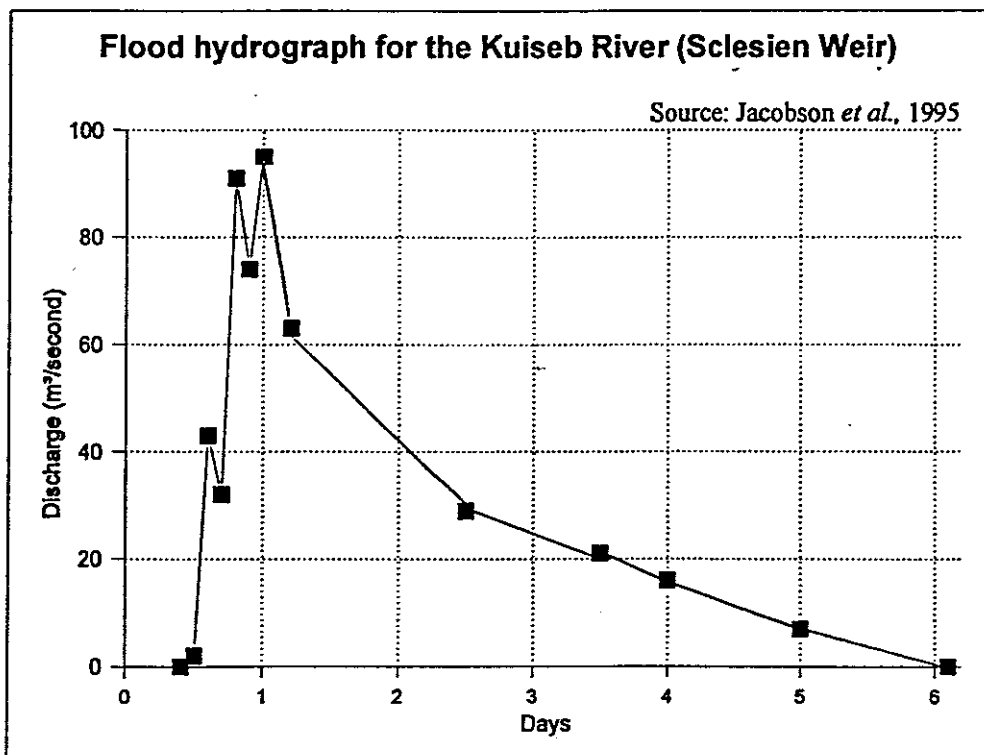


Figure 5.3

Even though discharges into the sea are rare events, flows further inland are recorded more often. According to Scheepers (1990) over 153 days of surface flows were recorded at Rooibank (which is situated approximately 25 km from the sea) between 1960 and 1984, at an average of 7 days a year. During this period run-off reached the Kuiseb Delta on two occasions (see Figure 5.1). Decreased downstream floodwater volume along the Kuiseb River has been recognised by Jacobson *et al.* (1995), and is a characteristic feature of many ephemeral rivers in Namibia. This is primarily due to increased infiltration into the sandy and gravelly alluvial deposits of the river-bed towards the coast. It has been noted by the Walvis Bay Municipality (1995) that, even though flows inland are occasionally recorded, they do not contribute significantly to groundwater recharge and cannot support deltaic vegetation. For this reason the decrease in high magnitude flood events is significant, as it not only has severe ecological implications across the delta and promotes rejuvenated dune movement, but also limits the amount of water available for abstraction purposes.

The reduction of flood events that inundate the delta can be attributed to several factors, including: long-term climatic fluctuations, upstream impoundments, and catchment farming practices. It is likely that long-term climatic fluctuations, together with a decrease in rainfall across the 15 500 km² catchment, are important factors causing fewer floods in recent times. Unfortunately the understanding of this variability is constrained by the lack of a long-term record of rainfall and flood-frequency data, as is evidenced by Figure 5.2. This curve shows that the return interval of major floods cannot be characterised without a longer record and hence the relationship between flood frequency and magnitude for the Kuiseb cannot be accurately determined.

A factor that may play a significant role is the increased number of farm dams in upper catchment areas. Jacobson *et al.* (1995) have highlighted this concern and have noted an increasing number of "ground dams" across the Khomas Hochland - the catchment of the Kuiseb River. They mention that the accumulated impact of these dams is significant and influences the intensity of flood events, thereby reducing the amount of water available downstream. In addition, a change in catchment land-use in recent times may also determine the amount and rate of run-off. The increased proportion of cultivated land may influence the run-off pattern and in turn affect the flood hydrograph. The arid characteristics of the catchment cause flood events to reach peak discharges very quickly (see Figure 5.3), however, increased cultivated land may lead to a greater infiltration and a gradual attainment of peak discharge. This would result in less intense flood events,

which, in a river that decreases in discharge downstream, may lead to fewer terminal flows.

5.2.2 Over-abstraction of Groundwater

The groundwater resources of the Kuseb Delta are an important provider of water for the Erongo Region, with the main users being the urban areas of Walvis Bay and Swakopmund, as well as Rossing Uranium Mine. An increased use of these resources has been highlighted by several recent studies (Huntley, 1985; Jacobson *et al.*, 1995; Walvis Bay Municipality, 1995) and are graphically indicated in Figure 5.4. These studies have shown that present rates of abstraction are unsustainable and are far exceeding natural recharge rates. The rapid decline of the water tables in the aquifers of the lower Kuseb River are displayed in Figure 5.5, where aquifers have shown a marked decline in water table levels since the early 1970s. It has also been noted by the Walvis Bay Municipality (1995) that these water tables are not very responsive to small floods that occur further up the Kuseb (see Figure 5.1), and virtually no increases in groundwater levels are experienced after such events. Water table lowering has significant implications both on the biophysical and socio-economic environments of the study area, as discussed later in this chapter.

Research by Ward and von Brunn (1985b) has shown that many deltaic plants are reliant on high groundwater levels for their survival, and the die back of vegetation across the delta, as observed in Chapter 4, is primarily a result of a lowering of these levels. It has been noted by the Walvis Bay Municipality (1985) that it is not only the lack of freshwater that causes this mortality, but also the resulting increase in soil salinity. This is due to an inland movement of the saltwater wedge and a surface concentration of salts due to evaporation (this process is discussed in more detail in Section 5.3.1). As has been mentioned, increased plant mortality and a decrease in percentage cover result in the destabilisation of dunes and contribute to driftsands encroachment.

5.2.3 Flood Diversion Wall

In 1962 a 7.3 km long diversion wall was built in the lower Kuseb River channel to protect the town of Walvis Bay from large floods (Stengel, 1963) (see Figure 1). The wall was constructed in the northern arm of the river diverting flow westwards into the dunes.

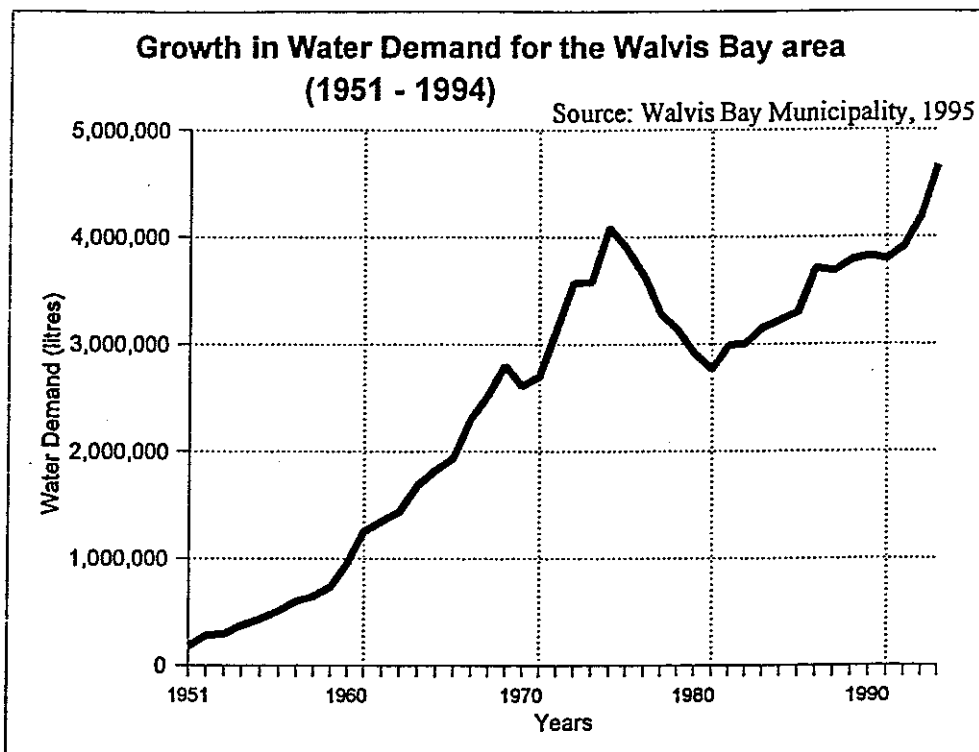


Figure 5.4

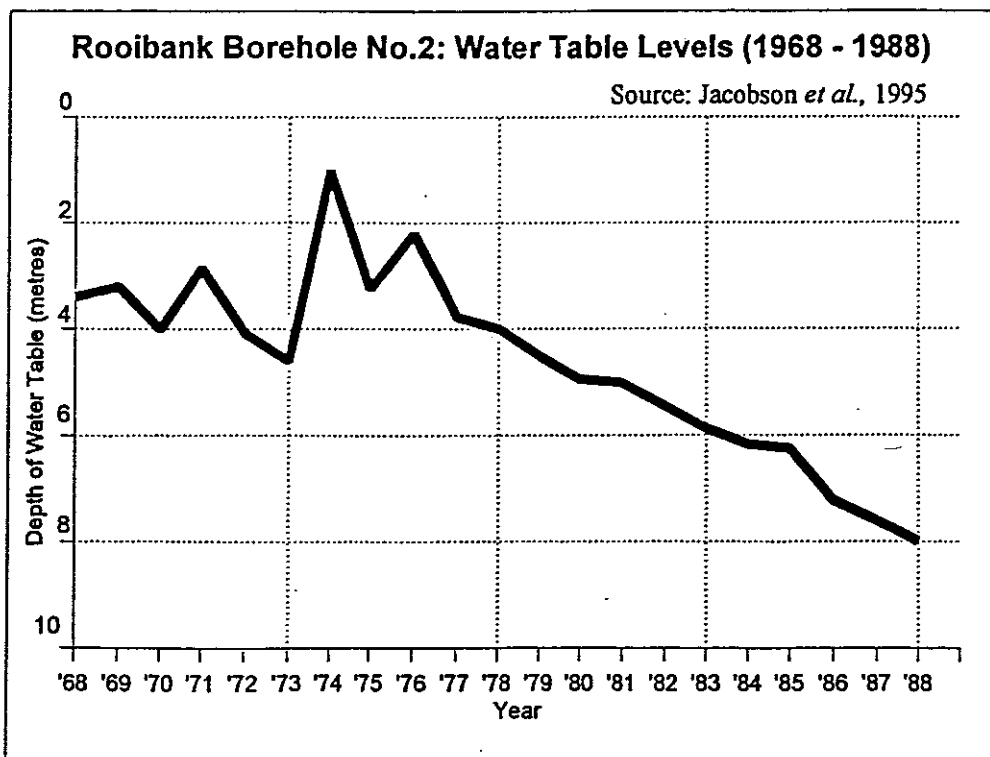


Figure 5.5

It is was this arm that previously carried the bulk of the flood, and in 1934 resulted in the town being inundated with water and fluvial sediment. The 1963 flood, which would have been the last major flood to have flowed down this arm, was successfully diverted by this wall (as a result, the last time the northern part of the delta was inundated with floodwater was in 1942). The main consequences of this development, in terms of sand movement, are two-fold: the northern stretches of the study area no longer receives floodwater; and fine fluvial sediments are no longer deposited into the lagoon from this source.

The implication of this diversion upon the north-eastern areas of the study site is that riparian and dune vegetation, that were previously maintained by irregular flows along this arm, are being starved of water. From the observations noted in Chapter 4 it is clearly evident that there has been a considerable reduction in vegetation cover, and from site visits, an obvious decrease in vegetation vitality in the area. Furthermore, there has been an associated increase in small mobile dunes throughout this zone. These impacts have been noted by the Topnaar communities living in the delta, who claim that their Inara fields are no longer receiving water (Dauseb, pers.comm., 13/02/1996). It is to a large degree that these Inara plants that provide an important trap for mobile sands, and helps stabilise flood-plain hummock dunes.

The other significant impact of the flood protection wall is that the potential longshore introduction of fluvial sediment to the lagoon from this source is eliminated. This therefore reduces the amount of sediment input and hence slows the rate of lagoon siltation. It has been argued by the CSIR (1992), however, that floodwaters diverted along the southern arm of the delta can now potentially reach the lagoon, and if floods do occur they will have a major impact on the system through the massive deposition of fluvial sediment.

5.2.4 Off-road Vehicles

Off-road vehicles (ORVs) are used in the study area for two main reasons: by anglers to transport themselves and their equipment onto remote beaches; and by thrill-seekers who use these vehicles expressly for the excitement of mounting dune slopes at great speeds and angles. The main areas of activity are the high dunes of the Swakopmund/Walvis Bay Complex and the coastal hummocks occurring both south and north of Walvis Bay.

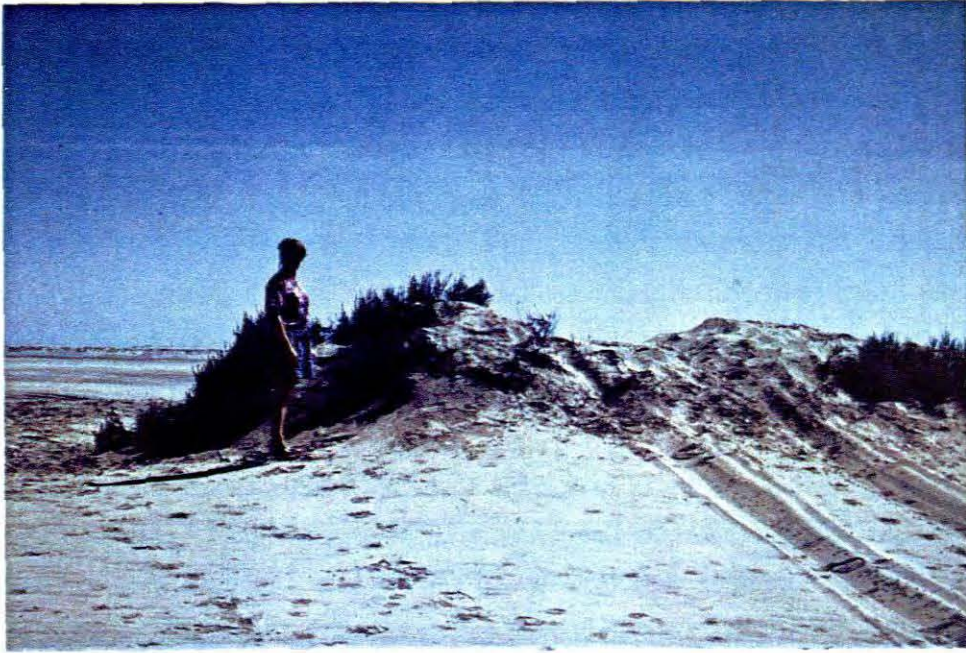


Plate 12 Off-road vehicle damage on coastal hummock dunes south of Walvis Bay.

The Swakopmund/Walvis Bay Dune Field, even though a popular tourist attraction and regularly exposed to ORVs, is relatively resistant to vehicle damage. This is because this complex is mostly unvegetated and characterised by soft shifting sands. Therefore, trampling damage is generally minimal and visual scarring from tyre tracks only lasts temporarily. On the delta and coastal tracts, however, this situation is a lot more serious. Here, the most significant damage caused by ORVs occurs during the first few passes as tyres trample dune vegetation (see Plate 12). This then exposes bare sands and initiates blowouts (Van der Merwe, 1988). Plant species diversity also becomes reduced, changing the micro-climate at the sand surface and affecting dune fauna. Due to the low resilience and sensitivity of this environment, dune vegetation once damaged can take many years to recover, if it recovers at all.

Another major impact of ORVs is that they crush many small animals that inhabit dune areas, including invertebrates, reptiles and small mammals. Furthermore, dune traffic disturbs many seabirds, such as Black oystercatchers (*Haematopus moquini*), Damara terns (*Sterna balaenarum*) and Chestnut-banded plovers (*Charadrius pallidus*), that breed in foredune areas along the coast. A further concern is that vehicle tracks, by destroying vegetation cover and breaking the protective salt crust, encourage sands to be blown about by the wind and therefore aid driftsand encroachment. According to Braby (pers.comm., 08/02/96) the impacts of trampling are not only the result of ORVs, but also to a lesser extent recreational walking and sand-boarding.

5.2.5 Urban Expansion

The establishment of Walvis Bay Town has had two important influences on sand movement in the study area. Firstly, urban growth has expanded upon coastal hummock dunes that previously occurred in these areas, and secondly these developments have effectively cut off much of the sediment influx into the lagoon under both south-westerly and north-easterly wind conditions.

As is evident from Figure 5.6, Walvis Bay has grown extensively over the last fifty years extending widely over the eastern edge of the lagoon. According to Giess (1971) these areas were previously characterised by small hummock dunes that supported sand-trapping plants. The role played by these hummocks was probably therefore important in binding loose sediments and influencing the movement of sands into the lagoon. Ironically, the rapid development of the town, even though eliminating many of these

small dunes, has performed a similar but more significant role. From the CSIR (1992) study on the sedimentation history of the Walvis Bay Lagoon, it is noted that the rate of sedimentation has greatly decreased over recent years as a result of urban expansion, and it is now only the upper eastern reaches that are vulnerable to aeolian sediment inputs.

5.2.6 Salt Recovery Pans

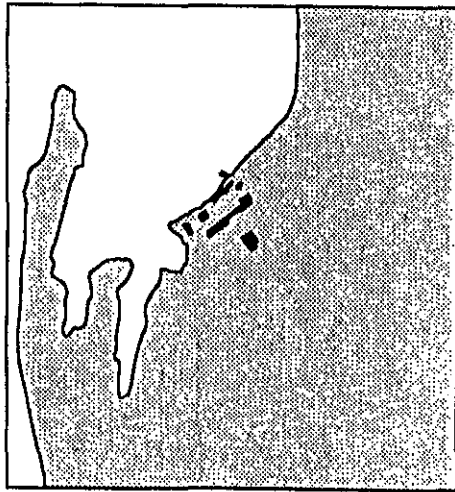
The expansion of Walvis Bay Town and the development of the flood diversion wall are not the only physical developments that have influenced the movement of sands in the study area. The construction of salt recovery pans at the southern and western perimeter of the lagoon have also had considerable impact (see Figure 5.6). These pans and the associated infrastructure have interrupted the aeolian sediment pathways towards the lagoon from both the Kuiseb Delta and the sand spit. According to the CSIR (1992), the process of sedimentation, which was generated by the south-westerly wind regime, has been significantly reduced. Furthermore, the inter-dune ponds and the trenches excavated parallel to the saltworks road along the eastern perimeter of the upper lagoon have effectively limited much of the influx of wind-blown sand from this area under south-easterly, easterly and north-easterly wind conditions (CSIR, 1992).

5.2.7 Dune Stabilisation

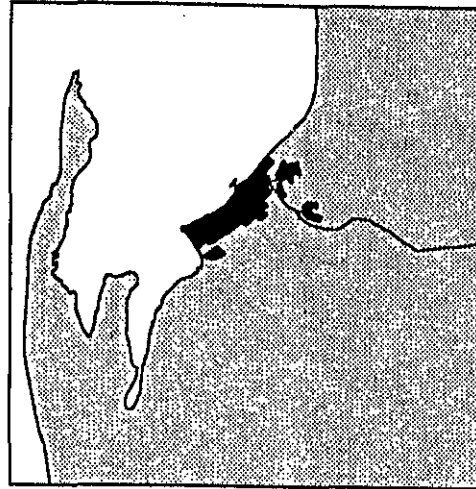
Sand dune stabilisation has played a significant role in preventing the movement of barchan dunes south of Walvis Bay Town and into adjacent urban areas. The history and success of artificial dune stabilisation in the vicinity of Walvis Bay Town is reviewed in Chapter 6.

Figure 5.6

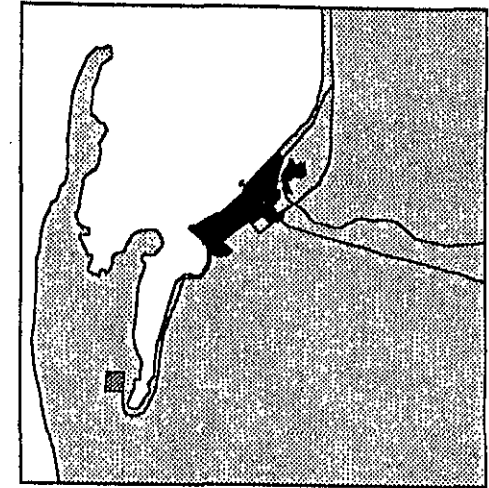
Urban Expansion of Walvis Bay (1943 - 1980)



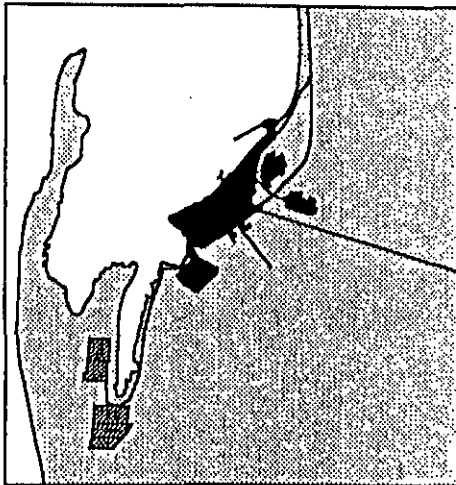
1943



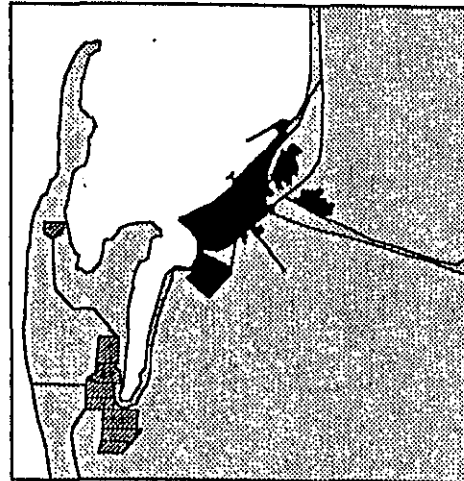
1963



1969



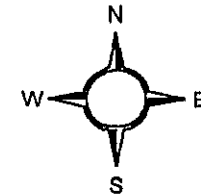
1976



1980

Notation

- Urban
- Salt Pan
- Road



5.3 ENVIRONMENTAL IMPACTS OF DRIFTSANDS

The impacts of driftsands on both the natural and socio-economic environments have been recognised throughout the world, particularly along desert boundaries and sandy coastal areas. Studies in Israel (Perry and Dmi'el, 1995) and Kuwait (Al-Ajmi *et al.*, 1995) have indicated the ecological effects of habitat fragmentation and destruction of wildlife caused by dune encroachment. Similarly, research in India (Pandey and Rokad, 1990), Egypt (Abu El-Ennan *et al.*, 1990) and the Western Sahara (Alvarez de Benito and Le Roux, 1976) have shown the socio-economic costs of driftsands on urban and cultivated lands. In southern Africa the consequences of dune movement have also been widely noted, for example studies in the Hout Bay area (CSIR, 1991b), the Eastern Cape (La Cock *et al.*, 1992) and the Kalahari Desert (Wiggs *et al.*, 1994). Problems of dune encroachment have been of particular significance along the central Namibian coast, where aeolian sands are being pushed into urban settlements. Recent studies in Henties Bay (CSIR, 1988; Ward and Bulley, 1989) have highlighted concerns pertaining to driftsands and have recommended several strategies for their control. Similar problems are experienced at Luderitz in southern Namibia, where mobile barchan dunes are encroaching into the town (Jacobson *et al.*, 1995)

The most prominent environmental problem in Walvis Bay are the effects of accelerated migration of dune sands across the Kuiseb Delta and into Walvis Bay Lagoon. The impacts of dune encroachment have been a serious concern since the colonial period, and much effort and large amounts of money are spent annually on clearing sands away from Walvis Bay Town. Yet scrutiny of the evidence has revealed that little was actually known about the real extent and seriousness of the problem, or even how it occurred, until recent times. This section will therefore attempt to highlight all impacts associated with driftsands encroachment in the Walvis Bay area, both ecological and socio-economic, as well as point out possible implications for future land-use planning and development.

5.3.1 Ecological Impacts

Terrestrial Impacts

As mentioned in Section 2.2.5, the study area lies at the point of transition between several vegetation types, and represents an ecotone characterised by a wide variety of

species. This area is therefore important nationally because of its transitional qualities, and the endemic species that it supports. Sand inundation, however, is having a significant impact on habitat diversity and plant cover, and it can be inferred that this is in turn reducing the richness and abundance of plants and animals across the Kuiseb Delta.

From the observations in Chapter 4 it becomes apparent that mobile dune forms are continually increasing in extent, in some areas at a rate of 15-20 m/yr⁻¹. In turn, habitats previously characterised by hummock dunes and salt marsh vegetation are being drowned by loose unconsolidated sands. Even though several species of plant are stimulated to grow by sand smothering (eg. *Sipagrostis sabulicola*), these species are generally pioneers and only represent early successional communities (Louw and Seely, 1982). Page *et al.* (1985) present evidence of overall community reactions to perturbation effects such as sand inundation, and suggest that species of semi-fixed dunes are not capable of fast reaction to change and fast recovery from disturbance. This is accentuated along the central Namibian coastline, where water is a limiting factor to growth and recovery is slow.

The deposition of sand also raises the level of the ground, and therefore increases the depth of the water table. This makes it very difficult for the establishment of plant species that rely on sub-surface water for germination. Furthermore, decreased freshwater availability leads to increased soil salinities, as a result of saltwater intrusion and a gradual increase in the concentration of evaporated salts at the soil surface. The consequences of this have been recorded in the Kuiseb Delta by the Walvis Bay Municipality (1985), where numerous *Salsola nollothensis* plants and other species have died as a result of their salinity tolerance levels being exceeded. Of note is that the tolerance levels of *Salsola nollothensis* are 7,2 %, more than double that of seawater which is between 3,3-3,4 %.

Micro-climatic changes are also associated with an inundation of driftsands. Certain plant species live in favourable micro-climates to avoid desiccation and exposure. Shade beneath larger plants and the moist sand at the base of dunes both provide suitable living conditions for many species in the region. The remobilisation of sands and an accelerated advance of dunes across the Kuiseb Delta is altering many of these areas, and in turn providing an unsuitable micro-environment for many plants.

The intra-relationships of ecosystems is a well recognised phenomenon, and it follows that any detrimental impacts on one aspect of an ecosystem will undoubtedly have ramifications on several other aspects. It can be inferred, therefore, that the inundation and die-back of plants across the study area has major ramifications for many animals, particularly in terms of the provision of food and shelter. As discussed in Chapter 3 many animals, especially the smaller invertebrates and reptiles, are limited in their distribution, and any significant decrease in suitable habitat could easily result in the local disappearance of several species, and possibly even extinctions. This applies specifically to the flightless invertebrates, many of which still have to be described. The smothering of plants by moving dunes also affects many larger mammals and birds which utilise dune vegetation for food, shelter from high daytime temperatures, protection from wind storms and for resting purposes. The abundance of the endangered Dune lark (*Mirafra erythrochlamys*), that nests in the Kuiseb Delta, could be threatened by the encroachment of vegetationless dunes.

An important ecological impact pertaining to terrestrial flora and fauna in the study area, therefore, is the fragmentation and reduction of suitable habitat by the encroachment of driftsands. Even though no indepth studies have been undertaken to verify this statement, it is apparent from the observations in Chapter 4 that vegetation cover is being greatly reduced and dune encroachment is extensive (the underlying factors for this are discussed in Section 5.2). It must be noted, however, that the ingress of mobile dunes themselves are also having a significant negative impact on both plants and animals across the Kuiseb Delta.

Estuarine Impacts

The Walvis Bay Lagoon provides a calm sheltered environment for a wide variety of macrobenthic invertebrates, estuarine fish and wading birds (see Section 2.2.6). As a result of its size and the number and density of birds that it supports it is generally recognised as the most important coastal wetland in southern Africa (Hockey and Bosman, 1983). The ecological significance of this lagoon has also been recognised internationally, resulting in its designation as a Ramsar site under the Convention on Wetlands of International Importance Especially as Waterfowl Habitat (1971). The vitality of Walvis Bay Lagoon, however, is being severely threatened by a rapid siltation and shallowing (CSIR, 1992). This is resulting in a significant decrease in suitable biological habitat.

The sedimentation of the lagoon has been analysed in detail by the CSIR (1989; 1992), who have indicated that infilling is primarily caused by the following factors: an influx of aeolian sediment off the sandspit due to the predominant south-westerly winds; and the constant input of aeolian material derived from the southern delta of the Kuiseb. A topographic monitoring programme undertaken by the CSIR (1989), has shown that since 1988 the accumulation of sediment has occurred predominantly in the exposed south-eastern reaches, due to an influx of wind-blown sand from the Kuiseb Delta. It was noted that while an aeolian sediment source exists adjacent to the upper reaches of the lagoon, the township development and various dune stabilisation procedures have effectively cut off the supply of sediment to the lower reaches. Furthermore, as a result of the lengthening of Pelican Point, the ebb tide flow velocities within the lagoon are considered to be too weak to redistribute the sediment accumulation towards the mouth. The process of sedimentation does not therefore appear to be having a significant influence on the lower reaches of the lagoon (CSIR, 1992).

Due to the relatively minimal impact the process of sedimentation is having in the lower reaches, the status of the biota in this part of the lagoon is unlikely to change significantly. However, sedimentation in the upper and middle reaches of the lagoon will have a progressively adverse effect on the biota established in these areas. It has been noted by Kensley (1978) that low species diversity and densities of benthos were found to occur in the coarse sediments deposited in the intertidal margin of the lagoon. Therefore, as sedimentation progresses this adverse environment is likely to expand, and as a consequence will reduce the area of organically rich, fine bottomed sediment. This decrease in suitable habitat will have a pronounced impact on both species density and diversity. Moreover, a shallowing will result in increased salinities in the lower reaches that can destroy macrobenthic communities - as has been observed at Conception Bay and Hottentots Bay along the Namibian coast (Kensley, 1978).

It is also likely that sedimentation in the middle and upper reaches of the lagoon will have an impact on the wader species. The population of the White-fronted plover (*Charadrius marginatus*) for example, has decreased dramatically as a result of a change in the grain distribution of the intertidal sediments due to the influx of wind-blown sand (Hockey and Bosman, 1983). This trend is likely to continue, with the area of suitable intertidal wader habitat becoming concentrated towards the lower reaches of the lagoon. A shallowing will also cause a shift in the number of shallow-water waders relative to

deep-water waders, another factor likely to negatively influence the species diversity of the lagoon.

A secondary impact to consider, as a result of driftsands encroachment into the estuary and resultant siltation, are the effects of dredging at the mouth of the lagoon. Dredging was undertaken in order to improve the tidal exchange through the mouth of the lagoon and to better the recreational potential of the wetland (CSIR, 1989). The impacts associated with dredging on the lagoon are:

- * the release of toxic substances from sediment layers;
- * a reduction in habitat for benthic organisms;
- * the smothering of benthic organisms;
- * a reduction in the rate of primary production.

The greatest dredging risk is that of releasing hydrogen sulphide (H_2S) and other toxic substances from the sediment layers underlying the lagoon. H_2S is a feature of the Walvis Bay environment and is formed by the breakdown of organic detritus under anaerobic conditions (CSIR, 1989). A release of H_2S into the water column can deplete oxygen in the water and result in the mass mortality of estuarine and marine organisms (Chapman and Shannon, 1985). The CSIR (1989) have noted that the macrobenthos, such as the Crown crab (*Hymenosoma orbiculare*) and the Paper mussel (*Anomia* sp.), would be affected most directly as their distribution appears to be restricted to this environment. In turn, a significant die-off of the benthic communities would have a detrimental ripple effect on all higher trophic levels within the lagoon, including the bird populations.

Apart from the extensive physical perturbation of the habitat and the risk of H_2S release, the dispersal of fine sediments into the water, that could smother benthic organisms, also represents a significant potential problem (CSIR, 1989). A further ecological impact of dredging highlighted by the CSIR, is the reduction in the rate of primary production that could occur. Even though this impact is considered to be only short term, increased water turbidity would represent a set-back for primary production within the lagoon, particularly for filamentous algae species.

In conclusion, therefore, the ecological implications of aeolian sedimentation of the lagoon are nothing less than catastrophic for the macrobenthic fauna, ichthyofauna and

avifauna that inhabit this environment. Furthermore, the dredging of this sediment from the lagoon also has considerable ramifications on the ecology of the area.

Impacts on the lower Kuiseb River

It has been noted by Jacobson *et al.* (1995) that many unique organisms occur in the western ephemeral rivers of Namibia and play a critical role in the ecology of the system. Recent studies in the Kuiseb have identified several species of fungi, millipedes and isopods that are new to science, highlighting how little is really known about this system. Therefore, an important factor to be considered is the impact increased deposition of wind-blown sand in the lower Kuiseb River will have on channel form, riparian and riverine habitat, as well as the magnitude and frequency of major flood events - all of which can adversely impact on the ecology of the river.

A study of the effects of tin mining has on the Ringarooma River in Australia (Knighton, 1989) showed that during a 100-year period over 40 million cubic metres of sediment was supplied to the river. The result of this was a replacing of the natural bed material and major adjustments to the channel. Aggradation was evident far downstream and channel widening and braiding became relatively common. A result was the degradation of much aquatic habitat, to which many organisms were specifically adapted. Aggradation in the Kuiseb may have similar consequences and lead to the elimination of much vital riverine habitat. Another consideration, is that sand inundation over riparian and river-bed vegetation may result in the death of many plants, and in turn affect many small animals that live in these reaches.

Many organisms that inhabit ephemeral systems are adapted to an opportunistic lifestyle and are reliant on variable flow events (O'Keeffe, 1986). Temporary pools remaining in the river-bed after such events are essential for the survival of many species. However, the movement of dunes into the river bed reduces the magnitude of floods downstream by such an extent that minimum flow requirements for many organisms may not be attained. In addition, this increased bedload (and decreased energy of the stream) may prevent surface flows from getting to the lower reaches and hence reduce the frequency of flood events. In recent years few flows have reached the delta, this being primarily a result of decreased flood frequency as discussed in Section 5.2.1, however, it is likely that accelerated deposition of wind-blown sand into the channel may also be a contributing factor to this.

5.3.2 Socio-economic Impacts

Many of the residential areas in Walvis Bay have been developed unwittingly in the path of wind-blown sand, causing dunes to build-up against buildings and walls. These accumulations of sand cause considerable inconvenience to residents of these areas and lead to numerous socio-economic costs that are often not realised by government authorities, planners and developers. Even though several attempts have been undertaken to control this build-up, costing a great deal of time and expense by the Municipality, very little work has been done in trying to understand all the problems associated with driftsands experienced by the residents of Walvis Bay.

In an attempt to obtain a preliminary perception of the problems faced, as part of this study, a questionnaire survey was undertaken in the suburbs of Kuisebmond (a lower income black residential area), Narraville (a lower to middle income coloured residential area) and Meersig (a middle to upper income white residential area) (see Figure 1.1). A total of 36 door-to-door interviews were carried out, 12 in each suburb, and focused on houses that were geographically sited on the wind exposed edges of these areas. Several questions were asked pertaining primarily to economic, engineering, health and social impacts caused by dune encroachment (see Appendix 4 for the structure of the questionnaire). Due to time constraints this survey was not expected to be statistically representative and was undertaken with the simple objective to obtain a further understanding of the above mentioned socio-economic problems.

Residential Impacts

Probably the most significant and noticeable impact of wind-blown sand on residential areas is the damage to houses and gardens. From the series of interviews it is apparent that a major problem is the accumulation of aeolian sand in roofs. This results in ceiling boards sinking under the weight of the sand, in some areas to such an extent that they have to be replaced every 2 to 3 years. A further problem is the build-up of sands against the outside of buildings, as well as next to slatted fences and low concrete walls. This consequently leads to yards being inundated to a depth of over 1.5 metres with sand (see Plate 13). In addition, the accumulation of sand against structures, such as garden walls, can exert so much pressure that it often leads to their collapse (see Plate 14). During the windier months sand inundation regularly occurs at such a rate that gardens need to be cleared 2 to 3 times a week, and in many cases this is not enough to ensure the survival of

plants and lawn. Another problem experienced is the influx of fine sands and dust inside the house, particularly through windows, doors and air vents, which settles into carpets, furniture, beds and curtains. Several residents have reiterated that they have to undertake a total spring clean at least once a week throughout the year. Other problems reported include the destruction to drain-pipes, wall paint, cars, washing machines, windows and door locks.

The financial costs associated with the above impacts are significant, particularly in terms of the average earnings families in these suburbs receive. A comparison of Table 5.2 (economic costs spent by residents to control and clear sand from their properties) and Table 5.3 (annual incomes of various population groups in Walvis Bay) highlights this point. The costs stated in Table 5.2 pertain to direct maintenance costs (for example, hiring a gardener to clear sand costs N\$30,00 a day), and do not consider indirect costs and externalities resulting from sand drift. With regards to long term economic expenditure, several homeowners have built artificial wind-breaks around their properties (see Plate 15). In addition, many residents have paved their gardens in order to facilitate the removal of sand. Both these developments can cost thousands of rand. Another factor to bear in mind is the high quantity of water that is required to upkeep gardens, as much water is used to disperse sand and dilute concentrated salts that are associated with the sand. From Figure 5.7 it is evident that escalating water tariffs in Walvis Bay make water bills no easier to pay, with costs rising from 31.2 c/kl in 1979/80 to a maximum of 292 c/kl in 1994/95 (Walvis Bay Municipality, 1995).

A significant long-term implication, particularly in the less wealthy residential areas where not as much money can be spent on household maintenance, is that many homes rapidly become run-down and depreciate in value due to the damage caused by aeolian sand. This in turn has numerous social ramifications. Moreover, the time and money spent on cleaning and maintenance, when it could be used for other needs, undoubtedly lowers the standard of living of many of these residents. Similarly, the damage to gardens and the lack of greenery is an intrinsic cost that impacts on the quality of life in the area.



Plate 13 Sand accumulation in residential gardens in Narraville.



Plate 14 Collapse of garden walls in Kuisebmond as a result of sand accumulation.



Plate 15 An example of a wind-break erected at a private home in Walvis Bay Town

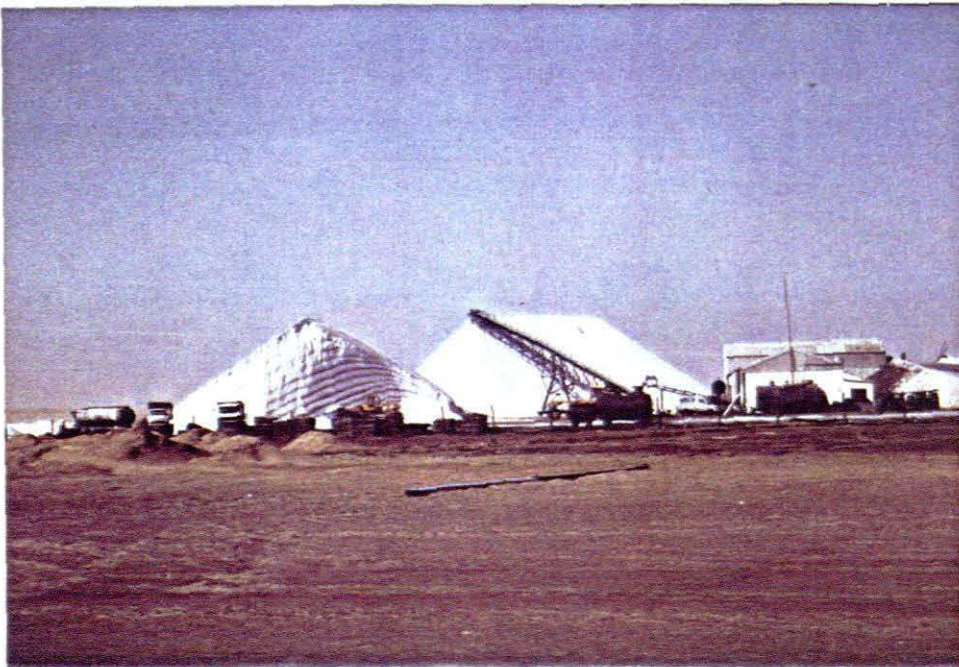


Plate 16 Salt works south of Walvis Bay Lagoon.



Plate 17 Municipal clearing of sand at Kuisebmond.



Plate 18 A sand-storm on the outskirts of Walvis Bay.



Plate 19 Sand inundation on the Walvis Bay to Swakopmund road.

Industrial and Commercial Impacts

Not only are the impacts of driftsands experienced at the home, but they can also have implications at the work place. The financial losses and opportunity costs resulting from excessive wind-blown sand are realised on a daily basis throughout the study area. For this report only three examples are specifically highlighted, however, it is likely that numerous other small businesses are also adversely affected by this phenomenon. The examples include a small nursery in Union Street, Walvis Bay Town, Walvis Bay Salt and Chemical Company at the southern and western edges of the lagoon, and Namport, a parastatal company that administers the Walvis Bay Harbour.

The impact of sand inundation on garden plants in the study area has been briefly discussed in the previous section. The financial costs of these plant losses have been highlighted by Mrs Kruger (pers.comm., 13/02/1996), who runs a small nursery that produces garden plants for commercial sale, in Union Street on the eastern edge of Walvis Bay Town. It was noted that sand drift, particularly fine mica sands resulting from easterly berg winds, can cause considerable damage to plant propagation in the Walvis Bay area. According to Mrs Kruger this nursery displays losses between N\$ 3 000.00 and N\$ 5 000.00 annually due to the smothering of seedlings by wind-blown sand. In bad years, such as in 1994, these losses can total over N\$ 11 000.00.

The impacts and opportunity costs of wind-blown sand on salt production in the vicinity of Walvis Bay are also significant. As discussed in Section 5.2.6, the Walvis Bay Salt and Chemical Company recovery ponds are directly exposed to the influx of sand from both the Kuiseb Delta and Pelican Point, and have played a major role in reducing the amount of lagoon sedimentation under south-westerly, south-easterly, easterly and north-easterly wind conditions (CSIR, 1992). It has been noted by Mr Marais (pers.comm., 05/12/1995), that the impacts experienced by this company are primarily related to the infilling of the salt recovery ponds with aeolian sand and the consequent entrapment of sand particles within the salt crystals. The recovery of high quality salt is, as a result, limited and only salt for industrial purposes is produced (see Plate 15). No figures could be obtained, however, it has been noted by Mr Klein (pers.comm., 12/02/1996) of the Salt Company in Swakopmund that coarse "high quality" salt, such as that produced north of Walvis Bay, fetches a much higher price on the international market.

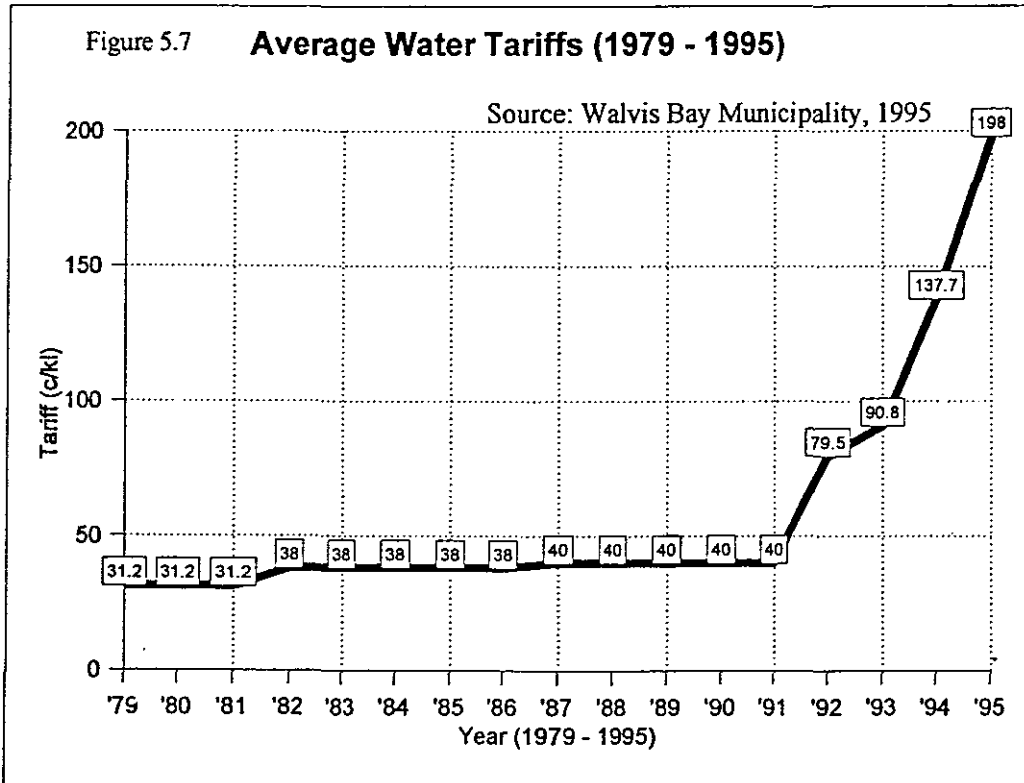
TABLE 5.2 ESTIMATED HOUSEHOLD COSTS SPENT ANNUALLY BY RESIDENTS OF WALVIS BAY TO CONTROL AND CLEAR SAND FROM THEIR PROPERTIES.

NS	0-200	200-500	500-1000	1000-3000	+3000	UNKNOWN
Kuisebmond	—	6	4	—	—	2
Narraville	—	1	4	6	1	—
Meersig	—	1	3	5	2	1

TABLE 5.3 ANNUAL INCOME OF BLACK, COLOURED AND WHITE POPULATION GROUPS IN WALVIS BAY (1991)

TOTAL ANNUAL INCOME IN R5	NONE	1-999	1000-2999	3000-4999	5000-6999	7000-9999	10000-29 999	30 000-49 999	50 000-69 999	70 000-99 000	100 000-299-999	R300 000+	
BLACKS	3218	213	5678	619	328	227	592	42	1	-	-	-	85
COLOURED	3371	85	269	167	195	256	844	81	13	2	1	-	22
WHITES	2755	96	574	139	115	182	1470	823	265	115	71	6	75
TOTAL	9345	394	6521	925	638	666	2909	946	278	117	72	6	182

SOURCE: Central Statistics Services (1991)



The Namibian Ports Authority (Namport) is a commercialised parastatal company that assumes responsibility for the port of Walvis Bay (UCT, 1996). An important undertaking of Namport is the dredging of the harbour, which is performed about every five years. It is estimated that on average 128 400 m³/year of silt and sludge is cleared from the harbour (CSIR, 1994). Even though the town and the lagoon shield the port from north-east and north-west winds, aeolian sand transport still influences depositional rates within the harbour. Since each dredge costs Namport an estimated several hundred thousand dollars, the role of aeolian sand, even though not the sole contributor of sediment in the harbour, is significant.

Municipal Impacts

The impacts experienced by the Walvis Bay Municipality are primarily economic and related to the costs spent in clearing roads, property, greenbelts and fences that have been inundated with sand. In reference to Brummer (pers.comm., 12/02/96) the removal of sand is a continuous process and involves over 28 labourers using earth-moving and mechanical street sweeping machinery (see Plate 17). Individual statistics on volumes moved are unfortunately not available, but amounted to N\$574 121,50 in Walvis Bay Proper, N\$269 158,65 in Kuisebmond and N\$194 037,00 in Narraville during 1995 (Walvis Bay Municipality, 1995). It has been noted by several residents of Narraville and Kuisebmond that even these efforts are far below what is required.

Another financial cost that is realised by the Walvis Bay Municipality is that of sand dune stabilisation. According to Barnard (1975) R2000,00² was spent on this task in 1965/66, by 1972/73 however this expenditure had escalated to nearly R 40 000,00. In recent years dune stabilisation is undertaken by both the Municipality and the Department of Forestry, with the latter spending up to N\$ 200 000,00 per year (Esterhuizen, pers.comm., 13/02/1996). The history and methods of dune stabilisation will be discussed in more detail in Chapter 6.

Further problems realised by the Municipality, include the blocking of stormwater drains with sand, the impacts of sand abrasion against buildings and road signs, and the costs of dredging the lagoon. It should be noted that all these expenses are essentially tax payers money and therefore reflect back upon the residents of the area.

2 Prior to 1994 the Walvis Bay enclave was under South African jurisdiction, and as such Rands were used as the form of currency.

Health and Safety Impacts

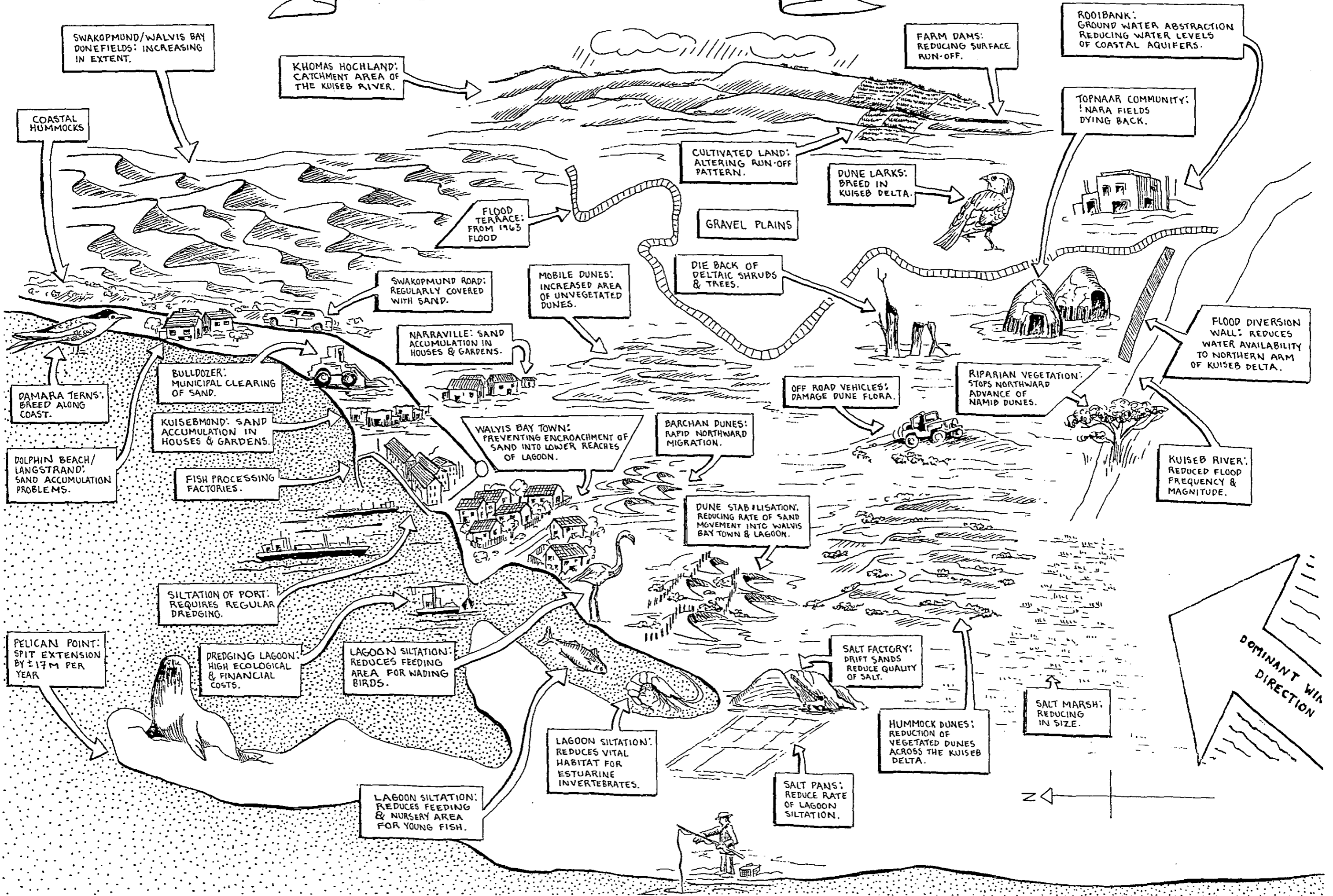
Another issue not been previously addressed in the study area is the associated health problems that result from the accelerated drift of sand into Walvis Bay Town. From the series of interviews it is apparent that the dust storms caused by easterly berg wind conditions, as well as the general build-up of sand and dust around the house, lead to the greatest problems. Another contributing factor is the blocking of air-vents by fine sands, preventing an adequate air-flow and resulting in houses becoming increasingly warm and humid during the day. The survey undertaken for this study identified several common health conditions that have been attributed to wind-blown sands. These are as follows:

- * asthma and other respiratory problems;
- * colds, flu, hayfever and sinusitis;
- * eye and ear infections;
- * skin irritations and allergies;
- * headaches.

Even though it is difficult to isolate wind-blown sand as the principle causative factor, it is important to note that all interviewees identified one or more of the above ailments, and reiterated the close relationship between wind-blown sands and health conditions. Furthermore, a medical doctor interviewed also highlighted the above conditions and related them to the influx of sand and dust both indoors and outdoors. It is important to note that increased health problems lead to numerous ripple effects that can be detrimental to all aspects of the socio-economic environment and seriously impact on the standard of living.

Aeolian sand not only has health ramifications, but also impacts on road safety in the study area. Severe sandstorms can inundate a road in minutes, therefore not only reducing visibility, but also causing vehicles to get stuck in the sand on tar roads (see Plates 18 and 19). In addition, the build up of sand on road corners has been recognised by several residents as a factor responsible for many motor vehicle accidents. This is because many drivers, by avoiding these accumulations of sand, veer into oncoming traffic.

FIG 5.8 KEY ISSUES PERTAINING TO DUNE MOVEMENT IN THE WALVIS BAY AREA.



5.4 CONSIDERATIONS FOR FUTURE LAND-USE PLANNING AND DEVELOPMENT

As discussed in Section 2.3, the new constitutional position of Walvis Bay, since its transferral to Namibian authorities on the 1 March 1994, has led to a rapid rise in the population growth rate and resulted in new policies for economic and industrial expansion in the area. Owing to the unique environmental setting of the town as well as the pressing needs for development and demands for resources, planners and decision-makers are faced with an awesome challenge. It is relevant to note that even though this environment is highly dynamic and probably not suitable for permanent development, appropriate planning may have mitigated many of the problems experienced. The following quotation aptly clarifies this point:

"If we don't order our affairs by bringing environmental planning in at an early stage, we will endanger natural resources and move from crisis to crisis"

Department of Environmental Affairs (1991)

The environmental impacts of dune movement, noted earlier in this chapter, highlight the significant constraints the natural environment provides in the day-to-day life of residents in the study area. This symbiotic relationship between people and the natural environment has been encapsulated in McHarg's classic book entitled "Design with Nature" (1969). Here McHarg expresses the need for development to realise the full potentialities and restrictive conditions that nature offers. This philosophy has more recently been noted in the Coherent Development Strategy for Walvis Bay (Dennis Moss Partnership, 1994), which states that 'planning and design be constantly guided by the objective to balance physical development with the natural processes and sensitivities that are inherent in the core-area'. In line with this, it is imperative that planning and development in Walvis Bay acknowledges the constraints of dune movement, as this will ensure that development is more sustainable and thereby improve the quality of life and general welfare of the community. This section, therefore, will briefly highlight considerations pertaining to dune movement that should be taken into account with any future planning and development in the vicinity of Walvis Bay. In addition, the implications of sea-level fluctuations upon dunes and land-use planning will also be discussed.

5.4.1 Town Planning Considerations

As discussed in Section 5.3, numerous impacts have been incurred by the ingress of driftsands in the Walvis Bay area. In order to limit these impacts in the future it is essential that zones of maximum dune movement are identified and developments are planned accordingly. From Chapters 3 and 4 it is apparent that certain dune types are more active than others, with hummock, linear and large transverse barchanoid dunes being relatively inactive, when compared to small transverse barchanoid and barchan dunes. From the analysis of spatial-temporal geomorphic changes in the study area (see Chapter 4), critical areas were identified and divided into zones of severe sand encroachment, moderate sand encroachment and slight sand encroachment (see Figure 5.9). It should be noted that these zones do not necessarily represent a measure for development, but rather a guide by simply highlighting areas faced with different degrees of sand inundation. It is important to consider that several other concerns also need to be recognised in terms of town and regional planning, for example, many of the more physically stable areas provide important habitat for a diverse fauna and flora, and development in these zones could be highly detrimental to the ecology of the area.

Zones of severe sand encroachment

The main zone of severe dune migration occurs to the immediate south, south-west and west of Walvis Bay Town, extending inland west of Narraville and southwards beyond the end of the lagoon. In this zone, areas most threatened are the eastern and southern edges of Narraville, Kuisebmond and Walvis Bay Town. Other zones of severe movement occur to the north of the Swakopmund/Walvis Bay Dune Field, however, this ingress does not pose a threat as no development occurs in this area.

Zones of moderate sand encroachment

Moderate dune movement is characteristic across most of the Kuiseb Delta, specifically in areas dominated by small transverse barchanoid dunes that occur north of the Kuiseb River, and to the north and north-east of Walvis Bay Town. Another zone of moderate sand movement occurs along the north-western edges of the Swakopmund/Walvis Bay Dune Field. Areas threatened by moderate levels of sand encroachment include the north and western edges of Narraville and Kuisebmond, as well as certain parts of the Swakopmund road that leads north from Walvis Bay.

Zones of Slight, Moderate and Severe Sand Encroachment in the Walvis Bay Area

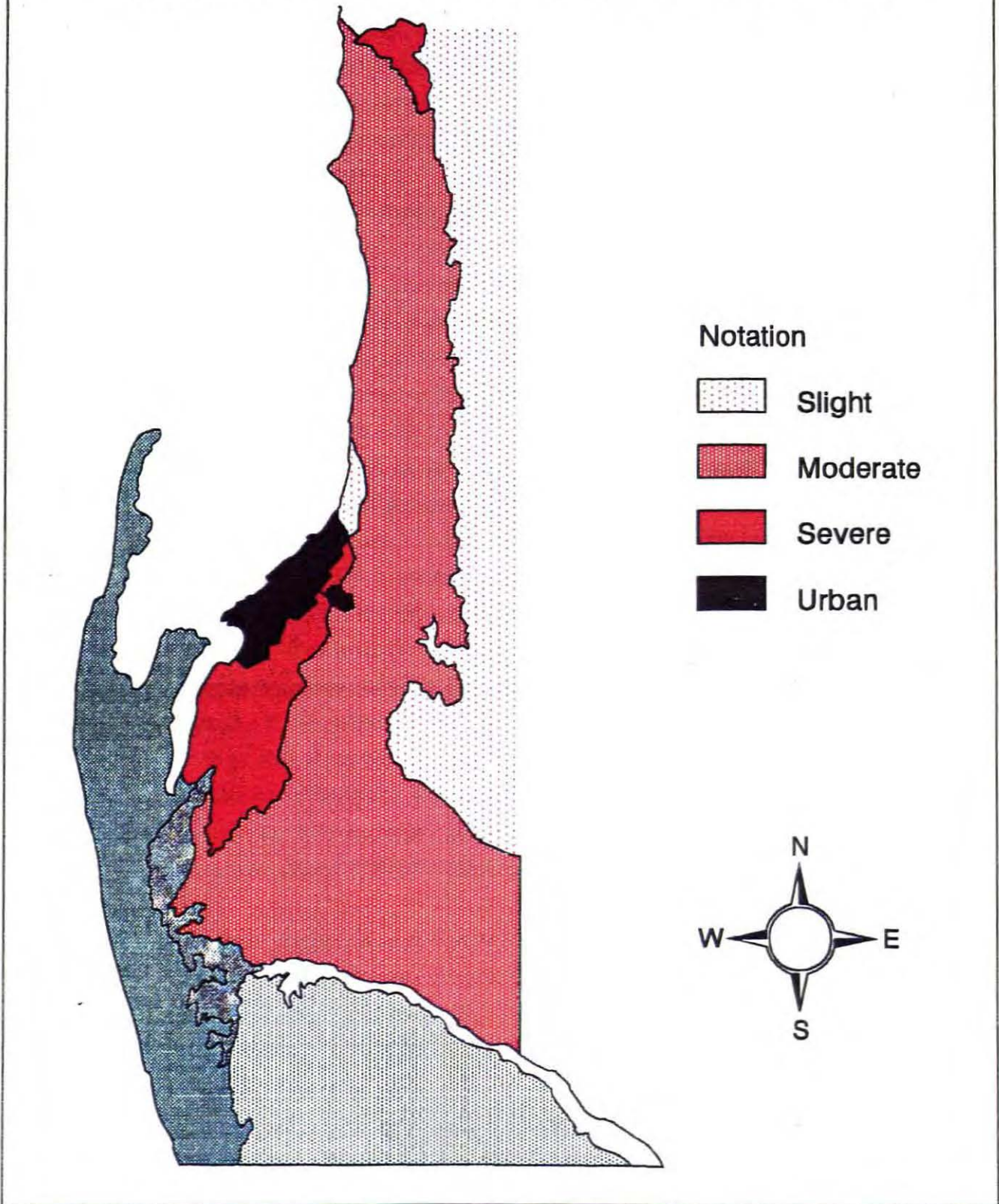


Figure 5.9

Zone of slight sand encroachment

In the study area these zones are of local occurrence, and where they do occur it is because their upwind portions are usually stabilised. Examples include certain areas to the north of Walvis Bay Town, parts of the coastal tract between Walvis Bay and Swakopmund, and the gravel plains inland of the Swakopmund/Walvis Bay Dune Field. Dune stabilisation practices south of Walvis Bay Town have limited dune movement in localised areas, and as a result enabled development in these zones.

Considerations with regard to future spatial requirements

As pointed out in Section 2.3, three possible growth scenarios are envisaged for Walvis Bay over the next twenty years. If the scenario with the highest growth rate of 3-4% is assumed, enormous spatial requirements need to be addressed. These requirements have been calculated within the Coherent Development Strategy for Walvis Bay (Dennis Moss Partnership, 1994) and are displayed in Figure 2.7. In terms of this scenario approximately 1 000 hectares of land would be required in addition to the existing approximately 600 hectares of developed land. With a population increase of nearly 50 000 by the year 2015 at least 630 hectares will be required for housing purposes in Walvis Bay, with over 400 hectares being planned in the vicinity of Narraville and Kuisebmond (this would require at least 11 000 dwelling units) (Dennis Moss Partnership, 1994). These areas have been identified as zones of high and moderate sand encroachment, as well as areas where the vast majority of problems relating to driftsands are experienced. If the principle housing objectives of the Coherent Development Strategy are to be met, these being to 'meet the basic need for decent living conditions in order to promote social harmony and the productivity of the workforce' and 'to improve the quality of living environments', problems pertaining to driftsands will need to be more adequately addressed in the planning stage of these developments.

As is evident from the previous section, the planning of commercial and industrial areas with regards to driftsands is also important. With Export Processing Zones presently being planned in Walvis Bay (Walvis Bay Municipality, 1995), and all the infrastructure that will be associated, it would be beneficial to consider zones of dune movement. The EPZ sites presently identified occur in zones of moderate to low sand encroachment, as they are relatively sheltered by Walvis Bay Town. However, the requirement of any further EPZ sites, which according to the Coherent Development Strategy is highly

likely, the problems associated with dune movement will need to be considered. It has been noted in this strategy that further industrial development would probably be sited east of the Swakopmund/Walvis Bay Dune Field (an area of slight sand migration).

5.4.2 Engineering Considerations

The considerable damage and costs resulting annually from dune encroachment highlight the need for future developments to recognise not only land-use planning implications, but also design and engineering implications. The provision of appropriate construction technology and design that is suitable to this coastal environment will not only benefit the local community, but also be more sustainable in the long-term. Even though these aspects of the built environment have been reiterated by other researchers along the central Namibian coast (eg. Bulley, 1983; Ward and Bulley, 1989), few attempts have been made to counter-act these problems.

Hill and Bowen (1995) proposed that for construction to be sustainable it should 'improve the quality of human life while demonstrating a responsible approach towards operating within the carrying capacity of supporting ecosystems, to ensure the well-being of all people, both now and in the future'. They noted that in order to achieve this definition, the following seven principles should be applied:

- * minimise resource consumption - conserve and reduce use of resources;
- * maximise resource reuse - avoid and reduce waste;
- * use renewable or recyclable resources;
- * protect the natural environment and restore environments degraded by past activities
- * create a healthy, non-toxic environment;
- * pursue quality in creating the built environment;
- * promote labour intensive methods, skills training and capacity building of local people.

The use of hardier materials and appropriate designs to prevent the accumulation of sands both inside and outside buildings may be initially an expensive outlay, however, in the long-term it would increase the life-span of the building and reduce the maintenance costs of the residents. Appropriate design can effectively assist in reducing sand accumulation on the outside of buildings. For example, free flow of wind around

buildings results in a beneficial self-cleaning effect, whereas, obstacles such as courtyards and wing walls aligned across wind result in considerable sand deposition. Boundary fences, particularly concrete walls and slatted fences, also promote the accumulation of aeolian sands. In terms of the abrasiveness of sands more resistant paints or stronger building materials could be used. An example that is presently being employed in the building industry along this coast is the use of finer concretes, as coarser concretes were absorbing aeolian sand grains. These grains would then lead to variable heating and cooling of the concrete and cause a crumbling of the building surface. In addition, salt crystals attached to sand grains were expanding, also contributing to the weathering of concrete surfaces.

Therefore, with over 11 000 dwelling units to be built within the next 20 years, attention should be given to appropriate materials and designs that are more resistant to sand abrasion and sand accumulation. In doing so an attempt would be made to achieve the principles of sustainable construction, and many of the socio-economic impacts discussed in Section 5.3.2 could be abated.

5.4.3 Global Warming and the Rise in Sea Level

In addition to an expected increase in many of the impacts discussed above, it is necessary to consider the potentially disastrous ramifications of the 'greenhouse effect'. The 'greenhouse effect' is thought to be the result of an increased release of gases such as methane, nitrous oxide and carbon dioxide into the atmosphere over the last few decades. The consequences of the enhanced 'greenhouse effect' are global warming and, following from this, a rise in sea level. The extent of this rise, and the time scales involved are currently being debated, but best estimates at the present point to an average increase in global temperatures of 3 to 4 degrees celsius and a rise in sea levels of between 35 cm and 1,5 m over the next century (McGwynne and McLachlan, 1992).

Southern African sea levels are rising at rates comparable with estimates of global sea level rise (Hughes *et al.*, 1991). Walvis Bay Town, lying just 2 m above mean sea level, is therefore particularly vulnerable to this phenomenon. Hughes *et al.*, (1992), noted four main categories of potential impact, these being: increased coastal erosion; increased saline intrusion; raised water tables; and flooding and inundation. It was determined that because of the extremely dynamic sediment budget of the area, the effect of coastal erosion would have limited impact on the Walvis Bay environment. What could possibly

result is the retreat of the littoral active zone and a scarping and re-activation of coastal dunes. It is also anticipated that sea-level rise may slow the process of lagoon siltation and the northward migration of Pelican Point (Hughes *et al.*, 1992).

Saline wedge intrusion is an important factor that needs to be considered, as rising sea levels will increase potential salt pollution problems in the coastal aquifers in the vicinity of Walvis Bay. This intrusion will not only impact on dune plants, such as *Salsola nollothensis*, but will influence the domestic and industrial use of groundwater in Walvis Bay Town. Furthermore, any over-extraction will cause the saline wedge to migrate landwards and hence exacerbate the impacts of sea level rise. A change in water table elevation may destroy dune plants in some areas, paradoxically however, in other areas it will aid the stabilisation of dunes across the delta by extending salt marsh areas and supporting salt resistant dune vegetation. A reverse trend would probably occur compared to that at present, with vegetated dune forms in the central delta becoming more dominant, thereby reducing rates of sand encroachment. Of greater significance would be the effects of a water table rise on Walvis Bay itself, as a rise of 1.0 m would likely flood the majority of the town below 1.7 m elevation (Hughes *et al.*, 1992).

By far the most serious consequence of rising sea-levels for Walvis Bay is that of higher, storm-induced, coastal water levels. Higher sea waters will raise the intolerable risk levels along the coast, and it is predicted that a rise of just 0.2 m will have a more devastating impact than a 1 in 100 year storm at present levels (Hughes *et al.*, 1992). When considering that much of Walvis Bay lies below 2 m elevation, the impacts will be considerable.

5.5 CONCLUSION

Dune movement in the study area can be attributed primarily to the reduction in the frequency and magnitude of flood events in the lower Kuisieb River that limits the provision of water to deltaic shrubs and trees. This reduction appears to be a result of both natural and human-induced changes, caused by climatic fluctuations, upstream impoundments and inappropriate catchment land-use practices. These impacts are being compounded in the Kuisieb Delta by the over-abstraction from coastal aquifers and the development of a flood diversion wall. The movement of sand, on a more local scale, is being influenced by off-road vehicles, urban expansion, the development of salt recovery pans and dune stabilisation practices. It is apparent that, unless flows with the magnitude

to reach the sea and recharge groundwater levels become more frequent, it is likely that the process of desertification will continue in the study area.

The ramifications of dune movement are significant and are being experienced both ecologically and socio-economically. An important ecological concern is the loss and fragmentation of habitat across the delta and within the lower reaches of the Kuiseb River. This could result in the disappearance of several species of animals and plants, and possibly even extinctions. Of international significance is the accelerated siltation of the Walvis Bay Lagoon, a registered Ramsar site and probably the most important wetland for migratory birds in southern Africa. Studies have shown that sedimentation is rapidly reducing habitat for macrobenthic fauna and in turn limiting food supplies for wading birds. Dune encroachment is also affecting the socio-economic environment and is causing immeasurable damage to residential houses, municipal buildings, infrastructure and several businesses in the Walvis Bay area. The enormous economic costs involved and the influence driftsands are having on community health is undoubtedly lowering the standard of living of many residents.

In order to reduce many of these problems, particularly in light of a rapidly expanding population, it is important that land-use planners and developers acknowledge the rigorous limitations of this environment. Industrial and township expansion needs to plan proactively around areas of severe, and even moderate sand encroachment so as to ensure that problems presently faced will be reduced in the future. A more sustainable approach to construction is required, using technologies and designs suitable to the Walvis Bay environment.

**DUNE MANAGEMENT IN THE
WALVIS BAY AREA**

6. DUNE MANAGEMENT IN THE WALVIS BAY AREA

6.1 INTRODUCTION

The dune systems of the Walvis Bay area provide a highly diverse and variable environment, combining outstanding scenic variation and beauty with a wealth of animal and plant life. Due to its interface between land and sea this area also has experienced a great deal of development in recent times, and is thus a multi-functional system of great importance to society, offering utility functions such as coastal defence, recreation, housing and conservation areas.

As discussed in Chapter 5, the study area is experiencing numerous environmental problems that result, to a considerable degree, from human activities. This chapter, therefore, reviews practices that have been undertaken to control dune movement in southern Africa, and more specifically the Walvis Bay area, and highlights considerations that may contribute to the more effective management of the system in the future.

6.2 DUNE STABILISATION

Dune stabilisation or reclamation can be defined as the process of limiting or preventing the movement of shifting sands by covering the surface with artificial material or by establishing a vegetation cover (Avis, 1992). This movement of sand is a natural and intrinsic component of the dynamic ecosystem of the Kuiseb Delta, and the shape and extent of dunes and beaches are constantly changing by erosion or accretion in response to the variable climatic and environmental factors experienced in the area. It was only when people started developing and exploiting this stretch of coast that these natural drift sands posed a threat, and the need arose to prevent sand movement. In recent times these problems have been exacerbated by the marked die-back of vegetation and a consequent destabilisation of dunes across the Kuiseb Delta.

Even though a great deal of information concerning dune stabilisation has been published internationally (Stoetz and Brown, 1957; Pickart, 1988; Pandey and Rokad, 1992; Al-Ajmi *et al.*, 1995), as well as elsewhere in the sub-continent (Keet, 1936; Walsh, 1968; Avis, 1989; McLachlan and Burns, 1992), a limited amount of literature is available for Namibia. Furthermore, the few accounts that do occur for the Walvis Bay area are mostly

contained in unpublished government and municipal reports (Le Roux, 1974a; Le Roux, 1974b; Walvis Bay Municipality, 1985). The aim of this section is, therefore, briefly to consolidate the historical accounts on dune stabilisation in southern Africa, and more specifically in Walvis Bay, and discuss both the past and present methods employed. Problems associated with dune stabilisation are also addressed.

6.2.1 Historical development of dune management practices in southern Africa

The earliest records of dune stabilisation in the sub-continent date back to the mid-nineteenth century, where programmes were developed in the Western Cape in order to protect roads and settlements from driftsand encroachment. These early methods simply involved sowing seed and planting seedlings directly into the sand (Avis, 1989). Both indigenous species, such as Hottentot fig (*Carpobrotus edulus*) and Pipegrass (*Ehrharta villosa*), and aliens such as Port Jackson wattle (*Acacia saligna*) were used. Later this work was expanded, with more alien species such as Long-leafed wattle (*Acacia longifolia*), Sweet hakea (*Hakea sauveolens*), Australian myrtle (*Leptospermum laevigatum*) and Cluster pine (*Pinus pinaster*) being introduced (Shaughnessy, 1986).

In the latter half of the nineteenth century new techniques were employed. One method entailed the placing of rows of half-meter high brushwood at random distances apart on the bare sand. Seeds of various indigenous and alien plants were then sown in between these rows. Also developed were screens of alien trees that were planted at 400 m intervals, with smaller shrubs and ground-cover placed in between (Avis, 1989). In 1875 the Cape Forestry Department took over the responsibility of stabilisation and decided that driftsands should be stabilised with tree plantations which could then be harvested for economic return. In order to achieve this goal, extensive areas in the Western and Eastern Cape were planted with Port Jackson wattle and various species of pine. The technique involved the spreading of city refuse across areas which were to be stabilised. This refuse, which contained a high proportion of horse manure, would help provide nutrients for the seedlings. The provision of this refuse, however, proved to be uneconomical and Marram grass (*Ammophila arenaria*) began to be used instead to stabilise sand before seeding (Avis, 1989).

Dune stabilisation methods changed little from 1900 to 1970 when control of driftsands fell under the jurisdiction of the Department of Forestry. During this period the method

was essentially threefold. The first step involved the trapping of sand with wooden barrier poles or Marram grass, this was followed by the stabilisation of the sand behind the artificial dune with brushwood or sewing grass. The third and final stage in the process involved the introduction of woody species, mainly Australian *Acacias*, by sowing seed amongst the grasses. In more recent times the threat to indigenous vegetation along the sub-tropical east and temperate west coasts by the invasion of woody alien species was recognised. Slowly the use of alien species was phased out and only indigenous and non-invasive alien species, such as Marram grass, used.

At this time the Department of Forestry reviewed its general policy on dune stabilisation and decided that natural ecological processes governing dune environments needed to be taken into account. It was realised that the injudicious stabilisation of vast areas of driftsand was restricting the natural cycle of deposition and erosion (Stehle, 1981). It was made policy that only when farmland and settlements were threatened would dune stabilisation be considered. Furthermore, it became mandatory that a management plan containing information on the area requiring stabilisation, why it should be undertaken and what methods were to be used, be prepared (Avis, 1992). In this line, techniques aimed at simulating dune succession were, and presently are, employed.

6.2.2 Early attempts at combating driftsands by the Water Affairs branch of the South-West African Administration

The problems of shifting dunes in the Walvis Bay area have been recognised since the arrival of early settlers in the mid-eighteenth century, as is evidenced by early photographs that indicate original houses being built on piles in order to curb the threat of sand inundation and occasional flooding. Le Roux (1974a) notes that even though the influx of sand was a continual problem, it was not until the 1950s that an organised dune stabilisation programme was initiated. This was undertaken by the Water Affairs branch of the South-West African Administration, who erected over 12,8 km of barrier poles with the object of establishing two artificial dunes to protect the town and access roads against encroaching sand.

These early methods began in May 1950 and involved the erection of round wooden poles, approximately 1,5 m long and 5 cm in diameter, which were driven into the sand as close together as possible and deep enough to withstand the strength of the wind. These poles functioned as a barrier to the wind resulting in the deposition of sand. As the

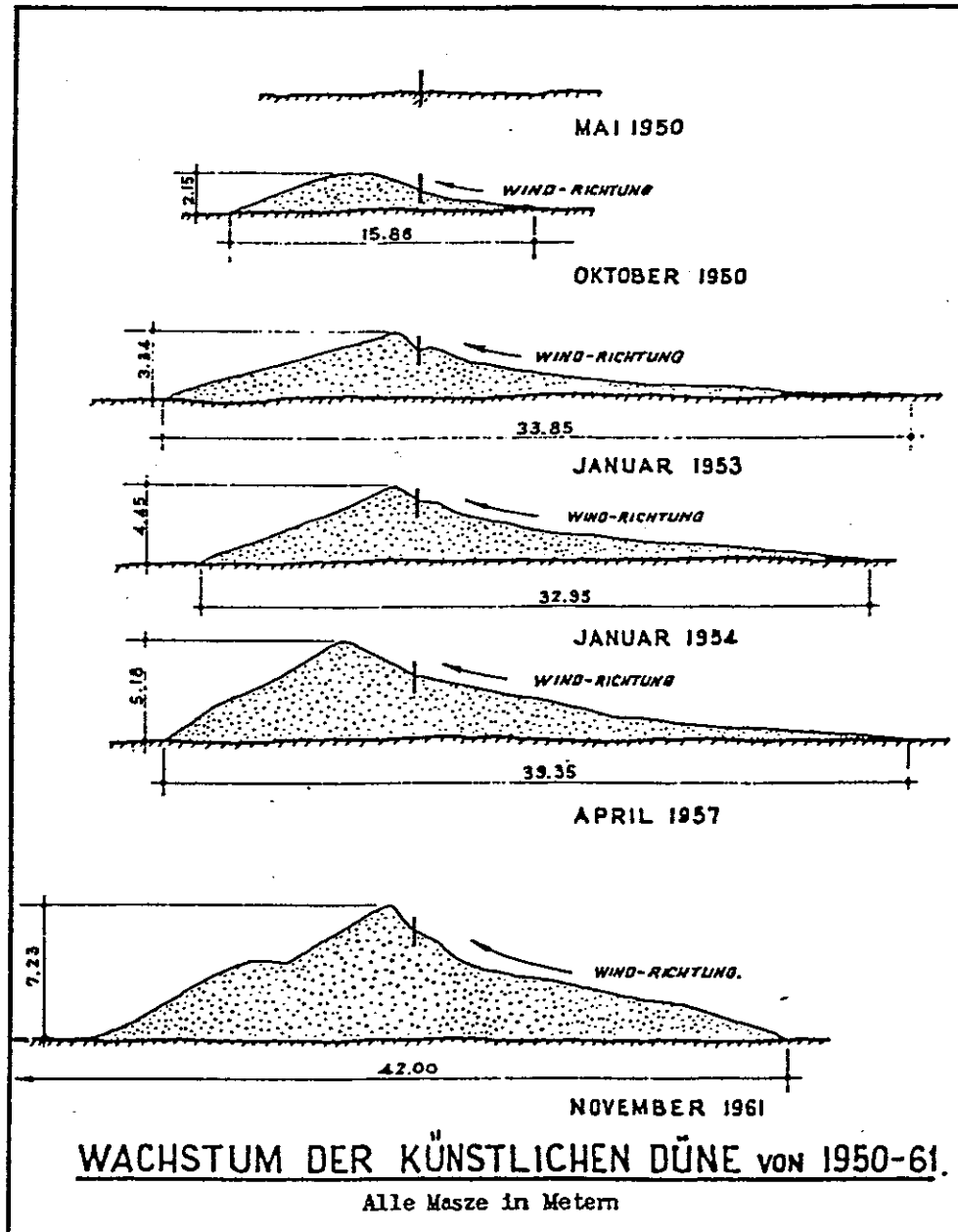


Figure 6.1 Growth of the Artificial Dune from 1950 - 1961 (all measures in metres)
(Source: Stengel, 1963)

sand accumulated, the poles were drawn up, causing the dune gradually to grow higher year by year. According to Stengel (1963), the artificial dune expanded to height of 5 m between 1950 and 1961 (see Figure 6.1), and was of a length of at least 14 km. In May 1970 the sand reclamation work that was undertaken by the Water Affairs branch was passed on to the Department of Forestry.

6.2.3 Methods undertaken by the Department of Forestry

The Department of Forestry³ is primarily responsible for the stabilisation and control of sand dunes south of Walvis Bay. The department utilises a combination of sand stabilisation techniques, these being:

- * pole barriers;
- * afforestation;
- * flooding of interdune areas (see Plate 20).

Pole Barriers

The pole barriers used since 1950 were employed with a fair amount of success, however, these poles required a great deal of maintenance as they had to be regularly lifted to be effective. A major problem encountered was that the increased wind velocity between the poles eroded a V-shaped gully into which the poles collapsed. To eliminate this damage the Department of Forestry started spraying saline solution in a thin strip on the windward side of the poles. This solution rapidly dried leaving a hard layer on the sand that helped reduce wind erosion (Le Roux, 1974a).

Due to the high maintenance costs and the expense of erecting poles, various experimental plastic barriers were tested. These barriers consisted of relatively permeable plastic sheets of between 3 to 5 mm in thickness and up to 1 m in height. These barriers proved to be inappropriate as they tended to tear (high replacement costs), curl (decreasing the height of the barrier), and were extremely difficult to raise once sand had been deposited against them (Le Roux, 1974a). Due to the poor results of these

3 With the hand-over of Walvis Bay to the Namibian Authorities in May 1994, the responsibilities of the Department of Forestry were taken over by the Directorate of Forestry, within the Ministry of Environment and Tourism.

experiments, the Department of Forestry has reverted back to wooden poles which are now extensively used south of Walvis Bay Town.

Afforestation

Since the early 1970s, various trials have been undertaken by the Department of Forestry to determine which plant species can be established successfully in the Walvis Bay area in order to stabilise encroaching dunes. Due to the arid climatic conditions and the high salinity of the soils that prevail in the study area, few plants are suitable for dune stabilisation. The trials tested 47 species of plant, 13 of which were locally indigenous (Le Roux, 1974b). The tests primarily aimed at determining which plants were able to grow from salt water irrigation, resist soil salinities of up to 7,6 % (seawater is between 3,3-3,4%) and overcome exposure and sand inundation. A list of species evaluated for dune stabilisation is provided in Table 6.1.

According to Esterhuizen (pers. comm., 13/02/1996) of all the plants tested over the last twenty years only four species were able to adequately withstand saltwater irrigation and other environmental factors, and proved suitable for the stabilisation of driftsands. These species are the locally indigenous shrub *Salsola nollothensis*, the exotic shrubs *Atriplex isoteria* from western Australia and *Atriplex nummularia* from South Africa, and the tree *Tamarix usneoides* from the Dead Sea area of Israel. Over the last few years a fifth plant has been added to this list, namely *Atriplex rhagoides*, a hybrid of *A. isoteria* and *A. nummularia*. These plantings not only play an important role in arresting sediment encroachment but are an aesthetically attractive feature alongside the lagoon, and also provide habitat for many small animals (pers. obs.).

Flooding of interdune areas

The function of this method is to stabilise interdune areas and small dunes by a regular flooding and drying. The water of the lower reaches of the lagoon is highly saline and, as it evaporates a salt crust is gradually left on the surface. This crust, along with the wetted sand, ensures that virtually no sand movement occurs. This method is controlled by a series of sluices that are situated under the road that leads along the perimeter of the lagoon to the saltworks (see Plate 21). As the tide rises these sluices are pushed open and interdune areas alongside the lagoon are flooded. As the tide drops, however, the sluices close trapping much of the water in large pools that slowly dry. According to Esterhuizen

TABLE 6.1 PLANT SPECIES EVALUATED FOR DUNE STABILISATION AT WALVIS BAY BY THE DEPARTMENT OF FORESTRY

SOURCE: LE ROUX (1974b)

SPECIES	CONDUCTIVITY
<i>Sarcocornia natalensis</i> *	76,5 x 10 ³
<i>Salsola nollothensis</i> *	61,0 x 10 ³
<i>Atriplex breweri</i> +	47,5 x 10 ³
<i>Atriplex canescens</i> +	47,5 x 10 ³
<i>Atriplex halimus</i> +	47,5 x 10 ³
<i>Atriplex lentiformis</i> +	47,5 x 10 ³
<i>Atriplex semi-baccata</i> +	47,5 x 10 ³
<i>Atriplex nummularia</i> +	35,0 x 10 ³
<i>Polygonum equisetiforme</i> +	35,0 x 10 ³
<i>Phragmites australis</i> *	30,0 x 10 ³
<i>Tamarix usneoides</i> *	30,0 x 10 ³
<i>Lycium tetrandrum</i> *	29,5 x 10 ³
<i>Odyssca paucinervis</i> *	24,5 x 10 ³
<i>Acanthosicyos horrida</i> *	18,0 x 10 ³
<i>Capparis hereroensis</i> *	18,0 x 10 ³
<i>Crotalaria colorata</i> *	10,0 x 10 ³
<i>Heliotropium curassavicum</i> *	10,0 x 10 ³
<i>Scirpus dioicus</i> *	10,0 x 10 ³
<i>Ammophila arenaria</i> ++	3,0 a 10 ³
<i>Artemisia monosperma</i> ++	3,0 a 10 ³
<i>Casuarina equisetifolia</i> ++	3,0 a 10 ³
<i>Ehrharta villosa</i> ++	3,0 a 10 ³
<i>Eucalyptus camaldulensis</i> ++	3,0 a 10 ³
<i>Eucalyptus gomphocephala</i> ++	3,0 a 10 ³
<i>Galenia secunda</i> ++	3,0 a 10 ³
<i>Leptospermum laevigatum</i> ++	3,0 a 10 ³
<i>Prosopis juliflorae</i> ++	3,0 a 10 ³
<i>Retama roctam</i> ++	3,0 a 10 ³

* Indigenous species
 + Irrigated with sea water
 ++ Irrigated with sewage water

Conductivity values
 represent natural &
 tested tolerance limits

(pers. comm., 13/02/1996), many of the interdune areas are below high water level, resulting in spring tides flowing inland for up to 1,5-2 km.

6.2.4 Methods undertaken by the Walvis Bay Municipality

In stabilising and controlling the movement of aeolian sand into Walvis Bay Town, the Municipality is responsible for the following developments and activities:

- * levelling and covering of dunes;
- * green belts;
- * slatted fences.

Levelling and Covering of Dunes

In 1964 the Municipality of Walvis Bay started to stabilise the dunes nearest the residential and industrial areas with either gypsum gravel, old motorcar oil or ash from the local power station (Walvis Bay Municipality, 1985). Dunes were usually flattened, using a grader, to an angle of less than 30° and immediately covered with one of the above mentioned materials. It has been noted by Le Roux (1974a) that, in order for this technique to be effective the sand must be covered by either a layer of gravel 25 mm thick, a layer of coal ash 15 mm thick, or oil that penetrates at least 10 mm into the sand.

According to Muller (pers. comm., 12/02/1996) these materials are not equally durable, with gypsum gravel and coal ash being the most resistant to wind erosion by constantly absorbing air-moisture and moulding into a tough surface capping. Oil, on the other hand, has a shorter life-span and rapidly breaks down and cracks under the environmental conditions, and as a result has to be regularly replaced. The costs of these materials varies, with gypsum costing up to N\$ 1000,00 per 100 m^2 , and coal ash and oil being relatively cheaper (Muller, pers. comm., 12/02/1996). Therefore, in application the cost effectiveness of each of these materials needs to be accurately determined.

Recently the Municipality conducted several experiments with the use of plastic emulsions and salt water irrigation. The use of plastic emulsions was initially successful, but were not durable and did not last very long in practice (Muller, pers. comm., 12/02/1996). The irrigation of dunes with highly saline groundwater, however, proved effective. As with the technique of interdune flooding, it was shown that the repeated



Plate 20 Dune stabilisation south of Walvis Bay Town undertaken by the Directorate of Forestry - pole-barriers, vegetation plantings and flooding of interdune areas.



Plate 21 A sluice that controls the movement of water into dune areas, with the Walvis Bay Lagoon in background.



Plate 22 Green belt of bamboo and Dead Sea tamarix south of Walvis Bay Town.



Plate 23 Slatted wooden fences erected south of Narraville to control driftsand movement.

application of saline water on a dune not only keeps the upper layer of the irrigated area moist, which retards sand movement, but also allows the accumulation of salt on the surface as the water evaporates.

Green belts

The effectiveness of vegetation in combatting driftsands has been recognised in southern Africa for over a century where several species of alien tree were introduced as wind-breaks along sandy coastal areas. In the 1970s and early 1980s the Walvis Bay Municipality started developing belts of vegetation along the southern and eastern boundaries of Walvis Bay Town in order to limit the movement of sand into residential and commercial areas.

Vegetation used had to be fast growing, able to withstand strong winds, as well as relatively resistant to high salinity levels in the soil. Visits to the study area indicated the use of the Dead Sea tamarix (*Tamarix usneoides*) and dense stands of bamboo (see Plate 22). In the vicinity of the sewerage works, to the east of the town, the reed *Phragmites australis* has been introduced and has become an important habitat for wetland birds. The green belts are cleared of accumulated sand on a continual basis by the Walvis Bay Municipality.

Slatted fences

Extending around much of the southern and eastern parts of the town, and often in association with green belts, are slatted wooden fences (see Plate 23). The function of these fences is similar to that of pole barriers - to catch sand. However, where poles are erected on the apex of dunes, slatted fences are erected on the downwind side of levelled and stabilised lands. Even though these fences are effective sand traps, they are regularly damaged and have to be constantly cleared and maintained.

6.2.5 Problems associated with dune stabilisation

Despite the obvious advantages of stabilising driftsand areas threatening human settlement, a number of disadvantages also exist and need to be highlighted. In developing a dune management programme it is important to consider the long-term effectiveness of different stabilisation methods, considering financial, social and

ecological costs. This section will briefly highlight several problems and issues pertaining to existing dune stabilisation methods in the Walvis Bay area.

As noted in Section 6.2.3 various exotic plants are being used for stabilising active dunes in the study area. Due to the arid and harsh conditions of this environment the likelihood of these plants becoming invasive is small. However, the presence of several invasives in the Kuiseb Valley does highlight the potential ability of introduced species, particularly species well adapted to arid coastal environments, becoming a threat. The greater use of more indigenous species would help conserve the natural flora and also benefit many of the animals that inhabit vegetated dunes in the study area.

Another ecological concern is the increased salinity of irrigated dune areas, to the extent that the conductivities of the soil exceed the tolerance levels of stabilising plants. This phenomenon has been recorded at various sites across the Kuiseb Delta (Walvis Bay Municipality, 1985), and it is possible that continued flooding and irrigation with hyper-saline water will have a detrimental long-term affect on dune plants in the area.

The levelling and covering of extensive tracts with oil, salt, ash and gypsum, also has important ecological implications. Several species of invertebrates, reptiles and small mammals inhabit the surface sands of this region, and the formation of a hard surface capping would undoubtedly result in their eradication from these areas. Another problem has been noted by Esterhuizen (pers. comm., 13/02/1996), who claims that holes in the surface capping lead to the development of deflation hollows. These hollows result in rapid erosion and may lead to the collapse and break-up of the surface capping. Another limitation of these stabilised areas is that they represent large grey, flat wastelands which are quite aesthetically unappealing when compared to the undulating dunes characteristic of the Walvis Bay environment.

A considerable problem associated with the control of driftsands is the expense involved. The direct costs spent by the Walvis Bay Municipality are briefly discussed in Section 5.3.2 and indicates a sum of nearly N\$ 1 000 000 per year (Walvis Bay Municipality, 1995). Most of the costs experienced by the municipality are concerned with the maintenance and clearing of stabilised areas, particularly green belts, fences and the replacing of gravels and ashes. According to the Annual Report of the Town Engineer (1995) over 250 m³ of sand was removed in 1994 from the boundary wall to the south of Kuisebmond alone. Similarly, high costs are also experienced by the Directorate of

Forestry who spend over N\$ 200 000 per annum on vegetation plantings and the maintenance of barrier poles in the dune areas to the south of Walvis Bay (Esterhuizen, pers. comm., 13/02/1996).

A significant concern in the study area is the apparent conflict of interest between management authorities. According to the Directorate of Forestry, the methods undertaken by the municipality are ineffective and only limit the movement of already stabilised sand. No allowance is made for the advance of dunes themselves on the outskirts of the town. Furthermore, the levelling of extensive areas alters surface form and results in sand particles rapidly saltating across flat surfaces and accumulating against the green belts and picket fences. The directorate argues that this results in an enormous amount of time and money being spent on clearing these areas. The municipality have an opposing argument, however, and claim that the use of pole barriers used by the Directorate of Forestry only aids in the build-up of sand around the town and does not stabilise the sand itself. In addition, it is contended that the areas of vegetation stabilisation are presently too small and unless a great deal more expense is outlaid, the effectiveness of these plantings will be limited.

6.3 FUTURE MANAGEMENT CONSIDERATIONS

Many of the dune management practices in the study area have been reactive, fragmented and non-participatory. This section attempts to briefly provide some perspectives on what approaches need to be undertaken in order to facilitate better future management of dunes in the Walvis Bay area.

6.3.1 The need for an ecological/geomorphological approach to dune management

The dune landscape of the Walvis Bay environment is extremely complex and varied in space and time, and as such a dynamic approach towards management is needed. This approach requires a clear understanding of the ecological processes active in the dune environment, and in 1992 Avis emphasized the importance of adopting an ecological approach to coastal zone management. It is believed by Clark (1974) that the fundamental goal of management is to ensure "best ecosystem functioning", and aspects such as ecosystem integrity, linkages between ecosystems, energy flow and storage should be considered. Also, since impact of many human developments are evidenced

through the ecosystem, the effects of specific projects or actions on the natural environment should be assessed.

The complex functioning of the Walvis Bay area has been researched by numerous authors and presented in several publications. However, the dune management practices and developments that have been undertaken to date apparently have had little consideration for the natural dynamics of the region. Many of the driftsands problems experienced are a consequence of a lack of appreciation of the broader context and the integrated nature of the environment, with only reactive individual site-specific management actions being implemented. Ranwell (1979) suggests that by recognising three levels of operation many problems, such as those experienced in the Walvis Bay area, can be overcome. At the site level, management actions are important in controlling dune problems, such as stabilising encroachment. However, Ranwell (1979) claims that these actions need to be based on regional research and the understanding of the ecological and geomorphological processes of the coastal system. The third level of operation is on a national level and entails developing policies and legislation on coastal zone management (this is discussed further in Section 6.3.3.). Therefore, management actions in the Walvis Bay area should take cognizance of the regional ecological and geomorphological processes, and in so doing will enable a better grasping of many of the problems that are presently experienced.

6.3.2 Administration Requirements

The dunes in the study area constitute a complex and dynamic ecological system, with alterations in one area having ramifications in another. Boundaries to the system are open and much interaction by animals, plants and sand occurs across these boundaries. Jurisdiction over the area, however, is divided between the Ministry of Environment and Tourism (Directorate of Forestry; Directorate of Resource Management), the Walvis Bay Municipality and private landowners. Control is thus separated making management decisions more difficult to co-ordinate and implement. This is partly evidenced by the "conflicting" dune stabilisation methods that are employed in and around Walvis Bay Town. Similar administrative problems have been highlighted by the University of Cape Town (1993) in a study on Table Mountain as a protected natural environment. This study noted the conflict between various management authorities, at all levels of government, and recommended the need for a single body to manage this area.

In order to effectively manage the dune systems of the study area, therefore, there is a need for the establishment of a single management body, possibly a dune management advisory board, that would include representatives from the Ministry of Environment and Tourism, the Walvis Bay Municipality and the local community. This board would serve as clearing house of information for co-ordination, and provide an on-site advisory service, with guidelines for permissible dune utilisation by both private and government agencies. An important aspect in this regard is to involve local people for whom planning and development is being done.

6.3.3 Legislative Requirements

Namibia inherited much of its legislation from South Africa. While some of the legislation is valid and appropriate, much of the law pertaining to the environment is outdated and has been criticised as being fragmented, incomprehensive and unco-ordinated (UCT, 1996). A variety of laws exist that pertain to activities in the study area, dealing with issues ranging from environmental conservation (Nature Conservation Ordinance 4 of 1975), freshwater management (Water Act 54 of 1956), control of coastal activities (Sea Shore Ordinance 37 of 1958), land-use planning (Town Planning Ordinance 18 of 1954) and others (UCT,1996). Even though several laws exist, each deals with a specific aspect of the environment, furthermore, each of these laws are administered by different ministries and even between different directorates within a ministry. The result is a fragmented and unco-ordinated approach to environmental problems.

In order to ensure the success of dune management, Namibia's environmental legislation needs to be reviewed and reformed (UCT, 1996). What is required is the development of an umbrella act that includes policy for effective coastal zone management. It has been noted by UCT (1996) that despite many of the shortcomings of the environmental law, particularly that pertaining to the coastal zone, a strong commitment exists on the part of the government to improve the legislation, affording the environment better protection.

6.3.4 Archaeological Value

Studies in the Kuiseb Delta have indicated several archaeological sites, containing mostly mussel shell middens and other remnants of temporary pastoral settlements (Jacobson *et al.*, 1995). These sites reflect the long history of people living in the area, and are of both

scientific and cultural significance. Archaeological sites provide the only basis for understanding human settlement and natural processes that occurred before the modern era. These remains are also extremely vulnerable and entirely irreplaceable. Due to the dynamic nature of the dunes in this area archaeological sites are constantly being covered and exposed, and it is critical that all of these sites are identified, and the possibility of further sites explored. In so doing, future developments can be accordingly planned and the preservation of the sites ensured.

6.3.5 Economic Value

The economic potential of the dunes in the study area is evidenced through both direct uses, such as dune mining, and indirect uses, such as tourism and groundwater abstraction. In order to effectively manage the dunes of this area the financial rewards gained from these uses will need to be carefully weighed up against the long-term ecological damage caused.

In February 1996 a heavy minerals prospecting licence was granted to Caledonia Mining Corporation by the Ministry of Mines and Energy, for Prospecting Area 2135 located in the Swakopmund/Walvis Bay Dune Field. Studies have shown that these dunes host an economically exploitable resource of heavy minerals, namely ilmenite, rutile, zircon, garnets and hematite (Walmsley Environmental Consultants, 1996b). If the prospecting is successful it is likely that over 65 km² of dunes will be mined for a period of between 20-25 years. The ecological implications of dune mining have been highlighted in several other studies in southern Africa (eg. EEU, 1991; EEU, 1992), and will need to be seriously considered in the study area. In addition, secondary and tertiary impacts of associated industrial development and population growth will also need to be taken into account.

Another factor that needs to be considered is the tourist potential of the dunes in the study area, and the associated impacts of recreational activities (for example off-road driving). Tourism in this region depends almost exclusively on the natural environment, particularly the scenic beauty and solitude of the desert dunes. If tourism aims to be the biggest industry along the Namibian coast in the near future (UCT, 1996), appropriate action should be undertaken to ensure that carrying capacities be determined and tourism management plans drawn up. Even though the Namib Naukluft Park encompasses much of the dune area south of Walvis Bay, many of the more sensitive areas, such as

vegetated dune areas, occur around the town and are afforded no formal protection. Therefore, sensitive areas throughout the Walvis Bay enclave should be highlighted and entry into these parts should be strictly controlled. The close relationship between conservation and tourism in Namibia is evidenced by the naming of the Ministry of Environment and Tourism, however, it is felt that a lot still needs to be done on developing this interface.

An indirect economic benefit of dunes in the study area, that needs to be considered within a management framework for the region, is the ground water aquifers that lie beneath the Kuiseb River and Delta. It is the porosity and permeability of the dune sands that allow for the development of these aquifers. As discussed in Section 5.2.2 the abstraction of groundwater in the past has been unsustainable and has resulted in numerous environmental problems. If environmental impacts of this abstraction are to be reduced, new sources of water will need to be developed and exploited. The planned construction of a saltwater desalinisation plant at Walvis Bay could be a solution.

6.3.6 Stabilisation Requirements

Several of the limitations of dune stabilisation activities that are presently undertaken in the Walvis Bay area are explained in Section 6.2.5. In order to ensure the future success of stabilisation it is imperative that the Walvis Bay Municipality and the Directorate of Forestry start co-ordinating their activities - as they are both essentially striving towards the same means. It is also vital that techniques employed attempt to recognise regional ecological and geomorphological processes, and begin to consider the origins of the problem. Methods should also try and benefit the fauna and flora of the area, by growing indigenous plant species that provides increased refuge and feeding habitat for dune animals. It has been noted by Tinley (1985) that before any reclamation programme is begun, the following seven features be identified:

- a) What is endangered or threatened by sand drift or dune migration (resources and/or man-made structures). If nothing, leave alone. If something of value, identify the next six points;
- b) the landscape and shoreline position and the relationship of the mobile sand;
- c) the reach of the littoral active zone (the landward limit of exceptional storm seas, and/or ongoing processes);
- d) the type of dune;

- e) which processes are active;
- f) the trend and direction of change;
- g) determine an action priority of highest to lowest.

This report has identified at least the first six of the above seven points, and it is now recommended that a plan of action be developed which should incorporate the aims of all interested and affected parties. This will contribute to the more effective management of all the dunes in the Walvis Bay area.

6.3.7 Educational Requirements

In order to provide a participatory approach to dune management it is important to educate the local population on the functioning of the system. This education should adopt both an active and passive approach. The passive approach should be through posters and notice-boards, such as those presently displayed along the esplanade next to the Walvis Bay Lagoon. An active approach could be through seminars and field excursions, as dunes provide a field laboratory where dynamics, succession and management can easily be taught.

6.4 CONCLUSION

The management of dunes in the Walvis Bay area is a concern common to government agencies, private companies and landowners. All agree that the control of driftsands is imperative, particularly in light of the numerous impacts incurred. Even though the various interest groups are all striving towards the same means, the control of dune movement has been conflicting and relatively uncoordinated between management authorities. Furthermore, the dune stabilisation programmes implemented have the primary objective of preventing local sand movement and have given little consideration for broader ecological and geomorphological processes.

In order to promote the more effective management of dunes in the study area, it has been suggested that an approach be adopted which involves local on-site management that recognises, and is based on, regional ecological and geomorphological processes. Dune management must consider the regional implications of groundwater abstraction, decreased flood frequency and magnitude, as well as more localised factors such as the implications of a flood diversion wall and recreational activities. For this management to succeed, however, national coastal zone management policies are required, authorities need to co-ordinate activities, and the local population must be informed and become involved in the decision making process.

CONCLUSION

7. CONCLUSIONS

The main objective of this dissertation was to investigate the functioning and dynamics of dunes in the Walvis Bay area, so as contribute to the better understanding and the more judicious management of the dune system. In order to achieve this objective the following specific aims were addressed:

- * to identify all dune types occurring in the study area, and discuss the geomorphological and ecological characteristics of each;
- * to provide an analysis of the long-term stability of dunes in the Walvis Bay area by means of aerial photograph interpretation;
- * to analyse all factors that are contributing to dune migration and highlight the ramifications of this movement upon the ecological and socio-economic environments;
- * to indicate factors that should be considered with any future planning of land-use and development;
- * to review dune management practices in the area of study and provide recommendations for the more effective management of the system in the future.

It was asserted that knowledge of this nature was required to effectively manage these dune systems. This final chapter draws together the information presented in the dissertation, and assesses the contributions made to future coastal zone management in the central Namibian region.

A total of six distinct dune types are identified in the Walvis Bay area, which can be grouped into three main categories. Hummock dunes are prevalent along the coastal tracts and across the Kuiseb Delta and are delineated into three types, based on their distribution and dominant vegetation. These included coastal hummocks, river delta hummocks and flood-plain hummocks. The vegetation of these dunes plays a vital role in the study area by trapping and storing large volumes of wind-blown sand, as well as providing a discrete ecological environment that supports endemic and specialised plants and animals. Of the more mobile crescentic dunes, two forms may be identified in the vicinity of Walvis Bay, these being barchans and transverse barchanoids. These dunes are mostly unvegetated and are primarily responsible for driftsand

problems experienced in the study area. In terms of linear dunes, only complex linear forms are represented in the area of study, and occur on the eastern edge of the Swakopmund/Walvis Bay dune field. Even though these dunes are characterised by limited vegetation cover and shifting sands, they are less mobile than crescentic forms. Studies have shown that complex linear dunes support a distinctive and wide variety of organisms that have become specifically adapted to this dune environment.

The variety of dune forms occurring in the study area gives an indication of the geomorphic and ecological processes acting in the region, and therefore provides a basis for quantifying any environmental change. The analysis of five sets of aerial photographs of the study area, dating between 1943 and 1980, reveals several trends that reflect a process of desertification *par excellence*. A vast increase in the area encompassed by mobile dune forms is noted, correspondingly matched by a significant decrease in the extent of flood-plain and river delta hummocks. Other trends observed included a gradual increase in the size of the Swakopmund/Walvis Bay Dune Field, an extension and broadening of the sand spit and beach south of the town, as well as a large reduction in the area of the salt marsh. These findings are indicative of the important geomorphological role vegetation plays in the dune systems of the Kuiseb Delta. It is inferred, therefore, that the migration of dunes is primarily attributable to the reduction in the frequency and magnitude of flood events that limits the provision of water to deltaic shrubs and trees. This reduction appears to be a result of both natural and human-induced changes, caused by climatic fluctuations, upstream impoundments and inappropriate catchment land-use practices. These impacts are being compounded in the Kuiseb Delta by the over-abstraction from coastal aquifers and the construction of a 7.3 km long flood diversion wall. It is also evident that the movement of sand, on a more local scale, is being influenced by off-road vehicles, urban expansion, the development of salt recovery pans and dune stabilisation practices.

Detailed studies on the susceptibility of the Walvis Bay environment to increased dune movement reveal an array of ecological and socio-economic impacts. An important ecological concern is the loss and fragmentation of habitat across the delta and within the lower reaches of the Kuiseb River. This could result in the disappearance of several species of animals and plants, and possibly even extinctions. Of international importance is the accelerated siltation of the Walvis Bay Lagoon, a registered Ramsar site and commonly regarded as the most important wetland for migratory birds in southern Africa. Studies have shown that sedimentation is rapidly reducing habitat for macrobenthic fauna and in turn limiting vital food supplies for wading birds.

Findings have also indicated that the ingress of dune sands is creating numerous socio-economic problems that are often not recognised by local authorities, planners and developers. The questionnaire survey reveals that driftsands are causing a great deal of damage to residential houses, municipal buildings, infrastructure and several businesses in the Walvis Bay area. The enormous economic costs involved and the influence of driftsands on community health is contributing to the lowering of living standards of many residents. The implications of these impacts are significant in light of the phenomenal rates of population growth presently being experienced in Walvis Bay, and the future township, commercial, industrial and recreational development that is envisioned for the region. Town planning and engineering considerations presented in this study highlight the importance of recognising zones of severe, moderate and slight sand encroachment during the planning phase of developments. Furthermore, the implementation of construction technology and designs that are appropriate to this environment are imperative.

It is hoped that the findings of this dissertation will make a valuable contribution to our current understanding of the functioning and dynamics of the dune systems in the Walvis Bay environment. With the dune landscape being an integral aspect of this environment, an understanding of these issues is very important if one wishes to effectively manage the coastal zone of the Walvis Bay area. The analysis of the impacts of dune encroachment, in light of future developmental needs, also highlights the requirement for competent land-use planning and resource utilisation. In addition, this dissertation should focus attention on the importance of considering ecological and geomorphological processes when managing the coastal dune environment. In conclusion, therefore, this study has provided information of great use to coastal management agencies, vital in the formulation of an Integrated Coastal Zone Management Plan.

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Personal Communication

- Mr Braby (08/02/96)
- Mr Brummer (12/02/96)
- Mr Dauseb (13/02/96)
- Mr Esterhuizen (13/02/96)
- Mr Klein (12/02/96)
- Mrs Kruger (13/02/96)
- Mr Marais (05/12/95)
- Mr Muller (12/02/96)

APPENDICES

SOURCE: THERON *et al.* (1985)

ACACIA ALBIDA COMMUNITY

1. *Acacia albida* variation
2. *Acacia albida* - *Salvadora persica* variation
3. *Acacia albida* - *Tamarix usneoides* variation
4. *Acacia albida* - *Eragrostis spinosa* variation
5. *Acacia albida* - *Stipagrostis sabulicola* variation
6. *Acacia albida* - *Suaeda plumosa* variation
7. *Acacia albida* - *tamarix usneoides* - *Acacia erioloba* variation (sometimes with *Eragrostis spinosa* or *Suaeda plumosa*)
8. *Acacia albida* - *Eragrostis spinosa* - *Pechuel-loeschea leubnitziae* variation
9. *Acacia albida* - *Pechuel-loeschea leubnitziae* variation

ACACIA ERIOLOBA COMMUNITY

10. *Acacia erioloba* variation
11. *Acacia erioloba* - *Salvadora persica* variation
12. *Acacia erioloba* - *Suaeda plumosa* variation
13. *Acacia erioloba* - *Suaeda plumosa* - *Pechuel-loeschea leubnitziae* variation
14. *Acacia erioloba* - *Pechuel-loeschea leubnitziae* variation
15. *Acacia erioloba* - *Stipagrostis sabulicola* variation
16. *Acacia erioloba* - *Eragrostis spinosa* - *Pechuel-loeschea leubnitziae* variation
17. *Acacia erioloba* - *Acacia albida* - *Pechuel-loeschea leubnitziae* variation
18. *Acacia erioloba* - *Acacia albida* variation
19. *Acacia erioloba* - *Eragrostis spinosa* variation

TAMARIX USNEOIDES COMMUNITY

20. *Tamarix usneodes* variation
21. *Tamarix usneodes* - *Salvadora persica* variation
22. *Tamarix usneodes* - *Acacia erioloba* variation
23. *Tamarix usneodes* - *Acacia erioloba* - *Salvadora persica* variation
24. *Tamarix usneodes* - *Suaeda plumosa* variation

25. SALVADORA PERSICA COMMUNITY

26. SALVADORA PERSICA - ACACIA ERIOLOBA - TAMARIX USNEOIDES - EUCLEA PSEUDEBENUS DUNE COMMUNITY

27. SUAEDA PLUMOSA COMMUNITY

28. ERAGROSTIS SPINOSA COMMUNITY

PECHUEL-LOESHEA LEUBNITZIAE COMMUNITY

29. *Pechuel-loeschea leubnitziae* variation
30. *Pechuel-loeschea leubnitziae* - *Eragrostis spinosa* variation
31. *Pechuel-loeschea leubnitziae* - *Eragrostis spinosa* - *Stipagrostis sabulicola* variation

32. KNOB DUNE COMMUNITY: STIPAGROSTIS SABULICOLA, ACANTHOSICYOS HORRIDA, ACACIA ERIOLOBA, ADENOLOBUS GARIEPENSIS, LYCIUM TETRANDRUM.

ACANTHOSICYOS HORRIDA DUNE COMMUNITY

33. *Acanthosicyos horrida* variation
34. *Acanthosicyos horrida* - *Stipagrostis sabulicola* variation

35. PSILOCAULIN sp cf SALICORNIOIDES COMMUNITY

36. ZYGOPHYLLUM STAPFII COMMUNITY

37. ZYGOPHYLLUM SIMPLEX COMMUNITY
ODYSSEA PAUCINERVIS COMMUNITY

38. *Odyssea paucinervis* variation
39. *Odyssea paucinervis* - *Suaeda plumosa* variation
40. *Odyssea paucinervis* - *Lycium tetrandrum* variation

DEAD PLANT AREAS

41. *Eragrostis spinosa*, *Datura* spp, *Nicotiana glauca*, *Ricinus communis*
42. Dead *Eragrostis spinosa* with living *Acacia erioloba*
43. Dead *Eragrostis spinosa* with living *Acacia albida*
44. *Eragrostis spinosa*, *Zygophyllum simplex*, *Suaeda plumosa*

APPENDIX 2: HISTORICAL CHANGES IN THE SURFACE AREA OF GEOMORPHIC AND OTHER FEATURES IN THE KUISEB DELTA (1943-1980) - PRESENTED IN KILOMETRE SQUARED AND PERCENTAGES

	HUMMOCK DUNES			CRESCENTIC DUNES		SALT MARSH	SAND PLATE	BEACH AND SPIT	OTHER	
	COASTAL	DELTA	FLOOD PLAIN	BARCHANS	SMALL TRANSVERSE					
1943	48km ²	56km ²	136km ²	19km ²	58km ²	52km ²	6km ²	79km ²	33km ²	area in km ²
	9,86%	11,5%	27,93%	3,9%	11,91%	10,68%	1,23%	16,22%	6,77%	% area of Kuiseb Delta
1963	44km ²	48km ²	126km ²	22km ²	83km ²	53km ²	5km ²	83km ²	23km ²	area in km ²
	9,03%	9,86%	25,87%	4,52%	17,04%	10,88%	1,03%	17,04%	4,72%	% area of Kuiseb Delta
1969	42km ²	40km ²	130km ²	32km ²	86km ²	42km ²	6km ²	86km ²	23km ²	area in km ²
	8,62%	8,21%	26,69%	6,57%	17,86%	8,62%	1,23%	17,66%	4,72%	% area of Kuiseb Delta
1976	42km ²	36km ²	106km ²	37km ²	109km ²	35km ²	5km ²	90km ²	25km ²	area in km ²
	8,62%	7,39%	21,77%	7,6%	22,38%	7,19%	1,03%	18,48%	5,13%	% area of Kuiseb Delta
1980	43km ²	29km ²	76km ²	53km ²	134km ²	25km ²	7km ²	92km ²	28km ²	area in km ²
	8,83%	5,95%	15,61%	10,88%	27,51%	5,13%	1,44%	18,89%	5,74%	% area of Kuiseb Delta

Note: Area measurements are approximate and rounded off to the nearest kilometre.

APPENDIX 3: HISTORICAL CHANGES IN THE SURFACE AREA OF THE SWAKOPMUND / WALVIS BAY DUNE FIELD (1963-1980) - PRESENTED IN KILOMETRE SQUARED AND PERCENTAGES

	CRESCENTIC DUNES			COMPLEX LINEAR DUNES	TOTAL AREA	
	BARCHANS	SMALL TRANSVERSE	LARGE TRANSVERSE			
1963	3km ²	10km ²	67km ²	38km ²	118km ²	Area in km ²
	2,54%	8,48%	56,78%	32,2%		% area of dune field
1969	4km ²	10km ²	66km ²	39km ²	119km ²	are in km ²
	3,36%	8,4%	55,46%	32,77%		% area of dune field
1976	6km ²	11km ²	68km ²	38km ²	123km ²	area in km ²
	4,92%	9,02%	55,74%	30,33%		% area of dune field
1980	8km ²	12km ²	69km ²	42km ²	131km ²	area in km ²
	6,15%	9,23%	53,1%	32,31%		% area of dune field

Note: Area measurements are approximate and rounded off to the nearest kilometre.

APPENDIX 4: QUESTIONNAIRE SURVEY

WIND BLOWN SAND - ISSUES AND CONCERNS

Race Group:
Suburb:

INTRODUCTORY QUESTIONS

1. How long have you lived in Walvis Bay?

Hoe lank woon u al in Walvisbaai?

.....

2. Do you experience any problems of wind blown sand, and if so, has it always been a problem?

Die sand wat van die duine waai is dit 'n probleem, as dit is, was dit altyd 'n probleem?

.....
.....

PHYSICAL IMPACTS

3. Does this sand cause any damage to your property, and if it does, what are the main problems?

Die sand al tot enige skade veroorsaak aan enige eiendom besit en watter skade is vevoorsaak?

.....
.....

4. Do you experience any other damage outside of the home?

Is enige ander skade veroorsaak buiten aan, of in, u woning?

.....
.....

HEALTH PROBLEMS

5. Does the accumulation of sand result in any health problems?

As gevolg van die sand ondervind u enige gesondheids probleme?

.....

.....
6. When do these problems mostly occur?

Gedurende watter tye van die jaar ondervind u die meeste probleme?

.....
EXPENDITURE

7. Are there any costs that you incur in trying to control these sand problems, and if so, in what bracket would you expect to spend a year?

Hoeveel het die gekos om die probleme reg te stel per jaar?

[0-200] [200-500] [500-1000] [1000-3000] [3000+]

.....
8. Do these costs reflect on your day to day lifestyle?

Beïnvloed hierdie uitgawes in maandelikse leefwyse?

.....
SUGGESTIONS

9. Do you think the relevant authorities are doing enough to control the problems of sand movement?

Doen die autoriteite genoeg om hierdie tiepe probleme te oorkom?

.....
10. What could be done to reduce these problems in the future?

Wat sal u voor kan gedoen word om hierdie probleme te oorkom?

.....
.....
THANK YOU VERY MUCH FOR YOUR TIME

