Coastal Dunes of South Africa

K L Tinley

A report of the Committee for Nature Conservation Research
National Programme for Ecosystem Research

SOUTH AFRICAN NATIONAL SCIENTIFIC PROGRAMMES REPORT NO 109

Issued by
Foundation for Research Development
Council for Scientific and Industrial Research
P O Box 395
PRETORIA
0001

from whom copies of reports in this series are available on request.

Printed in 1985 in the Republic of South Africa

ISBN 0 7988 3565 6

Author's address

Dr K L Tinley
Department of Environment
and Conservation
1 Mount Street
Perth 6000
Western Australia

GAcsir 24H4505*8509

PREFACE

The National Programme for Ecosystem Research (previously Environmental Sciences) is one of several national scientific programmes administered by the CSIR's Foundation for Research Development. This report is produced under the auspices of one of the sectional committees of the National Programme, namely the Working Group for Habitat Conservation of the Committee for Nature Conservation Research.

The National Programme is a coordinated multidisciplinary undertaking, designed to promote scientific research concerned with problems in the environment. It includes research designed to meet purely local needs as well as projects undertaken in southern Africa as contributions to international scientific activities. The purpose of the National Programme is to obtain knowledge on current and future environmental problems sufficient to conserve and manage ecosystems most effectively.

The ever increasing threat to Africa's native ecosystems and their component animal and plant species, poses enormous conservation problems. The need for development, together with the man-induced modification and destruction of natural habitats that so often accompanies it, provides conservation managers with their most taxing dilemma.

The coastal dune ecosystems of southern Africa are probably of greater importance, and therefore of greater value per unit area, than any other biome or group of ecosystems in the region. These coastal attributes, which are common to all continents, are due to the coincidence of, and resulting conflict between, their ecological and economic values. Their ecological or functional values as dynamic, living buffer zones, with great properties of energy absorption and self renewal are vital to the protection and stability of the coastal zone. Their economic values as prime sites for urban and industrial development and as the foremost recreational and aesthetic residential regions in the country, have led to poorly controlled ribbon development.

In recognition of the rapidly declining conservation status of the coastal zone and the need for a descriptive overview to provide a basis for conservation and development planning, Dr Tinley was commissioned to compile this report in 1981.

ACKNOWLEDGEMENTS

The coastal dunes project was funded by the Foundation for Research Development (FRD), previously Cooperative Scientific Programmes of the CSIR. The Cape Department of Nature and Environmental Conservation kindly permitted me to use their research quarters at Rocher Pan Nature Reserve in December 1981.

It is my pleasure to thank the following people for stimulating and valuable discussions and for drawing my attention to useful references: Mike Bremner, Johann Breytenbach, Mike Burns, Paul Camp, Keith Cooper, Richard Cowling, Tony de Freitas, Paul Dutton, Jim Feely, Alan Heydorn, Leighton Hulett, Brian Huntley, Fred Kruger, Annelise le Roux, David MacDevette, Anton McLachlan, Manie Steenkamp, John Rogers, Isak Rust, Rudy van der Elst, John Ward, Roddy Ward and Pablo Weisser.

For identifying plant specimens, I am particularly grateful to Annelise le Roux, Richard Cowling and the staff of the National Herbarium at the Botanical Research Institute in Pretoria. My thanks also to Dr Bill Coaton for identifying termites, Dr Stefan Endrody-Younga for the dune tenebrionid beetle, and Dr Brian Stuckenberg for the milkwood moth.

The processing staff of the East London Camera Shop achieved the fine quality printing of the plates, and Murray de Villiers printed the beetle plate. David Berger most helpfully computed the data for construction of the sand roses.

Thanks are due to Nola Johannsen and Tereza Labuschagne of Wordpro, East London, for the initial word processing. I am most grateful to Tony Ferrar and Fifi Bierman for their tenacious labour in editing this work, and to Lynette van Niekerk and Margaret Orton, all of the FRD's Ecosystem Programmes for their painstaking preparation of the final text. I would like to thank Brian Huntley, head of Ecosystem Programmes and the Coastal Dunes Steering Committee for their trust and patience.

Finally I would like to thank my wife Lynne, for her support at all times, her editing help and her valuable role as a sounding-board for ideas.

Except where otherwise acknowledged all plates and figures are by the author.

ABSTRACT

A synthesis is presented on the ecology of South African coastal dune ecosystems, which comprise about 80% of South Africa's 3 000 km shoreline.

A detailed description of the extent, structure and functioning of these ecosystems is given. The descriptive section is divided into geographic setting, physical features, ecological features and dune dynamics. Emphasis is placed on the factors affecting dune formation and erosion and the biogeography and dynamics of dune vegetation. Current use, management and degradation of the soft coastline is assessed, and guidelines for sustainable development are outlined. The conflict between the physical needs of urban development, and those of retaining the energy absorbing barrier function of the dune cordon, is analysed. Recommendations are made for the protection, conservation, management and reclamation of dune ecosystems. A comprehensive list of proposed conservation areas and an extensive bibliography are also provided.

SAMEVATTING

'n Ekologiese sintese van die kusduinekosisteme van Suid-Afrika word voorgestel. Hierdie duine beslaan ongeveer 80% van Suid-Afrika se 3 000 km kuslyn.

'n Gedetailleerde beskrywing van die omvang, struktuur en funksionering van hierdie ekosisteme word gegee. Die beskrywende afdeling word ingedeel in geografiese agtergrond, fisiese kenmerke en duindinamika. Klem word gelê op die faktore wat duinformasie en erosie beïnvloed en die biogeografie en dinamika van duinplantegroei. Huidige gebruik, bestuur en agteruitgang van die sagte kuslyn word in oënskou geneem en die gevolglike riglyne vir die handhawing van ontwikkeling word beskryf. Die konflik tussen die fisiese behoeftes van stedelike ontwikkeling en die noodsaaklikheid van die behoud van die bufferfunksie van die duine word geanaliseer. Aanbevelings word gemaak vir die beskerming, bewaring, bestuur en herwinning van duinekosisteme. 'n Volledige lys van voorgestelde bewaringsgebiede en 'n uitgebreide bibliografie word ook voorsien.

TABLE OF CONTENTS

Page

Preface (iii)

Acknowledgements (iv)

Abstract (v)

Samevatting (v)

INTRODUCTION 1

RATIONALE AND OBJECTIVES 3

IDENTITY OF COASTAL DUNES 4

- Origin 4
- As an ecosystem 4
- Nomenclature 5

1. GEOGRAPHICAL SETTING 7

1.1 Position 7
1.2 Oceans and ocean currents 7
1.3 Pressure systems and winds 9
1.4 Swell and wave regimes, coast configuration and littoral drift 9
1.5 Tidal environment 10
1.6 Coast regions or sectors 11

2. COASTAL DUNE CHARACTERISTICS 13

2.1 Classification and description of dune types 13
2.1.1 Bare or free dunes 15
2.1.2 Vegetated dunes (wind and plant formed) 20
2.1.3 Dunes related to topographic barriers 27
2.1.4 Dunes related to wetlands 30

2.2 Patterns of coastal sand and dune occurrence 32
2.2.1 The patterns 32
2.2.2 Wind direction, coast shape and dune orientation 34
2.2.3 Beach sand provinces and dune occurrence 36
2.2.4 Larger dunefields 37
2.2.5 Highest dunes 38
2.2.6 Smaller dunes 38
2.2.7 Roaring and squeaking sands 39

Page

2.3 Older dunes and changes in climate and sea level 39
2.3.1 Changes in climate and sea level 39
2.3.2 Glacial Ice Age environmental conditions 41
2.3.3 Warm interglacial environmental conditions 42
2.3.4 Implications for dune dynamics 44
2.3.5 Oxidized and lithified dunes 46

3. **ECOLOGICAL FEATURES** 71

3.1 Physiography and the terrestrial sources of sand 71
3.1.1 The continental plateau 71
3.1.2 The continental margins 72
3.1.3 Major terrestrial sources of sand 76

3.2 Climate 78
3.2.1 Classification 78
3.2.2 Controls of climate 79
3.2.3 Elements of climate 81
3.2.4 Implications of large scale sea surface temperature - atmospheric interactions 103

3.3 Dune soils 107
3.3.1 Classification and form 107
3.3.2 Processes, characteristics and properties 108

3.4 Dune vegetation 118
3.4.1 Zonation, succession and gradients 118
3.4.2 The plant communities 127
3.4.3 Seed dispersal 150
3.4.4 Phenology 155

3.5 Plant geography and conservation 170
3.5.1 The arena 170
3.5.2 Biomes and formations 172
3.5.3 Ecosystem and floristic affinities 174
3.5.4 Imbricate distribution and attenuation of species overlapping from opposite directions 177
3.5.5 Conservation strategies as determined by nodes of endemism amongst coastal trees 181

3.6 Human influences 189

3.6.1 Human succession and its exponential impact on coasts and catchments 189
3.6.2 Coastal dunes as a human habitat 190

4. **DUNE DYNAMICS** 199

4.1 Sand sources and sand losses 199

4.2 Dynamic status of the South African coastline 201

Page

4.3 Coast configuration and exposure to effective winds 204
4.3.1 Salient features and modifying influences 204
4.3.2 Wind and sand roses 205
4.3.3 Rates of bare dune movement 207

4.4 Mobility status and trends of dunes 207
4.4.1 Trends of bare reversing dunes 208
4.4.2 Trends of parabolic blowouts in vegetated dunes 209

4.5 Dune form succession 209
4.5.1 Bare dune sequences 209
4.5.2 Vegetated dune sequences 210

5. **PROTECTION AND UTILIZATION OF SOFT COASTS** 235

5.1 Characteristics: natural features and processes 235

5.2 Uses, conflicts and solutions 238

5.3 Values of coastal dunes 240
5.3.1 Coast buffer zone and local weather modification 240
5.3.2 Economic uses 241
5.3.3 Recreation 242
5.3.4 Cultural, educational and scientific 243

5.4 Key on-site guidelines for planners and users of soft coasts 244
5.4.1 Introduction 244
5.4.2 Specific guidelines 245
5.4.3 Dune mining 248

5.5 Management of coastal dunes 251
5.5.1 Introduction 251
5.5.2 Salient features 251

5.6 Continued damage to coast resources 259
5.6.1 Introduction 259
5.6.2 Some of the problems 260
5.6.3 Some solutions 261

5.7 Summary of main points 262
5.7.1 Administrative requirements 262
5.7.2 Planning and utilization requirements 263
5.7.3 Reclamation requirements 265
5.7.4 Values of coastal dunes 266
5.7.5 Education 267

6. **ECOSYSTEM PROTECTION STATUS OF COASTAL DUNES** 273

6.1 Unique coast dune areas requiring protection 275

	Page
Glossary of terms	279
Bibliography	285
Recent titles in this series	299

INTRODUCTION

An ecological synthesis of the coastal dunes of southern Africa below the 20° latitude is presented here. The emphasis is on those dunes occurring in South Africa along some 3 000 km of coastline where more than 80 per cent of the shoreline is composed of sandy beaches backed by dunes.

Enormous parabolic dune systems, or their remnants, whose form indicate a high sand supply/wind energy ratio of the past, and ancient oxidized and lithified dunes extend far inland in many places along the South African coastline while the submarine cores of old dune cordons dating from the Last Glacial 100 m drop in sea level occur on the continental shelf.

In contrast the present beige-coloured dunes made up of modern and old dune sands, occur as a narrow coastal cordon. Their dimensions and form display relatively low dynamism with continued erosion of the seaward slopes by waves and wind and extensive reworking of existing sands.

Many of the coastal forms and dune characteristics are therefore modified or reworked features inherited from the past climatic and sea level oscillations that occurred over the last two million years of the Pleistocene. Davies (1980) cautions that because of this inheritance, care must be taken in interpretation as "it is generally inaccurate to argue from present process to present form".

In considering existing coastal features as an arena for a variety of human activities the following dynamic processes should be borne in mind: sandy shores are in a constant state of flux due to sea and wind action; recurring erosion of soft coasts by storm seas; a changing sand supply from rivers and the nearshore zone to the littoral; a slow 10 cm per century worldwide rise in sea level (King CAM 1962; Davies 1980); the interference or modification of river sand supply and longshore processes by man-made structures.

Since 1900 the human population in South Africa has grown from five million to 25 million in the 1970's and is expected to double within the next 30 years (South African Offical Yearbook 1977). The key limiting factor to human activities in South Africa is water, and the landscapes most under siege therefore are the better watered lands marginal to the southern and eastern coasts.

Increased overstocking and cultivation of all river catchments over the last 100 years has led to intensified erosion and massive sediment infilling of all historically deep river mouths. Man-induced siltation has accelerated what would have happened over a much longer period of time. Superimposed on the tendency for estuaries to become increasingly silted is the effect of dams in reducing the sand input to the littoral zone. Any shortage of sand supply in this zone results in increasing amounts being taken from the frontal dunes by wave erosion. The onset of erosion on soft coasts in parts of southern Africa appears to bear close relationships to the coincidence of these factors.

Apart from the estuaries which have seen a concerted conservation effort during the 1970's, the South African coast viewed as a whole integrated system has, until recently (Heydorn and Tinley 1980), received the least attention, study or planning from a resource conservation standpoint. This at a time when human pressures on coast resources of all kinds are increasing fastest without restraint or guidance. The impact is greatest on soft coasts which bear the brunt of heedless invasion aggravated by speculators, political machinations, and covert outdated engineering policies.

RATIONALE AND OBJECTIVES

The rationale for this survey has been to pre-empt the predicament before it has gone too far by providing basic data required for creative conservation action.

- Apart from the few detailed studies of littoral dunes in Zululand, little is known of the variety, distribution, resource and conservation significance of coastal dunes in South Africa.

- Coastal dune ecosystems are vulnerable to misuse by fast growing human population pressures and demands for recreation, access routes, resorts, township development and industry.

- The lack of basic practical guidelines for permissible development in dune systems, or for the sustainable utilization of the coast as a whole, has resulted in a waste of finance and material structures, and continued attrition or damage to coast resources.

- Coastal dunes are of considerable economic importance because of their buffer role, sand and heavy mineral resources, and the high costs of stabilization management of problem mobile dune areas.

The objectives of the survey were therefore to identify and describe the following features:

1. The types of dunes, their distribution, dynamic processes (geomorphic and ecological), present erosional status and trends.

2. The nature and priority of dune related problems.

3. To provide an overall framework of data, ideas and guidelines for the study, management, conservation and responsible utilization of coast dunes.

4. The variety of dune plant communities and the key plant species involved in dune succession.

5. The geography of plant species in the linear coast dune system as a basis for defining areas or sites of highest conservation value, and the choice of viable representative examples of the variety of dune ecosystems in the different coast regions.

6. Sectors or sites most to least threatened by natural or man-induced erosion and damage on which to base priority conservation action, research and management.

IDENTITY OF COASTAL DUNES

ORIGIN

Coastal dunes form where sand deposited onshore by the sea and at river mouths, or exposed by a dropping sea level as in past glacial times, dries out and is blown landward by the wind.

AS AN ECOSYSTEM

Though coast dunes are a distinct and unique geomorphic feature, it may be questioned whether they constitute a discrete ecosystem separate from the larger physiographic units against which they are banked.

The six dune features noted below indicate that coast dunes are a distinctive interacting and interdependent ecological complex composed of several serally related ecosystems.

1. Sand dunes are a unique mobile physical medium and ecological environment.

2. Frontal dunes form part of the sediment exchange system of the littoral active zone influenced by changes in climate and sea level which affect sand supply/wind energy ratios.

3. On the coast, dunes display a progressive ecocline of increasing size, age and complexity from the seashore landwards.

4. Dunes display unique progressive and multidirectional geoecological successional sequences over the short and long term. Plant communities of contrasting appearance, structure and content are seral to one another.

5. Dunes contain endemic and/or specialized plants and animals.

6. On dunes plants display an imbricate, linear longshore pattern of distribution, and support distinctive plant communities which relate to geographical position, climate, edaphic influences, particular modes of seed dispersal and species contributions from the abutting landward biotas.

Coast dunes thus exhibit unique processes of genesis, dynamics and zonation determined by fluctuating sand supply/wind energy ratios related to daily, seasonal and long term changes in climate and sea level, to edaphic and aspect influences, plant succession and exposure to saltspray. These features closely fit Dyksterhuis's (1958) holistic ecosystem definition elaborated here: "The ecosystem involves the accumulation, circulation and transformation of energy and matter through physical processes such as precipitation, erosion and deposition, and biotic activities involving dispersion, photosynthesis, herbivory and decomposition with coactive influences between the physical and living parts and between organisms themselves."

NOMENCLATURE

The nomenclature used for dunes and dune zonation on coasts are illustrated below in profile diagrams to clarify the synonomy and overlap of terms commonly used in the literature (Figure 1).

Dune: A hill, mound or ridge of sand which is composed of particles transported and heaped up into accumulations by the wind (Moore 1959). Generally the windward slope against which the sand is blown is gentle in contrast with a steeper leeward slope formed by falling and sliding sand, referred to as the slipface. This transfer of sand from the compacted windward side to the leeward avalanching slopes results in a dune moving or migrating in a downwind direction. Windward faces are more stable due to denser packing of sand particles by the wind (Moore 1959). Sunward slopes, and especially the crests, are the driest and hence the most mobile facets. The shade slopes are cooler and moister and hence relatively more stable.

Plinth or dune base: The compact base of a dune, especially conspicuous on reversing dunes where the mobile crest changes shape and direction with various winds leaving the plinth least changed.

Dune trough: A linear depression between dunes. In arid regions they are flat-floored and open and may contain pans, playas, desert pavement or smaller dune types. Forested troughs are usually elliptic in profile.

Slack or swale: A seasonally or perennially wet depression between dunes, oval, irregular or linear in shape.

Hollow: A dry depression between dunes.

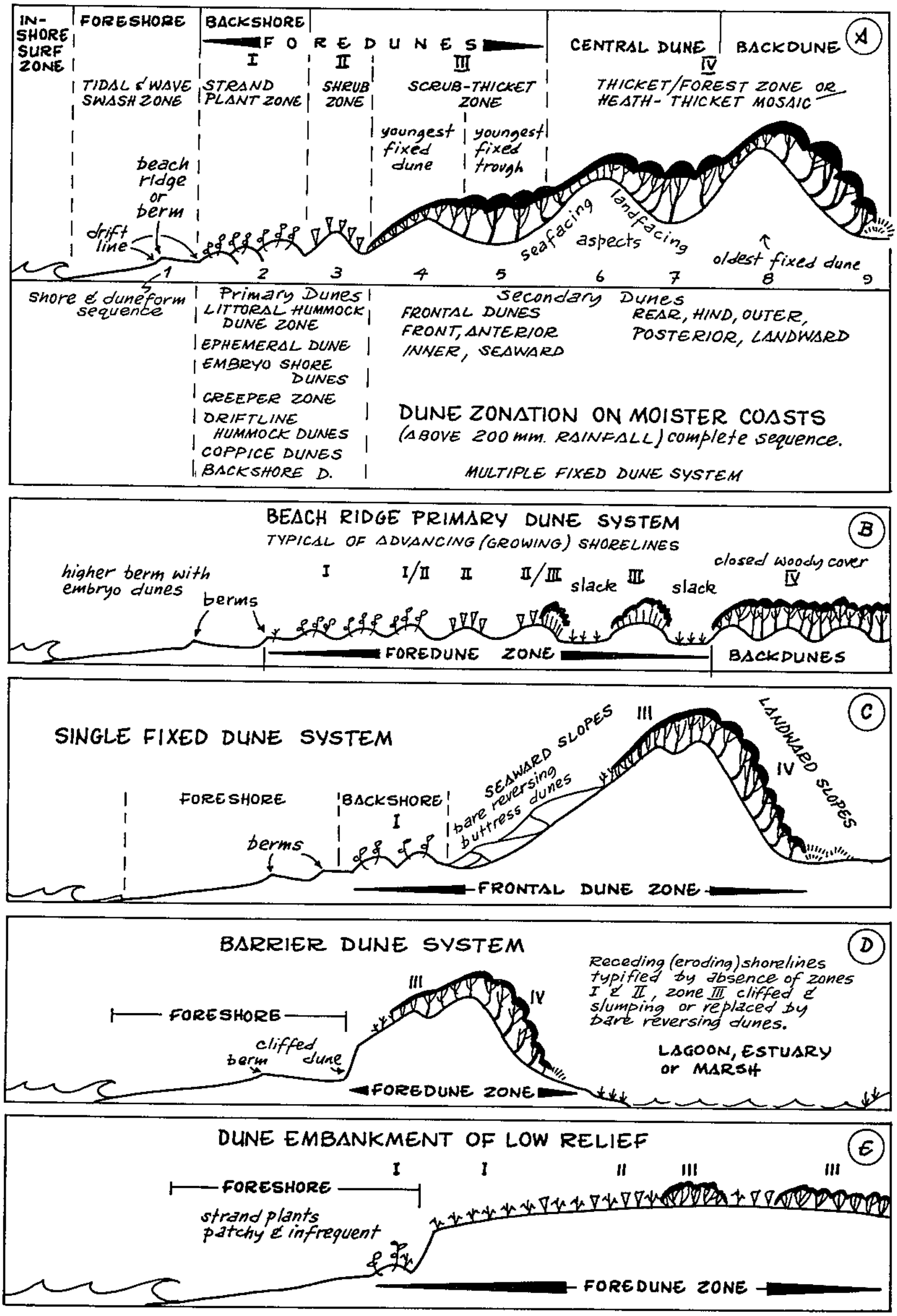


Fig 1 COAST DUNE NOMENCLATURE & VARIATIONS OF ZONATION SEQUENCES.

ERRATA

COASTAL DUNES OF SOUTH AFRICA
South African National Scientific Programmes Report No 109

Page 91 Second paragraph, second sentence should read: ... mean morning velocity in January is 18 km/h increasing to 30 km/h in the afternoons whilst in July the change is from 14 km/h to 20 km/h in the afternoons.

Page 120 Soil sample 5(a): the second sample depth is at 100 cm not 10.

Page 125 First word of the last sentence should read outliers not outlets.

Page 203 Second paragraph, lines 5 and 6 should read: (c) the southern part of the south-east coast south of the Kei mouth.

1. GEOGRAPHICAL SETTING

1.1 POSITION

Dunes and dunefields of the South African coastline occur intermittently along some 3 000 km of seashore. Extending from the Orange River mouth (28° 38' S, 16° 27' E) on the Atlantic coast around the southern tip of the continent at Cape Agulhas (34° 50' S) to the Mocambique border on the south-east Indian Ocean coast at Ponta da Ouro (26° 51' S, 32° 53' E). Refer to Figure 2.

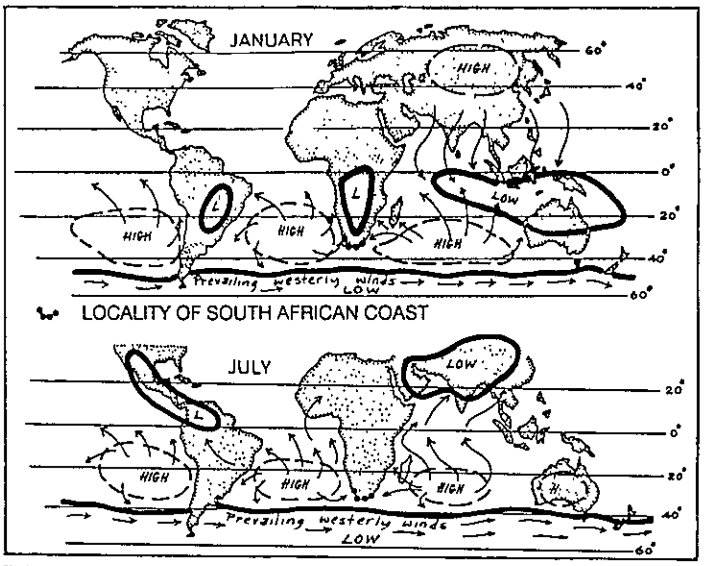
1.2 OCEANS AND OCEAN CURRENTS

This southernmost portion of the African continent is situated at the junction of three ocean masses. The south Atlantic on the west, the Southern Ocean open to the circumpolar Westerlies, the "Roaring Forties", on the south, and the south Indian on the east.

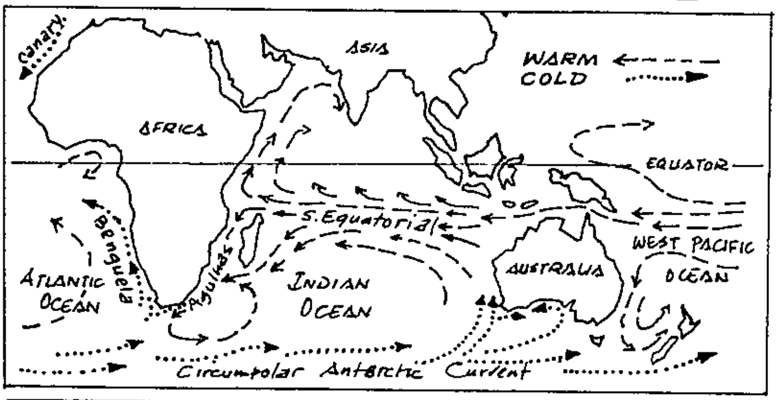
The subcontinent is largely subtropical and is affected by two major currents. The cold, north-flowing, Benguela Current of upwelled inshore waters along the west coast, and the warm south-flowing Mocambique-Agulhas Current of equatorial waters immediately offshore on the east and south-east coast. These currents carry colder water and organisms into warmer areas and vice versa on opposite sides of the subcontinent. The pattern of sea surface temperatures around southern Africa shows a marked asymmetry, well defined by the 20° C isotherm (Figure 9). The temperatures of upwelled waters on the west coast at 33° S vary between 8° and 16° C, while those of the Agulhas Current at the same latitude vary seasonally between 20° and 28° C (Heydorn and Tinley 1980).

Within this major pattern is another significant feature; the recurvature of all the sea surface isotherms along the south, south-east and east coasts where they meet a narrow inshore zone of cool coastal waters interposed between the Agulhas Current and the seashore. It is most strongly developed on the south and south-east coasts northwards to near the Kei River mouth (33° S).

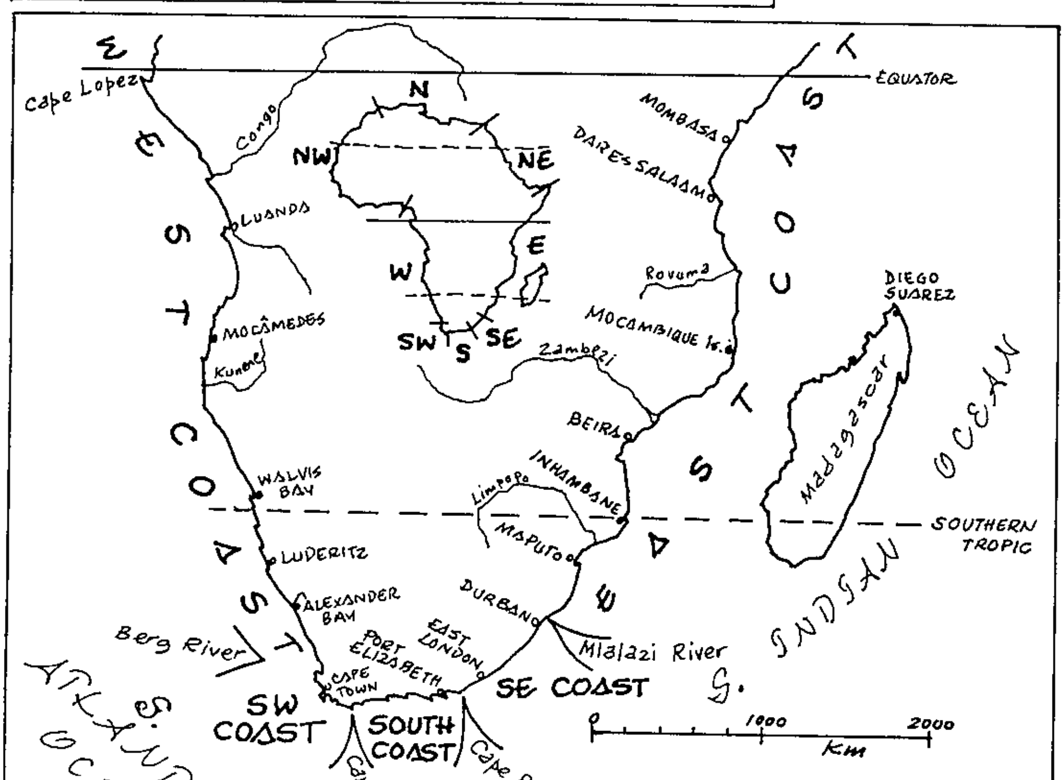
The contrasting sea surface temperatures of the two major ocean currents and the inshore circulations are major factors conditioning air masses which affect the climate of the subcontinent. This has resulted in the geographic asymmetry of climate and thus of its ecological patterns.



POSITION OF THE SOUTHERN AFRICAN COAST IN RELATION TO THE MAJOR PRESSURE & WIND SYSTEMS OF THE SOUTHERN HEMISPHERE.



MAJOR OCEAN CURRENTS AFFECTING SOUTHERN AFRICA.



SOUTHERN AFRICA - ORIENTATION OF COAST INTO 5 SECTORS.

Fig 2 Geographical Setting.

The two major currents form part of the anticlockwise surface circulations of the southern hemisphere's oceans, linked via the west wind drift. A direct connection exists between the west Pacific and Indian Oceans by means of a south Equatorial current branch which passes between Indonesia and Australia (Figure 2). These connections have contributed to the high degree of biotic similarity between the two oceans, and this includes the strand flora which plays a fundamental role in coast dune formation, many species of which are dispersed by ocean currents (Muir 1937; Good 1964).

1.3 PRESSURE SYSTEMS AND WINDS

Due to its subtropical geographical position, weather processes in southern Africa are dominated by the interaction of three major pressure systems. Two semipermanent highs alternate with series of polar lows.

Successions of east-moving low pressure cyclones which develop in the circumpolar westerlies (40-60° S) interact with two subtropical high pressure anticyclones which are centred over the south Atlantic and south Indian Ocean. A landward extension of the latter anticyclone is centred above the Eastern Transvaal and lower Limpopo River ("Limpopo High"). Both anticyclones fluctuate in position, ridging in south of the subcontinent where they cause strong easterly winds to blow, particularly in summer when they have shifted between 5° and 10° further south in latitude (Jackson and Tyson 1971). In this position with the land on the right and their trajectory onshore on the east and south coasts, and parallel or offshore on western coasts, inshore surface waters are moved seawards (to the left) causing replacement upwelling of cold waters of Antarctic or intermediate bottom water origin. In winter the pressure systems move further north, entraining a greater frequency of east-moving cyclonic cold fronts which bring rain chiefly to the south-west and south Cape, and the eastern coasts below the Great Escarpment.

The major winds along the coast are thus bidirectional, and oblique or quasi-parallel to the coastline trend. Hence southerly winds alternate with north-westerly winds on the west coast, westerly with easterly wind along the south coast and south-westerly with north-easterly on the eastern coast. Gale winds are common along the whole coast south of the tropic, with highest frequency (over 30%) along the south-west and south-east coasts from Cape Town to East London (Africa Pilot II, 1963).

On the east coast from the Limpopo Bight south of the Tropic northwards to about the 17th latitude, between Pebane and Moma, is the coast sector under the maximum influence of the year-round dominance of the south-east Trades. North of this latitude the south-east Trades take part in the seasonal alternation of the monsoons. In late summer the monsoon coast experiences the highest frequency of tropical cyclones (hurricanes) which cross the Mocambique Channel from Madagascar (Tinley 1971b).

1.4 SWELL AND WAVE REGIMES, COAST CONFIGURATION AND LITTORAL DRIFT

In addition to their physical impact on shorelines, waves and wind generate nearshore surf zone currents. The angle of swell approach to the coast, the type of wave and the resulting littoral currents formed are major coast shaping forces which erode, transport or deposit sediments. The most important of these sediments is sand responsible for the formation of beaches. The beaches in turn supply sand for the development of wind-formed dunes.

The net amount of sand transported alongshore in a particular direction is thus a function of persistent swell direction coupled with the intensity of wave energy. Most of the subcontinent's coastline is a moderate (1-2 m) to high (2-3 m) wave energy environment, dominated by persistent south-west and south swell generated in the westerly gale belt of the "Roaring Forties" (Davies 1964; Heydorn and Tinley 1980). Around the east coast this swell is refracted to approach from between south-south-east and south-east. The coasts on both sides of the Mocambique Channel are however classified as low energy environments (Davies 1964) despite their macrotidal regime and the seasonal occurrence of tropical hurricanes (Tinley 1971b).

Persistent swell from one oblique direction moves sediment alongshore, eroding between headlands to form asymmetric bays of a "half-heart" (Silvester 1960) or a "zetaform" shape (Davies 1980). A configuration similar to the curve between opened thumb (the promontory pointing in the downdrift direction) and forefinger (the longcurve of the bay). Conversely the existence of such bays indicates the direction of the persistent swell and of net sediment movement (Silvester 1960).

Half-heart bays are a characteristic feature of the subcontinent's coastline. On the west coast the half-heart bays, which are a mirror image of those on the east coast, extend to 1° north of the equator but on the east coast they occur only to near 21° S at Pontal Macovane (just south of the Save River mouth) and Bazaruto Island. The largest bays of this kind occur on the southern coast eg Algoa, St Francis, Plettenberg, Mossel Bay, Struisbaai and on the west coast at St Helena Bay. The divide between the net sediment transport directions equatorwards (northwards) up each coast lies between Cape Point and Cape Agulhas (Rogers 1971b).

Davies (1964) defines the west coast type as being dominated by strong regular swell (Cape Rollers), and the east coast type as having a more variable swell regime due to the alternating influence of the onshore trade wind generated waves where swell, and thus longshore sediment transport, reversals take place with the opposing easterly and westerly winds. On the west coast reversals also occur from the predominant southerly and south-westerly direction to northwest with the passage of a cold front or coastal low. However the direction of the west coast swell from the south-west and west-south-west (Africa Pilot II, 1963) is reinforced by the recurvature of high pressure anticyclone winds to blow from southerly directions.

1.5 TIDAL ENVIRONMENT

Tidal range controls the vertical spread of wave action on coasts, and this influences the kinds of coast forms and depositional or erosive features. In a world classification of tidal environments three major types are identified (a) microtidal (range 2 m), (b) mesotidal (2 to 4 m) and (c) macrotidal (greater than 4 m) (Davies 1964, 1980).

Although Davies (1964, Figure 5) includes the greater part of the southern African coastline, from Angola to Natal, as mesotidal, this sector has an average springtide range of 1,8 m and is thus an upper microtidal environment.

This contrasts with the Mocambique and Madagascar macrotidal coasts on either side of the Mocambique Channel where the highest springtide range of 6,4 m occurs at Beira (Tinley 1971b). The coast sectors between Inhambane and St Lucia, and again north of Mocambique to Somalia are mesotidal (Africa Pilot III, 1954).

On microtidal coasts wave action is concentrated along a narrow band of the shoreline. Characteristic features are (a) tidal currents insignificant, (b) single beach berms, (c) simple offshore topography with a break-point bar, (d) inhibited salt marsh development, and (e) few tidal channels (King, CAM 1962).

Typical features of the macrotidal coast in central Mocambique where shallow shelf seas meet low coast plains are, (a) flat lower beach profile rising gently landward to steepen abruptly upwards at the high tide level. Though wave attack is spread over a wide expanse of beach, quite different wave types result at low and high tides. At low tide they are creative, sliding waves but at high tide are dumping waves with strong backwash resulting in ongoing erosion and recession of the zigzag coast sectors aligned parallel to the south-east swell direction; (b) no break-point bar; (c) local formation of multiple beach ridges and slacks near river mouths; (d) immense areas of mangrove and estuarine salt marshes due to far tidal reach; (e) extremely strong tidal ebb and flow currents around islands, at river mouths, in estuaries and along channels; (f) extremely broad linear sandy beaches and sand banks exposed at low tide; and (g) low and relatively small dunefields.

As the greater part of the South African coastline falls between the micro- and mesotidal classes, features of each are to be found depending on local inshore and littoral topography (Heydorn and Tinley 1980; Day 1981).

1.6 COAST REGIONS OR SECTORS

Major changes in coast-trend are used as primary divisions in coast classification. That is, the main quarter to which the coast is exposed to onshore open-ocean influences, or conversely, is protected from them. Five regions are recognized, each composed of a variety of coast forms (Figure 2). This augments the classification used for the Cape coast by Heydorn and Tinley (1980).

1. West coast: Kunene to St Helena Bay. Coastal Trade Wind fog desert and subdesert with rare rain occurring in winter south of Luderitz and in summer northwards. The full extent of the desert coast stretches from Ponta das Salinas (12° 50' S) near the Coporolo River in Angola south to about the Olifants River (31° 42' S) (Koch 1961). West-south-west to west-facing.

2. South-west coast: Stompneuspunt to Cape Agulhas. Warm temperate Mediterranean climate with winter rain, and high all seasons rainfall confined to orographic highs. South-west facing.

3. South coast: Cape Agulhas to Cape Padrone. Warm temperate - all seasons and bimodal equinoctial rainfall, with isolated winter rain areas at Cape St Francis, Cape Recife and Bird Island (Heydorn and Tinley 1980; Figure 9). South to south-south-east facing.

4. South-east coast: Cape Padrone to Mlalazi River mouth (28° 57' S). Linear trending monoclinal coastline with irregular indented rocky shores separating linear or arcuate beaches. Subtropical bimodal equinoctial rains to unimodal summer rains. South-east facing.

5. Mocambique coastal plain sector of the east coast: From Mlalazi River northwards to the Rovuma River. Alternating zigzag pattern of linear coastlines cut in unconsolidated Quaternary to Recent Sands with dune rock forming reefs and small north-east trending points subtending half-heart bays to 21° S near the Bight of Sofala. Coast line alternatively facing south-south-east and east (Tinley 1971b). Tropical south-east Trade Wind zone with unimodal summer rains highest at the coast to north of the 17th latitude, where it is replaced by monsoonal summer rains.

2. COASTAL DUNE CHARACTERISTICS

The maritime zone of the subcontinent south of the tropic, has probably one of the greatest diversities of types and varieties of dunes to be found anywhere in the world. Dunes range through six coastal geographic regions and eight biomes from the extreme Namib Desert within the tropic on the west coast, through subdesert dwarf shrubland, winter rainfall heathland, Afrotemperate forest, arid subtropical thicket, to grassland, moist savanna and tropical rain forest on the eastern coasts. This succession of systems is determined mainly by the rainfall regimes and edaphic features of the subcontinent which are a consequence of the asymmetry of physical factors summarized in the previous chapter, and a latitudinal gradient of 12° south of the tropic.

There are seven determinants to dune development along the coast, (1) wind regime, (2) sand supply, (3) coast trend and configuration of shorelines (degree of exposure and deflection of the effective winds), (4) rainfall regime, (5) plant colonization, (6) sea (wave action and longshore drift), and (7) river mouth dynamics (change of flow and sand input). The latter marine and fluvial influences are confined mainly to the foredune zone.

In addition to being arrested by plant growth coastal dunes occur in a year-round perhumid environment where they abut the coast. A major high humidity input is from the copious aerosol of saltspray carried onshore by one of the predominant winds, and moisture brought in by advective sea fog. This is quite apart from the amount and distribution of rains in the various coast sectors.

A greatly increased wind strength is required to initiate movement of damp sand hence the coincidence of strong winds with arid periods or dry seasons becomes crucial in identifying the periods of sand transport and quiescence, as these may show little correlation to sand roses of effective winds derived from wind data alone.

2.1 CLASSIFICATION AND DESCRIPTION OF DUNE TYPES

Although there are relatively few simple or basic dune forms, many combinations of dune types exist and an almost endless number of varieties (McKee 1979).

Dune combinations are of three categories:

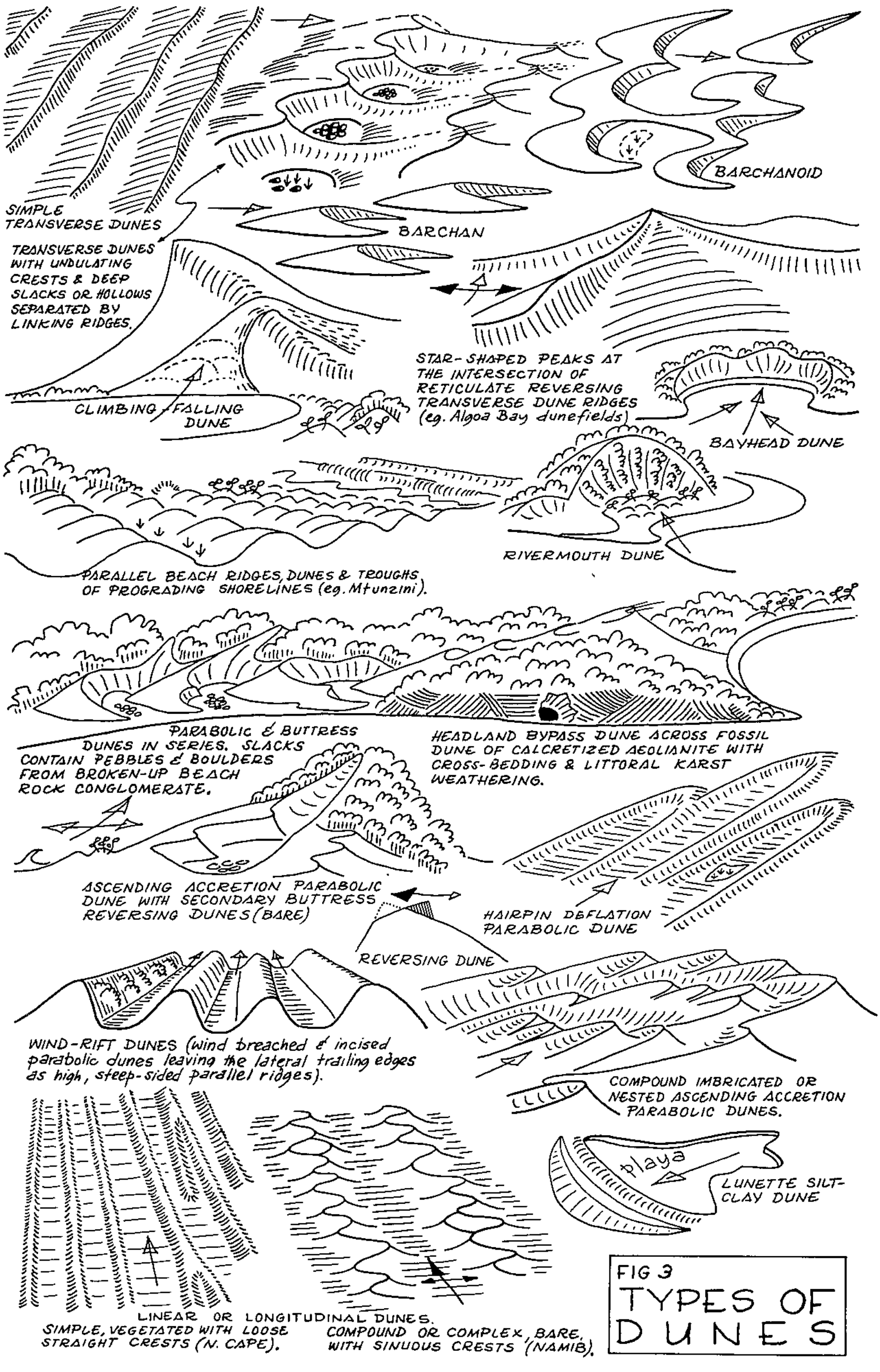


FIG 3
TYPES OF DUNES

1. Compound dunes: composed of two or more dunes of the same type, coalescing, overlapping or superposed.

2. Complex dunes: combining two or more different types occurring together or superposed.

3. Combinations of compound and complex dunes.

Most coastal dunes are compound or complex or both but simple forms also occur. Compound examples include superposed sets of nested parabolic dunes, and reversing transverse barchanoid dunes. Complex examples include the combination of parabolic and transverse dunes, transverse and hummock dunes, parallel beach ridges and parabolic blowouts, stardunes in barchanoid fields, etc. Combinations of compound and complex forms include superposed nested parabolics with transverse, blowout and hummock dunes, or transverse dunes with barchanoid, reticulate, star and hummock forms.

The terminology of world-wide dune classifications compiled by Mabbutt (1977), McKee (1979) and Davies (1980) have been followed as closely as possible (Table 1). These avoid the use of complicated colloquial or local dialect terms. Inevitably one or more types may not be represented or defined, particularly in the coastal environment where many more variables are at play than in continental desert dunes, hence a classification is elaborated here to fit the dune types encountered by the present survey (Table 2). Four major dune groups are recognized (a) bare or free dunes, (b) vegetated dunes, (c) dunes related to topographic barriers, and (d) dunes related to wetlands. Dune type distribution is shown in Figure 4.

2.1.1 Bare or free dunes

A. Mobile sand sheets and mounds.

On the coast these sand bodies display a rippled surface with a few to no low tranverse slipfaces. They feed climbing dunes, windward dunes, parabolic dunes and precipitation ridges.

B. Crescentic or transverse types.

The crests and slipfaces of all these types are orientated transversely to the wind direction, the concave curve of the leeward slipfaces facing downwind (Plates 1-6, 30, 37, 106).

1. Barchan. Isolated, crescent-shaped dunes, typically occurring in groups on firm desert floors, their axes at right angles to the wind (Plates 1-2). Barchan dunes are formed where there is a steady though sparse sand supply carried by moderate sand-moving winds which are persistent from one direction (Plates 1-2). In a bare dunefield zonation sequence they are thus typical of both the source area and downwind end as clearly shown on the microscale by Plate 4 and on the macroscale by their occurrence at each end of the Namib Sand Sea. The leeward avalanching slipface tapers towards the sides where two streamers of sand form wings or horns which advance downwind faster than the higher central body of the

TABLE 1. Classification of aeolian sand forms

(a) ACCORDING TO 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
- Barchanoid 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

(b) ACCORDING TO 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

(c) COASTAL DUNE CLASSIFICATION ACCORDING TO DAVIES (1980)

A. Primary dunes (derived from the beach)
   (i) Free dunes with vegetation unimportant (transverse ridges, barchans, oblique ridges, precipitation ridges and so on). Wind oriented and generally lying perpendicular to the direction of constructing winds.
   (ii) Impeded dunes with vegetation important (frontal dunes, sand beach ridges, dune platforms, etc). Nucleus oriented and generally parallel to the rear of the source beach.

B. Secondary dunes (derived from erosion of A (ii))
   (i) Transgressive dunes (blowout dunes, parabolic dunes, longitudinal dunes, transgressive sheets, etc). Wind oriented and generally lying parallel to the direction of constructing winds.
   (ii) Remnant dunes (remanie dunes), eroded remnants of vegetated primary dunes.

crescent. The barchan thus advances downwind by movement of sand from the windward edges over the gentler windward slope, avalanching in sand tongues down the steeper slipface and along the wings by creep (streamer effect). Eddy motions on the lee side help maintain the concave profile. In cross-section they display dune-bedding (Finkel 1959; Hastenrath 1967; McKee 1979).

True barchans are confined to a few sites on the Namib coast of the subcontinent, scattered north of 28° S between Buchuberg and Pomona and in a concentrated train between Elizabeth Bay and Kolmanskop inland of Luderitz Bay (Dr R Rogers pers com). Some occur north and south of the Kuiseb River mouth and a large group north of the Unjab River mouth (Plates 1-2). On the South African coast a few, mostly linked, barchans occur at the eastern downwind end of the Algoa Sand Sea near Cape Padrone, where they lie on a raised bare limestone plateau next to the sea. Barchan dunefields are a mobile archipelago ecosystem (Endrody-Younga 1982).

TABLE 2. A classification of the coastal dunes of southern Africa (this study)

2.1.1	<u>Bare or Free Dunes</u> (wind formed)		
	A	Mobile sand sheets and mounds	
	B	Crescentic or transverse dune types	
		1	Barchan
		2	Barchanoid
		3	Transverse
		4	Reversing
		5	Buttress barchanoid
	C	Linear	
	D	Star	
2.1.2	<u>Vegetated Dunes</u> (wind and plant formed)		
	A	Strand plant hummock dunes	
		1.1	Driftline embryo dune
		1.2	Hummock or hillock dunes
		1.3	Parallel beach ridge hummocks
	B	Precipitation dune or retention ridge	
	C	Parabolic dune types	
		3.1	Blowout
		3.2	Accretion ascending parabolic
		3.3	Deflation hairpin parabolic
		3.4	Parallel wind-rift ridges
2.1.3	<u>Dunes Related to Topographic Barriers</u>		
	A	Climbing-falling dune	
	B	Headland bypass dune	
	C	Windward diverging dunes	
2.1.4	<u>Dunes related to wetlands</u>		
	A	Hummock dunes of slacks, washes and river flats	
	B	Playa lunette dunes	
	C	Lagoon-shore dunes	

2. Barchanoid. Parallel rows of linked or coalesced barchans with a single slipface on each arc. Where the ridges are straighter they are referred to as transverse dunes (Figure 3).

3. Transverse. Parallel straight to slightly curved dune ridges with their axes oriented at right angles to the wind direction. Simple forms with a unidirectional wind have a single slipface. In reversing types with bidirectional winds an alternating slipface occurs. The above three types may occur in a gradational sequence in the same dunefield area.

4. Reversing. A transverse or barchanoid type which periodically and seasonally develops a second slipface nearly opposite to that of the previous slipface. Formed typically where winds alternate seasonally and periodically from opposing directions. Although the crestline and slipfaces vary with opposing winds, the main dune body (the plinth) retains its curved form which is related to the dominant or persistently stronger of the opposing winds. Most of the transverse and barchanoid dunes on the southern African coastline are reversing types due to the alternation of strong winds from opposing quarters (Plates 5, 6, 9-13).

5. Buttress barchanoid. Rows of reversing barchanoid or transverse dunes inclined upwards at right angles from the beach onto the bared seaward slopes of otherwise forested high parabolic dune cordons. The term is derived from their similarity to the plank buttresses which occur around the base of many rain forest trees. Typical along the south-east and east coast forested dune sector (Plates 9-13).

The seaward ends of buttress dunes are frequently truncated and the interdune troughs inundated by storm seas which are coincident with high spring tides.

The crescentic dune types show a definite sequence from barchan through barchanoid and linear to transverse dunes as a function of increasing sand abundance and its potential transport (Hack 1941; Mabbutt 1977; McKee 1979).

C. Linear or longitudinal dunes.

Dune ridges elongated in lines parallel to the formative winds, separated by sandy, gravelly or rocky interdune corridors or streets (Figure 3). The simple forms are single or bifurcated ridges with narrow crests. Compound and complex linear dunes, as well exemplified by those of the Namib Sand Sea, generally have much broader basal plinths below a narrow anastomosing, sinuous barchanoid crestline with lateral slipfaces alternating on both sides and enclosing dune hollows (Plates 7, 8), or with peaked summits with whorled radiating stardune slipfaces (Mabbutt 1977; McKee 1979).

The greater part of the Namib Sand Sea, which extends from the Kuiseb River near Walvis Bay southwards for about 350 km, is composed chiefly of bare linear dune systems (Barnard 1973; McKee 1979). Here they attain their greatest dimensions in relief, linear and aerial extent (Barnard 1973).

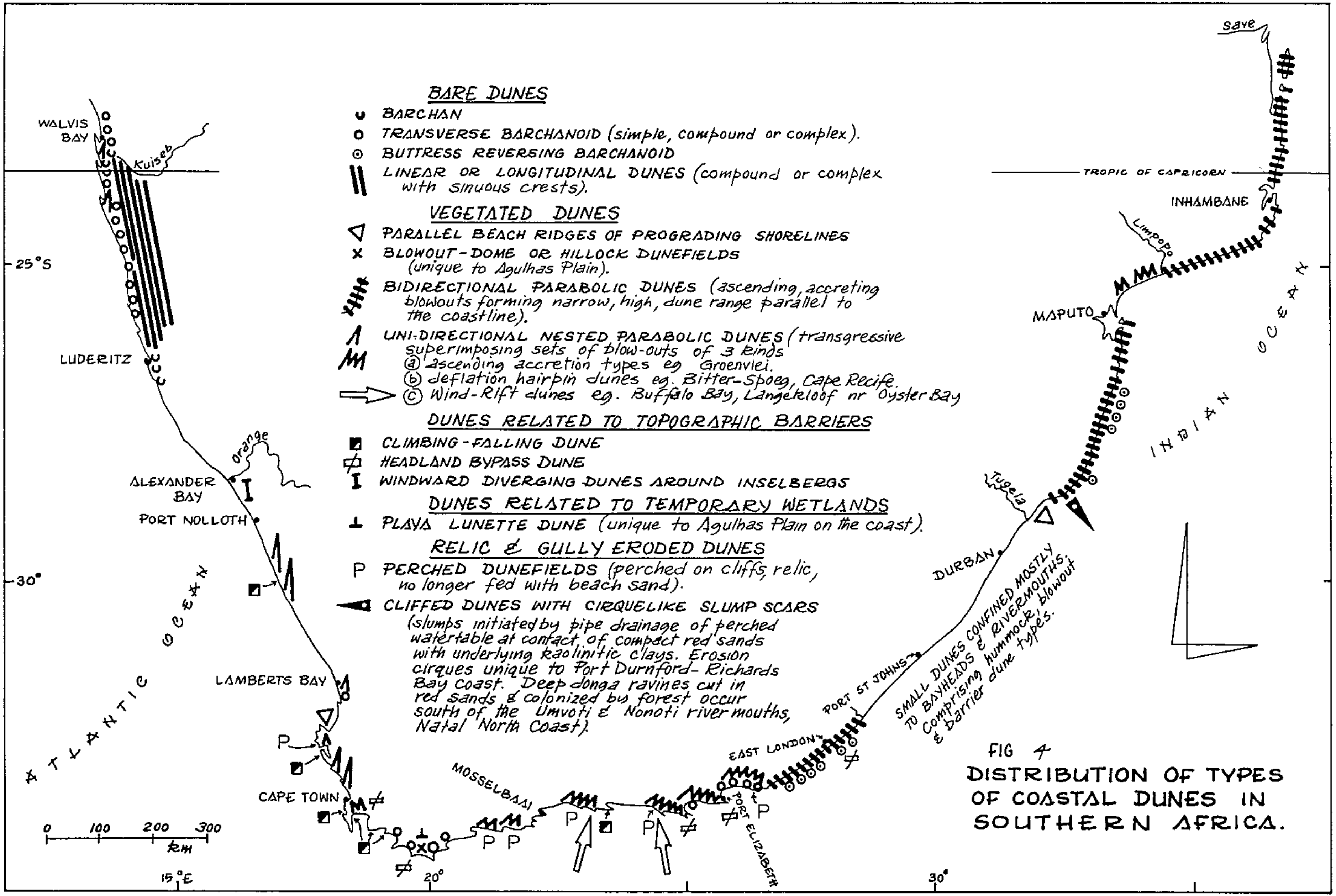


FIG 4
DISTRIBUTION OF TYPES OF COASTAL DUNES IN SOUTHERN AFRICA.

Continental linear dune systems, now mostly fixed by plant growth, are disposed peripherally around the Kalahari Sand Basin of the Interior Continental Plateau.

D. Star dunes.

Peaked dunes having three or more whorled radiating sinuous arms (barchanoid) with multiple slipfaces formed by effective winds of moderate strength blowing from several directions. Growth is mostly vertical rather than lateral. Star dunes occur in simple, compound and complex form. Simple star dunes occur as regularly spaced isolated mounds on gravel plains. In their complex forms they occur at the confluence or intersection of crestal ridges in a variety of dune types (Mabbutt 1977; McKee 1979).

On the South African coast star dunes are found only in complex dune forms where they combine with or are superimposed on transverse and barchanoid dune types in the following situations:

(a) where onshore and offshore (land breeze and berg winds) secondary winds are sufficiently effective to be formative,

(b) where the leading points along a sinuous crestline, which alternate with concave slipfaces and their lee hollows, act as sand chutes directing sand forward in streams onto the windward slope of the transverse dune downwind of it. These linear sand deposits avalanche laterally to form sharp crested linking ridges. In this way a reticulate pattern is formed with star dunes at the intersection of four crestlines (common in the Algoa Bay dunefield, Figure 3, Plate 5),

(c) small star dunes often develop at the upper junction of buttress dunes with the retreating forest front where a deep scour hollow is formed by wind turbulence against the forest edge. This results in an upward growing peak with several radiating sand ridges (Plates 9, 12).

2.1.2 <u>Vegetated dunes (wind and plant formed)</u>

As living organisms, plants are unique sand traps. Their aerial shoots provide an open, flexible, obstacle to wind-driven sand. The sudden drop in wind velocity and the sifting effect of the open obstacle results in the sand being deposited in and around the plant. Burial by sand stimulates further growth up through the sand and in this way mounds and hummocks are formed and from these embryonic dunes, giant parabolic blowout dunes can eventually develop.

Wave and wind action imposes continuous multidirectional change on sandy foreshores. Strand plant-growth fluctuates with erosion and accretion of the foreshore, and the dunes they form entrain further multiple changes. Many coastal dunes occur in high water-table areas and this affects dune form and dynamics and plant colonization where deflation exposes the permanently moist horizon. The high water-table occurs both in the foredune zone as well as in the immediate hinterland across which migrating dunes travel.

The form and dynamics of vegetated coastal dunes is thus controlled mainly by three features: (a) The coincident occurrence of effective winds with dry or wet sand conditions, (b) various degrees of stabilization by plants, and (c) presence or absence of high water-table conditions.

A feature of plant-arrested dunes in coastal areas receiving more than about 30 mm mean annual rainfall is the successional sequence from embryo dunes begun by specialized creeping strandplants along the driftline nearest the sea, through increasingly older and relatively more stable dunes landwards, covered by denser more complex vegetation of shrubs, scrub, thicket or forest depending on the rainfall regime.

A. Strand plant foredune hummocks.

The strand plants are a specialized dune pioneer flora able to withstand the extreme conditions of the upper beach. This zone is subject to continual movement by waves or swash and wind; to phases of berm formation and destruction; a nearly continuous rain of salt spray, and is fully exposed to the sun and wind.

The strand plant flora is composed mainly of creeping herbaceous plants with upright branches. Their growth habit is rhizomatous, stoloniferous or sympodial, and by the continuous production of shoots and roots dune plants are able to grow ahead of accumulating sand.

Hummock dune or hillock topography is formed by sand accumulating amongst and around the aerial parts of isolated plants. Another term used for these mounded dunes of various dimensions up to about 10 m maximum height are "coppice" or "shrub-coppice" dunes (McKee 1982). However, coppice is a definitive term used to describe the multiple stemmed regrowth of woody plants after their aerial parts have been damaged. The mounded hummock foredunes along the South African coastline are formed by herbaceous and suffrutex plants (Figure 3, Plates 13-19).

1. Driftline embryo dunes. The earliest stage of dune formation by plants are the small mounds of sand built up around the isolated colonizers of bare sand in a variety of situations. On the foreshore strand plants initiate and promote the development of embryo dunes along the driftline and higher beach berms (Plates 13, 14). These may either be eroded or destroyed by high seas, or continue to enlarge and coalesce laterally to form an initial temporary foredune. With further development the embryo dune grows into the larger hummock or hillock dunes noted below.

2. Hummock or hillock dunes. Rounded or oval plant formed dunes, isolated, clumped or in lines. These dunes develop in situations such as along the foreshores of seas and lakes, on river mouth flats, the margins of estuaries or slacks and in other interdune sites. Apart from the continued addition of wind driven sand, a moist subsoil appears to be an important determinant for the maintenance of hummock dunes.

Their usual size ranges from about one to five metres in height with diameters of 1 to 15 m. Where they coalesce some attain more than 10 m in height and cover a large area (Plates 15, 18, 19, 70). Their shape becomes exaggerated by undercutting from wind shear to an unopened mushroom form where the adjacent surface is moist or compact.

3. Parallel beach ridge hummocks. These are hummock dunes formed along parallel swash bars or beach berms, each ridge separated from the other by a slack or trough forming a catena sequence (Figure 3). They are most distinctive of accreting shorelines, often near river mouths, as best exemplified on the Zululand coast sector between the Tugela and Mlalazi River mouths. The only other sector with a broad sequence of parallel dunes in South Africa is at Dwarskersbos in St Helena Bay on the west coast (Plates 100, 102-105). The largest areas of parallel beach ridges in the subcontinent occur in Mocambique, on the south side of the Zambezi Delta (Plate 105), and on the southern side of the headland south of the Lurio River mouth and its bay (Tinley 1971b).

The age sequence of parallel dune ridges from youngest embryo dune ridge on the upper beach to oldest on the landward side is clearly depicted by the increasing density, height and structural complexity of the dune vegetation landward where mature forest is the climax cover on moist coasts.

The development of blowouts and parabolic dunes by oblique or onshore winds often disrupts or eventually totally masks and superposes a system of parallel dunes (Plate 23).

B. Retention ridge or precipitation dune.

A precipitation ridge (Cooper 1967) is a dune produced where sand carrying winds meet a vegetated front, lose velocity and drop their sand load along the junction (Plate 22). Its profile and advance is similar to a transverse dune, except the growth of existing vegetation through the slipface and/or of colonization by strand plants along the base of the slipface results in the upward growth of the dune ridge. Plant colonization of the windward slopes occurs if the sand source is cut off in some way. For example if the source area is reduced to deflation base by exposure of a water-table or the foredune zone has become stabilized by plant growth.

The upper part of the ridge is often breached by blowouts, and small parabolic dunes may originate from the dune crest. These ridges are parallel or oblique to the coast and the largest have developed at (1) river mouths, (2) in bayheads, (3) where parabolic dunes have been bared of their seaward plant cover, or (4) form sections of the slowly advancing dune escarpment on the landward front of large bare dunefields as exemplified by those in Algoa Bay.

At river mouths these, and other kinds of dunes such as parabolic dunes, originate from the sand blown off spits or bar deposits and swept upwards in a fan pattern resulting in a high kidney-shaped dune with its concave slope facing the wind and sand supply. The finest examples of river mouth dunes occur at Buluga River mouth north of East London and North Sand Bluff at Port Edward (Plates 20, 21).

C. Parabolic types.

A parabolic dune is a U- or V-shaped blowout or tongue of advancing sand with its sides and leading leeward slipfaces partially stabilized by vegetation. Its leading edge is a concave mound of sand forming a steep rounded nose that migrates slowly downwind. The crescentic nose is opposite to that of the barchan dune which is convex to the wind.

Parabolic dunes vary greatly in size, and although they originate in a variety of situations and from several causes their origins have one factor in common - the existence of an opening or gap in the plant cover which allows breaching by the wind to occur (Plates 23, 25, 28, 30, 31, 107, 108).

Sets of similarly-aged parabolic dunes can originate simultaneously in the foredune zone where high seas have caused cliffing, undercutting and slumping of plant stabilized berms or foredunes, providing a fresh sand front for wind breaching. In this way series of parabolic dunes, related to phases or episodes of foredune erosion by storm seas, become superposed on one another; the younger mobile blowouts overriding the older plant stabilized parabolics beneath (Plates 28, 29).

Parabolic dunes can also originate from bare or sparsely vegetated openings between adjacent patches of dune plants. Where stabilized by dense low fynbos heath shrubs for example, blowouts are initiated on dune crests where fire has temporarily denuded the cover which in the Renosterkop dune area west of Cape Agulhas has resulted in the development of a unique duneform (Plate 41).

Sand slumping on steep slopes, or wind thrown canopy trees, produce gaps in the dune forest or thicket canopy. Here further enlargement of the opening is caused by salt spray "burning" of the once protected vegetation, and these allow blowouts to be initiated in the gaps.

Similar openings are caused by human agency, from features as trivial as footpaths, careless siting of access roads onto beaches, or where patches of dune forest on seaward slopes are cut open for shifting cultivation.

Varieties of simple, compound or complex parabolic dunes occur at intervals along most of the vegetated sandy coasts of southern Africa. They are absent along the greater part of the Namib Desert coast north of Port Nolloth, and are of small size on the monoclinal south-east coast between the Kei and Tugela Rivers.

1. Blowout. Crater-like deflation and wind scour hollows initiated in openings or weak spots of dunes partially stabilized by vegetation, moisture, or both. Blowouts are variable in shape but are commonly oval or narrowly elliptic (parabolic) in shape (Plates 23, 24, 28, 41).

associated with vegetated dunes in a variety of situations. They evolve in one of two ways. On the foreshore they commonly develop into parabolic dunes of one kind or another. Away from the foreshore in dune areas covered by grass or short fynbos shrubland blowouts are initiated by gale winds where this cover has been weakened by some agency. Oval or elliptic blowouts are formed with nonmigratory, standing or stationary dunes accumulating on their periphery. The long axes of the blowouts are parallel to a predominant strong wind. The standing dunes are generally colonized by plants except where they are overridden by tongues of sand which may develop into parabolic dune initials.

Where blowouts have been developed by gale winds on the crests of dunes, temporarily bared of vegetation by fire and in the dunefields west of Cape Agulhas for example, the hollow is scoured out to below the level of effective wind erosion allowing sufficient time of relative quiescence for plant colonization to anchor the hollow (Plate 24). This unique hummock-blowout dune topography developed by the process of repeated crest breaching is found nowhere else on the subcontinent's coastline (Plates 41, 84, 85).

Many of these blowouts become stabilized by exposure of a compact horizon such as a high water-table or exposure of stones, pebbles or rock. On the Mocambique Plain, in the coastal sand grasslands immediately behind the forested dune range, blowouts have resulted in the formation of lakelets, some as large as 1 500 x 300 m. Some blowouts in the troughs of extinct parabolic headland bypass dunes are of such antiquity that sand-blast faceted rocks and stones occur on the floors of the trough as at Mendu Point in the Transkei and on the top of Cape St Francis (Plate 52). In these sites are patches of desert pavement composed of wind-faceted pebbles (ventifacts or dreikanters), large asymmetrically sculpted dolerite (Mendu), and quartzite (St Francis) boulders. Ribbed and fluted silcrete cappings to calcrete also occur in the second site.

2. Accretion ascending parabolic. A bare, trough-shaped mobile dune breached into and overriding vegetated dunes which surround it on three sides (Plates 25, 29, 31A, 107, 108). This parabolic type grows both upwards and forwards burying everything in its path. It is open at its sand-source end at the foreshore. The leading edge is formed by a rounded nose of sand with a leeward slipface below the ridge curve and its sides. These slipfaces are partially or temporarily stabilized by through-growth of the vegetation being buried and its colonization by dune pioneer plants (Plates 34, 35).

Generally the lower and middle parts are typically trough-like with steeply scoured sides anchored by the existing vegetation. The upper third or more, near the nose, is often higher than the surrounding dune topography that it is overriding (Plates 26, 27).

The sand within the trough moves forward as large mound-like ripples with transverse slipfaces. As the nose migrates downwind it leaves behind it the steeply scoured sides of the trough which form paired asymmetric walls or ridges (Plates 31, 37).

At the nose the outer leeward slipface slopes may be as steep as 35° and the inner accumulation slopes between 12° and 25°. These slope relationships, however, vary down the length of the parabolic dune. In the trough sector the inner slopes are steeper than the slipfaces. In cross-section therefore, a mature blowout parabolic has a flatter section in its lower part, a concave, trough-like central section or is convex down the centre with scour channels along the sides.

The leading nose of the parabolic dune can be single, multiple where series of compound parabolic blowouts override each other (imbricate form as exemplified at Groenvlei), palmate or finger-like (Plates 31A, 94, 107).

Many active parabolic dunes in the forested dune ranges of the east coast have become self-stabilizing where deflation base-level has reached moist sand in the foredune zone (Plate 107). Plant colonization is primarily in this moist zone, in dune hollows and from the margins. The last site to be covered by plant growth is the head of the dune where sand continues to be shifted because of its exposed position (Plate 109).

The largest fields of unidirectional, nested or imbricate (also known as M or W-dunes), ascending parabolic dunes occur along the south coast in the Wilderness Lakes section between Swartvlei Mouth and the Goukamma River (Plate 31). Here the highest vegetated dune (201 m) in southern Africa overlooks Groenvlei (Plate 32).

In this area remnants of large dune cordons occur as calcretized submarine ridges immediately seawards of the existing dunes, and landwards are higher, wooded, calcretized and laterized dune ridges indicating their much larger dimensions in the past as a consequence of the last glacial drop in sea level (Martin 1962; Tyson 1971; Birch 1980).

Remnant forested stubs of the Groenvlei dune-type, now replaced by bare transverse dunefields, occur on the landward margins of the Gamtoos-van Standens dunefield in St Francis Bay, and in the extensive Algoa Bay dunefields which extend from west of the Sundays River mouth eastwards for 60 km to near Cape Padrone.

The largest and highest simple ascending parabolic dunes occur on the Zululand sector of the Mocambique Plain, near Cape St Lucia (183 m), north of Cape Vidal (171 m) and at Lake Sibayi (165 m). These dunes form a narrow, high dune range due to the upward growth of parabolic sets against each other (bipolar) in response to whichever of the two predominant winds the configuration of the coast exposed them to (Figure 7) and as a function of dense plant growth (Plates 79, 80).

Where high velocity wind regimes predominate, as evidently occurred in the past, ascending parabolics of accumulation can evolve into the deflation or wind-rift types.

3. Deflation hairpin parabolic. A deflation migratory dune type with a convex nose of sand advancing downwind leaving paired parallel ridges behind it. The resultant dune ridge lines, or their traces on airphotographs, are in the form of a long narrow hairpin. The open end and

upwind tips of the paired dune ridges face their source area (Plates 30, 37, 106).

Deflation parabolics occur on flat to undulating, sparsely vegetated (eg semidesert dwarf shrubland, grassland or herbaceous vlei) terrain where they are blown across older sands partially stabilized by vegetation or a contrasting substrate such as gravel, clay or high water-table area (Figure 5A). They are found for example on the edges of the Namib Sand Sea, on the seaward lagoon margins between Meob Bay and Sandwich Harbour and inland on the semidesert margins.

The largest fields of compound hairpin parabolics occur on the west coast where separate fields take off from the north side of the Bitter and Swartlintjies River mouths and extend obliquely inland for nearly 30 km (Plate 30). Two others which may be longer are those which originate from Ysterfontein and Melkbosstrand on the south-west coast and extend northwards towards the Great Berg River.

All these hairpin dunefields have now been converted to complex dune types with bare transverse dunefields replacing the original vegetated hairpin parabolics. These secondary dunes have arisen from natural and man-made disturbance of the plant cover, the transverse dunes are thus composed of remobilized sand derived from the broken-up parabolic dunes.

4. Parallel wind-rift ridges. Unidirectional parabolic dunes with breached noses, the lateral slipface rims, left behind by the nose migrating downwind, remain as parallel dune ridges. The blowout trough is thus open at both ends, and the lateral ridges parallel to the effective wind are referred to as wind-rift dunes (Hack 1941; Mabbutt 1977).

At first sight these parallel ridges appear to be linear or longitudinal types as incorrectly identified for example by myself in Heydorn and Tinley (1980). Closer inspection especially with stereo-pairs of airphotographs, show the remaining traces of the typical parabolic curves and hairpin shape. The strong slope asymmetry of the ridges, with the steeper slope occurring on different sides of the parallel ridges are a further diagnostic feature. The steeper slope occurs either on the oversteepened wind-scoured inner slope of a trough, or on the outer lateral slipface slope.

Small wind-rift parabolics are to be found in the compound hairpin dunes on the west coast, at False Bay on the south-west coast, and on the Cape Recife headland on the south coast (between Maitland River mouth and Summerstrand). A larger set of complex wind-rift dunes occurs on the headland between Goukamma River mouth and Buffalo Bay (Plate 31B).

The largest and most spectacular wind-rift dunes are the perched fields at Langekloof, on the south coast between the Tsitsikamma and Klipdrift (Slangbaai) Rivers west of Cape St Francis. These are high vegetated parallel dune ranges, some up to 12 km long and rising 177 m at the highest point. They ascend between 50 to 100 m from the interdune trough floors to the ridge crestline, and these slopes are 35° on the steep sides and between 12° and 25° on the gentler slopes (Plate 33). Similar perched wind-rift dunefields with more diffuse relief occur above a cliffed coast for 6 km west of the Tsitsikamma River, with an isolated field 6 km further west at Boskloof between Bishops Cove and Grootpunt.

Many of these perched wind-rift dunes are composed of oxidized orange to red sands with partially calcretized cores, and with patches of remobilized drift sand areas.

2.1.3 Dunes related to topographic barriers

A large variety of obstacle-related dunes are reported from the desert regions of the world (eg Cooke and Warren 1973; Mabbutt 1977; McKee 1979). These include leeward accumulations such as sand shadow, sand drift and lee dunes. Windward accumulations include wrap-around dune, windward dunes or sand shields and echo dunes.

The commonest of the large obstacle-related types on the South African coast are the headland bypass dunes and the rarer climbing-falling dune.

Minor obstacle-related dunes, most of them ephemeral depending on persistence of a particular wind direction, are common on sandy foreshores all around the coast wherever rock outcrops or bush clumps and strand plant hummocks occur (Plate 36).

A. Climbing-falling dunes.

Where strong sand-laden winds meet opposing hillslopes a climbing dune is banked up against the windward slope, and the finer sand blows over the hill dropping in the lee down the slope to form the falling dune counterpart. Climbing dunes are generally sand accumulations formed in the standing wave of the wind blasting over a hill or mountain. They rarely form migratory dunefields though transitional forms between this and the next type can be found.

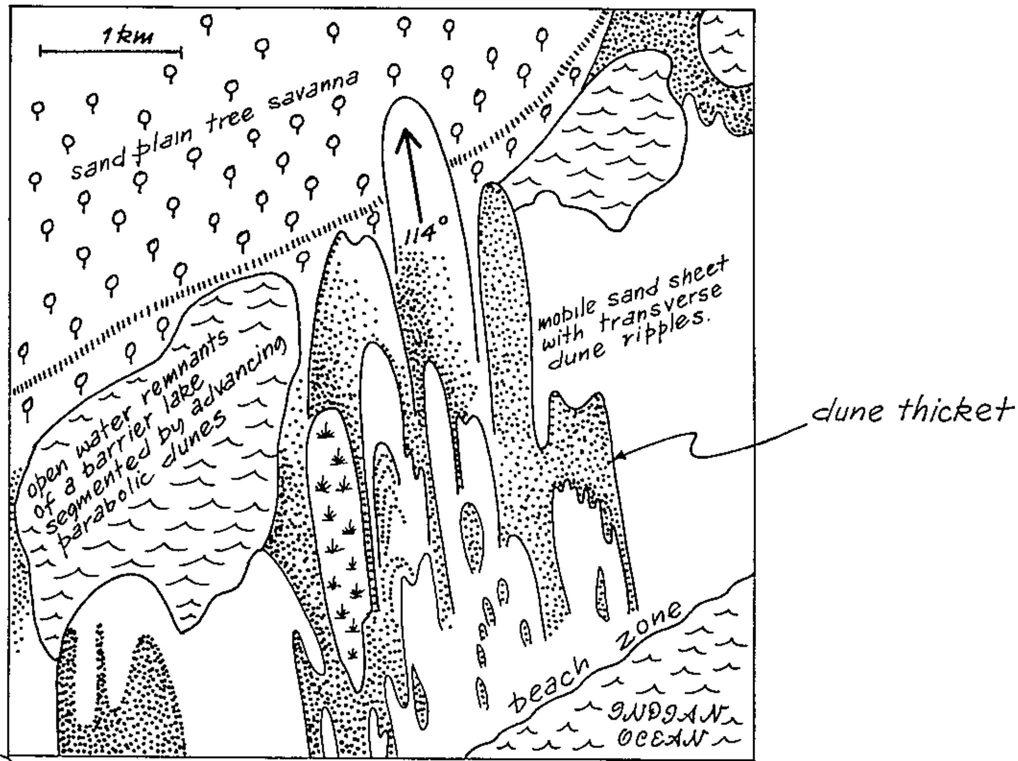
About seven of this dune type occur along the South African coast:

a. across a cliffed headland between arcuate bays north of the Spoeg River on the west coast, formed by strong southerly winds,

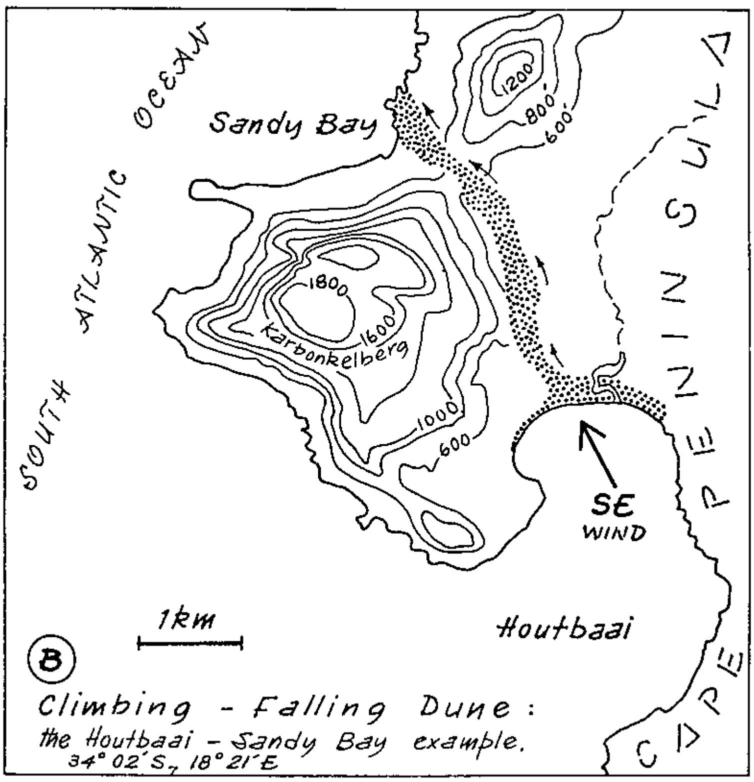
b. four on the Cape Peninsula, two of which are on the Atlantic coast. One crossing the Karbonkelberg neck from Hout Bay to Sandy Bay (Figure 5B), and a smaller field at Sandkop near Witsandbaai. Two occur on the False Bay side, the larger originating from Fish Hoek beach onto the Dassenberg, and the other form the foreshore at Elsies Bay across the Brakkloofrant to the Fish Hoek Gap. Except for the Sandkop occurrence formed by south and south-westerly winds, the others have been formed by strong south-easterly winds,

c. the Blesberg dune at Silversands near Betty's Bay formed by the south-east wind (Plate 135),

d. the climbing-falling dune across Robberg Peninsula at Plettenberg Bay. Formed by south to south-westerly winds carrying sand off a tombola beach.



(A.) Muandje Lakes near San Martinho, Southern Coast of Moçambique 25° 17' S., 33° 16' E.



(B) Climbing - Falling Dune : the Houtbaai - Sandy Bay example. 34° 02' S., 18° 21' E

FIG 5. MIGRATING PARABOLIC DUNES & CLIMBING - FALLING DUNE.

The Hout Bay-Sandy Bay and Robberg occurrences are classic examplts of this dune type on the coast.

B. Headland bypass dunes.

Related to and originating in the same way as climbing dunes. Unlike climbing dunes, however, this type develop strips of migrating dunes which cross the plateau or undulating plainsland of the headland to feed the shoreline of the embayment opposite with sand. Most of this sand would otherwise be lost to the beaches and dunes on the downdrift side by its deepwater entrapment in submarine spits off the rocky points of the headland (Birch 1980), or by it falling into deep water on the opposite side.

The important role of headland bypass dunes in maintaining the longterm downdrift flow of sand supply along the coast is well exemplified by the erosion of Algoa Bay beaches which followed the stabilization of the bypass dune across Cape Recife (Hydraulics Research Unit, CSIR 1970).

The most spectacular dunefields of this type occur at Cape St Francis (Plate 37). Here a series of parallel dune strips developed between Slangbaai (Oyster Bay) and the Krom River mouth in St Francis Bay, a distance at the longest point of 18 km, forming a 'backdoor' sandlink behind the two headlands. The most important in terms of effective past sand input to the beaches on the downdrift side in this area is the set between Thysbaai and the corner of the bay at St Francis town which are now stabilized to protect housing development.

Much longer, but lower and inconspicuous since artificially stabilized with the alien 'rooikrans' wattle, are those across the headland which separates St Francis and Algoa Bays. These originated in the Sea View-Shelly Beach area and traversed 25 km to the Humewood sector of Algoa Bay. Shorter bypass dune strips exist between Shelley Bay, Summerstrand, and Cape Recife. Of these only the latter bypass dune remains partially active.

These strips of migrating dunes belong to the parallel-sided deflation hairpin parabolic type, whose formation here is influenced by a high water-table as well as by natural plant growth on the lateral and leading slipfaces. The effective dominant wind in these two areas blows from between west and west-south-west.

Small bypass dunes also occur across the peninsula tips at Cape St Francis, Cape Recife, Nahoon Point and Dwessa Point. The dunefields which traverse Mudge Point (between Bot and Onrus River mouths) and Quoin Point appear either to be perched types or a combination of climbing-migratory-falling dune types. They are at the same time headland bypass dunes.

C. Windward diverging dunes.

On the west coast north of the Holgat River mouth, coastal dunes migrating northwards, obliquely inland from the coast, have diverged around both sides of a 4 km broad hill which rises to 322 m (Visagiefonteinkop). The area lies 10 km inland from the twin Boegoeberg inselbergs between 28° 43' to 28° 50' S and is bisected by the 16° 40' meridian.

By diverting the windstream around it, which at the same time sweeps the obstacle clear of sand, the hill has affected sand transport and deposition up to 2 km upwind of it where the dune lines are divided to follow the contours around the lower slopes of the hill.

Judging from topographic maps, similar diverging dunes and other obstacle-related types are to be found amongst the inselbergs on the west coast south of Port Nolloth to the Sout River. They appear to be especially common between the Swartlintjies and Groen Rivers (eg Kwabskop 17 km inland from the coast). These will require stereo-airphotograph analysis as they are old plant covered dunes with diffuse relief.

2.1.4 Dunes related to wetlands

A. Hummock dunes of slacks, washes and river flats.

In the above sites away from the seashore and also occurring inland are hummock or hillock sand or silty-clay dunes, formed by wind and plant growth in the same way as those on the sea coast. Their mode of origin is however often the opposite.

Most of the temporary wetland habitats occur along the west coast in the desert and subdesert regions (Plates 38-40). The washes and river mouth flats have a high, often saline, ground water-table. Their surfaces are modified episodically by fluvial processes which provide the typical micro-relief of anastomosing or fan deposits of both fines and sands. Wherever these form convexities they are first sites of colonization by salt plants on the fines and dune plants on the bumps of sand. Thereafter both groups form hummocks on the larger hillocks as wind-driven sediment is trapped by the individual plants. These may coalesce or go through a phase of increasing growth followed by undercutting from wind or floodwater and their complete or partial damage. In many areas hummock dunelands appear to maintain a steady state in the size of the individual clumps.

The largest areas of hummock dunefields occur on the river mouth flats along the Namib Desert coast (Plates 39, 40). On a small scale hummock dunes develop on the margins of temporarily inundated slacks with high water-tables. Here minor swashbank or other micro-relief zonation provide convexities for plant colonization.

B. Playa lunette dune.

The largest area of coastal playas with lunette dunes on their downwind eastern margins occurs on the Agulhas Plain (Figure 3, Plate 41). Although many saline depressions occur on the subdesert west coast between the Buffels River mouth and Orange River, none seen on a low-level survey flight of the Cape coast had lunette dunes (Heydorn and Tinley 1980).

River mouth or estuarine playas occur on some of the west coast rivers, such as the Jakkals, where occasional riverflow or high seas overtopping or breaching the sandbar across the mouth temporarily inundate the river mouth playa. The Jakkals River example may show either lunette or parallel ridges and hummocks along its northern, downwind shore.

Under present-day conditions the Agulhas region experiences high year-round wind velocities, a six to seven month dry summer season (October to April) and 445 mm of winter rainfall on the longterm, with an average of only 11 days receiving 10 mm or more rainfall. The playas therefore dry out and are subject to deflation during the hottest and driest period of the year. The wind regime is bimodal with an annual frequency of 27% westerly winds (west to west-south-west) and 24% of easterly winds (east-north-east to east-south-east). The strongest winds occur in the spring to autumn periods (September to April) when there is a 40% frequency of winds stronger than 26 km/h. Gales are most frequent in March and between September and December (South African Weather Bureau 1960, 1975).

The three playas inspected in the field, and judging from the diagnostic outline of the others on the 1:50 000 topographical maps, all have smooth, faintly arcuate eastern shores with a lunette dune. The formative winds are thus the westerlies. The western shores are irregular in outline and lack lunettes which seems surprising as the co-dominant easterly winds are a feature of the late summer months. Overall there is a ratio of 2:1 of strong westerlies to easterlies. Although the lunettes seen appear to be mostly fossil due to calcretization, silty clay powdery sediments are still being deposited. In some a smaller dune, which may be related to wet season swashbank formation has developed parallel to the eastern shore of the playa.

Lunette dunes are non-migratory, with their concave (new moon) curve facing the playa. The saline silty clays produced on playa floors by the alternation of periodic flooding and drying produces fine aggregates of clay minerals with similar dimensions to dune sands (Bowler 1973).

Lunettes and sandier dunes are more abundant inland where they occur on the margins of many of the pans in the great panveld region of the Interior Continental Plateau. This region embraces the central and southern Kalahari, northern Cape, Bushmanland, western Orange Free State and southern Transvaal.

For details on lunettes elsewhere and their value for elucidating palaeo-environments and the geomorphic genesis of the playas themselves refer to Campbell (1968), Bowler (1971, 1973), Reeves (1972) and Mabbutt (1977).

C. Lagoon-shore dunes.

Low dune ridges and hummocks related to old shorelines, beaches, spit and swashbar deposits occur in many of the coastal lagoons. They are most conspicuous where they are wooded and examples can be seen at the southern end of Langebaan near Geelbek, in the north-east corner of Lake St Lucia at Sengwana, on the swashbar deposits separating the chain of Kosi Lakes, the lakes south of Delagoa Bay and the lagoons along the Limpopo Bight.

2.2 PATTERNS OF COASTAL SAND AND DUNE OCCURRENCE

2.2.1 The patterns

Coastal dunes tend to form where parallel and onshore winds strike beaches which are continually replenished with sand by waves or longshore currents.

Along the South African coastline the most obvious sand input is from fluvial sources, as well as continued erosion of sandy foreshores updrift of sand accumulating sectors. Sandbanks and bars of the surf zone also contribute sand as all compartments of the littoral active zone are involved in the exchange of sand.

Nodes of sand accumulation occur wherever the transporting medium of wind or water loses velocity and drops its load. Deceleration and consequent deposition occurs in response to a large number of interference factors, acting alone or in combination. These can be of continental dimensions involving major changes in coast trend, and/or increasing downwind and downdrift distance where slacker conditions prevail out of reach of the strongest wind and swell influences generated by the large scale interactions of the two major high and low pressure systems.

At an intermediate scale the combined geometry of headlands and bays alter swell direction and set up patterns of converging and diverging littoral wave formed currents contrary to the nett drift direction at the time. Changes in coast configuration locally modify wind direction and velocity due to the alternation of exposed windward and protected leeward aspects which affects sand transport. Major sand plumes are deposited at river mouths where an abrupt change in riverflow occurs at its junction with the sea. On the microscale sand transport and deposition on embryo dunes and sand ripple patterns are affected by surface roughness and the smallest obstacles.

The most striking large scale coast sand features are the zonally paired vast sand accumulation areas of the Namib and Mocambique on opposite sides of the subcontinent (Figure 6). Both these areas are coincident with the mean winter position of the Trade Wind high pressure anticyclone axis which marks the tropicward limit of the 27° to 35° S zone in which these Trades attain their highest velocity (see Section 3.2 Wind). This northernmost position of the Trade axis (Wellington 1955, Figure 38) is where a divergence in Trade Wind direction occurs and is also near the tropicward limits of the effective reach of strong south-westerly winds from east-travelling low pressure cyclonic polar frontal systems which interact with the anticyclones. The two major coast sand regions thus lie on the slacker downwind and downdrift sides of the coasts which southwards experience the strongest swell, wave and littoral drift.

In addition to the nett northward transport of sand on both coasts, a main supply of sand for the Namib Sand Sea is derived from the Orange River (Rogers 1977) or proto-Orange which in the past included the Malopo-Nossob catchment and, for the Mocambique coastal plain, from reworked shelf sands exposed by a lower sea level and the massive input of sediments from the series of 13 major sand bearing rivers which debauch on the plain from the Zambezi south to the Tugela. Prior to the Pleistocene phase of incision (Congo Cycle) related to the glacial drops in sea level, this series of

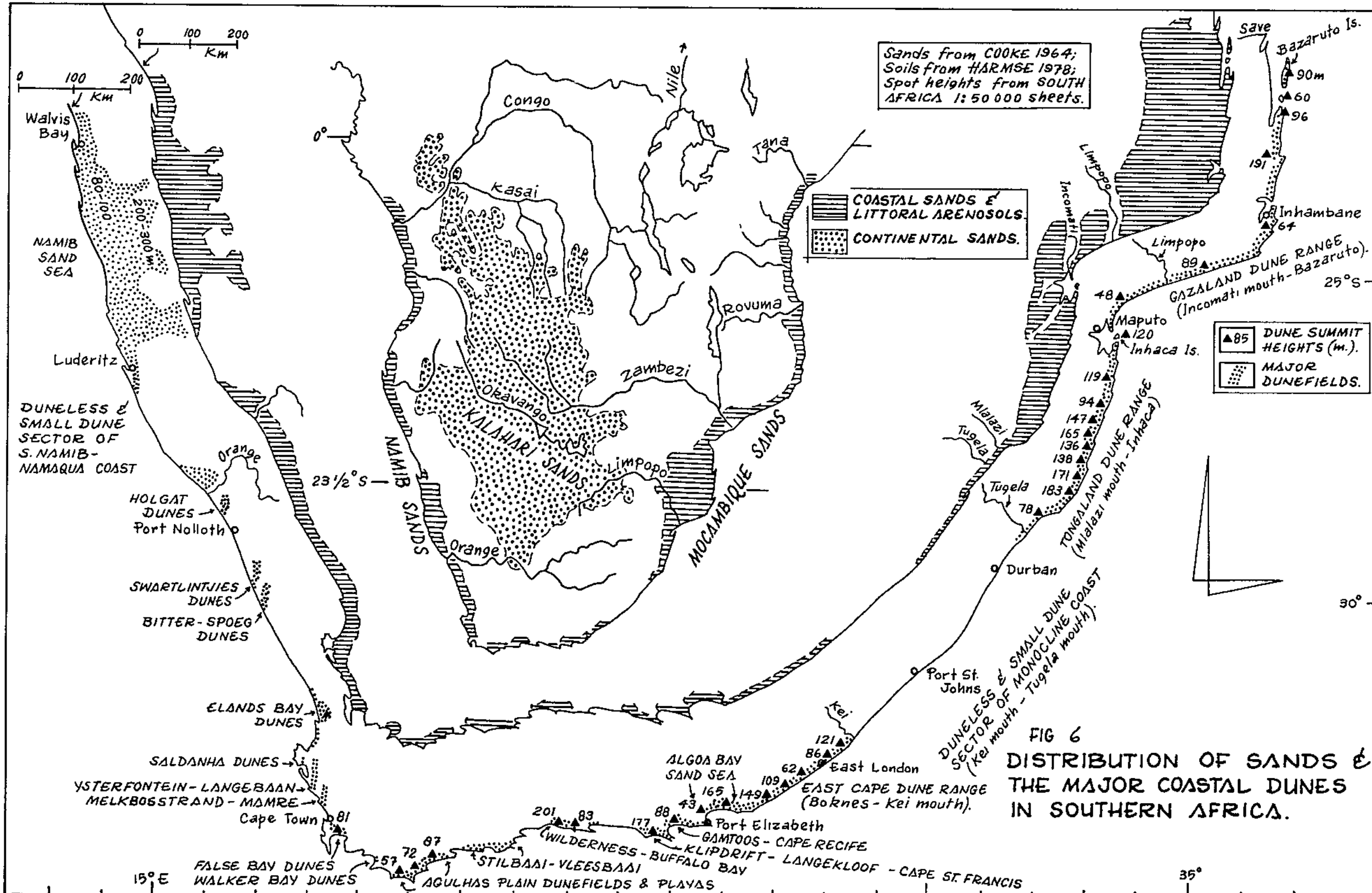


FIG 6

DISTRIBUTION OF SANDS & THE MAJOR COASTAL DUNES IN SOUTHERN AFRICA.

rivers formed a sediment apron (peripediment) of laterally coalescing or abutting giant alluvial fans on the coast plain below the oldland junction.

The Namib Sand Sea lies between latitudes 23° and 26° and the Mocambique Sands between 21° and 29° S. Though lying generally within the same latitudinal zone, the east coast occurrence extends further south in parallel with the slight asymmetry of the anticyclone axis which is related to the thermal asymmetry imposed by a tropical warm current there and a cold temperate current along the west coast (Figures 6, 9).

The patterns of sand accumulation on the mesoscale are best exemplified by the major sand accumulations immediately downdrift of river mouths, especially on the long curve of half-heart bays and against shorelines which bulge seaward (Figure 6).

Five major patterns of dune occurrence are exhibited along the subcontinent's coastline (Figure 6).

1. Extensive, high, bare dunes on the west coast, Trade Wind Desert of the Namib. These grade from high barchanoid dunes on the coast to linear dunes with sinuous crest in the centre and 200 to 300 m high stardunes on the inland margin (Barnard 1973; McKee 1977, 1982).

2. Bands of low vegetated hairpin dunes, some fields extending obliquely inland for more than 30 km, on the southern west coast and south-west coast between Table Bay and Langebaan.

3. Broad, high, vegetated, imbricate parabolic dunes and bare barchanoid dunes on the south coast.

4. Narrow, high cordon of forested, bipolar, parabolic dunes on the southern south-east coast between Boknes and Kei Mouth, and the east coast from Richards Bay to Bazaruto Island (21° S).

5. Small dune and duneless coasts in the following regions or sectors (Figure 6).

   a. Equatorwards from 15° 45' S on the west coast and 21° S on the east coast (ie northwards from Porto Alexandre 170 km north of the Kunene Mouth on the west coast, and north of Bazaruto Island on the east coast).

   b. Associated with monocline coasts between Elizabeth Bay (south of Luderitz) and Saldanha on the west coast, and between the Tugela and Kei Rivers on the south-east coast.

   c. On a local scale wherever cliffs and rocky coasts or estuaries occur.

2.2.2 Wind direction, coast shape and dune orientation

The marked feature of the wind regimes around the South African coast are the alternating sequences of high and low pressure systems which give rise to alternating, opposing winds, that blow obliquely parallel to the coast.

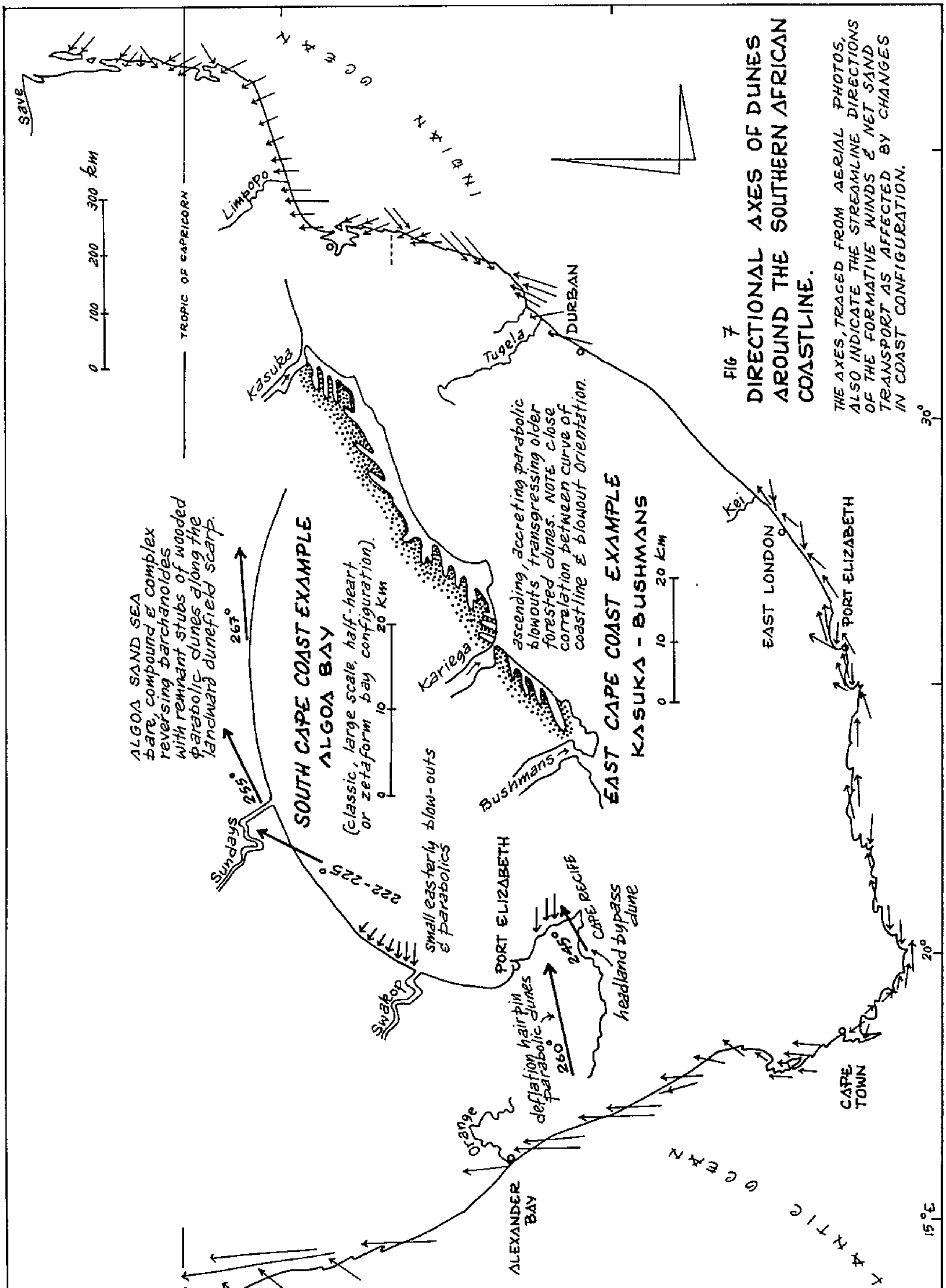


FIG 7
DIRECTIONAL AXES OF DUNES AROUND THE SOUTHERN AFRICAN COASTLINE.

THE AXES, TRACED FROM AERIAL PHOTOS, ALSO INDICATE THE STREAMLINE DIRECTIONS OF THE FORMATIVE WINDS & NET SAND TRANSPORT AS AFFECTED BY CHANGES IN COAST CONFIGURATION.

Generally the opposing winds are onshore or alongshore on west, south-west and south coasts. Along the eastern coasts the polar cyclonic south-west winds are offshore and the high pressure anticyclonic winds are onshore.

The predominant winds on the west coast are southerly (south-south-east to south-west) with a lesser north-westerly opposing wind developing from coastal lows. The predominant winds on the south-west coast are north-westerly and southerly (south-south-west to south-east), on the south coast they are south-westerly and easterly; north-easterly and south-westerly winds on the south-east coast, and on the east coast, easterly and southerly (Figure 7).

Three exceptions to these basic patterns occur. The first is on the central Namib Coast where south-westerly to westerly onshore winds prevail from Meob Bay (25° S), north to Swakopmund, where high, bare barchanoid dunes occur (Bremner 1977; McKee 1982). The second occurs south of Luderitz on the west coast, where the coincidence of anticyclonic and frontal to post-frontal winds from the south, reinforce each other to form unidirectional, migrating hairpin dunes more than 30 km in length. The third exception is on the north-east trending sectors of the east coast where the Trade Winds and polar frontal winds coincide from the same south-east quadrant and strike the coast at right angles. Here, massive parabolic blowouts and hairpin dunes have migrated landwards and filled in a linear barrier lagoon system at intervals, dividing it into a chain of separate lakes (Figure 5A).

Within the above generalizations concerning dune forming winds, the most important feature affecting the orientation of dunes and dune movement is the local configuration of the coast.

With changes in sea level the same winds would be modified by changes in coast trend and local configuration to blow from other angles. Many of the dune axes shown are those of the oldest backdunes and hence may relate to the shape of the coastline at a lower sea level (Figure 7).

2.2.3 Beach sand provinces and dune occurrence

Despite the changes in climate and sea level during the Cainozoic, coast dunes still show a close relationship to the geographical and physical variation of sandy beaches along the subcontinent's coastline.

Sand grain size of beach and river mouth sediments, which are the coast dune sand sources, will be an important parameter in the effective development of dunes. Four sand grain particle sizes are recognized (Monkhouse 1976): fine (0,02-0,2 mm), medium (0,2-0,5 mm), coarse (0,5-1,0 mm) and very coarse (1,0-2,0 mm). Beaches subject to winnowing of the fine sands by heavy wave action and strong onshore winds tend to have coarse sands and steep beaches, sheltered beaches tend to have finer sands and flatter beaches (Davies 1980). To correlate the physical and biotic characteristics of beaches with degree of direct wave influence an exposure rating system, with a maximum of 20, has been developed by McLachlan (1980a). On these parameters and their carbonate content five beach provinces are recognized for the South African coastline (McLachlan et al 1981).

1. South Mocambique-Tongaland: fine to medium sand; exposure rating approximately 14.

2. Cape St Lucia to the Transkei Border: coarse to very coarse sand; exposure rating approximately 17,5.

3. Transkei to East London: fine to medium sands; exposure rating approximately 13.

4. East London to False Bay: fine to medium sands; exposure rating 12-16.

5. Western coasts from Cape Peninsula north past the Orange River mouth to Bogenfels: medium to very coarse sands; exposure rating 13-18.

Generally high dune areas are associated with beaches containing fine to medium sand grain particles, and low or small dune areas with steeper coarse sand beaches. The coarse-grained beaches are associated with the two downwarped monoclinal coasts on the west and south-east where there is also direct input of coarse sediments from the nearby granite exposures.

The exception to this relationship is on the Transkei Coast, which forms part of the south-east coast monocline, where small dunes are associated with fine to medium grained beach sands and apparently a relatively low exposure rating to high energy waves (McLachlan et al 1981). Under present conditions where most soft coasts are eroding, the presence of fine sands in beaches will more likely be related to active erosion of foredunes and their reincorporation in beach sands and longshore drift.

2.2.4 Larger dunefields

The surface area dimensions of coastal sands are broadly outlined by the occurrence of the Cainozoic coast sediments of various kinds shown on geological maps and of littoral sands on soil maps (Figure 6).

The Namib Sand Sea of 34 000 km^2 (Barnard 1973) represents the largest area of bare dunefields on the subcontinent. In South Africa the 120 km^2 bare barchanoid dunefield area along the northern margin of Algoa Bay is the largest sand desert environment on the coast. These bare dunes are of sufficient antiquity to have allowed the evolution of several endemic animals (Callan 1964; McLachlan et al 1982). This and its desert-like features make it a unique ecosystem type in South Africa.

The Algoa Sand Sea and other large coast dunefields such as those at Stilbaai, Wilderness and St Francis are associated with the long curve of zetaform bays downdrift of river mouths that enter the bays, or with the littoral margin of coastal plains as at Agulhas, Tongaland and south Mocambique.

2.2.5 Highest dunes

The highest dunes of the subcontinent are the giant star dunes of the Namib Sand Sea, which rise to between 200 and 300 m in height (Barnard 1972). These bare, stationary dunes occur on the inland margin of the sand sea and the largest are associated with the deflation floors of dune-enclosed end points of two seasonal rivers, Tsondab and Sossus, which rise on the western Great Escarpment.

The highest vegetated coastal dunes, and also the highest dune in South Africa, is that above Groenvlei Lake at Wilderness, which rises to 201 m (Figure 6). Here the plant cover is mainly dune heath (Plates 32, 82). Other high dunes occur on the Cape south coast west of St Francis, and on the long curve of St Francis and Algoa Bays. These are all compound parabolic dune types and wind-rift dunes formed by strong westerly cyclonic winds.

A second area of high vegetated dunes, covered in forest, occurs on the southern end of the Mocambique Plain between Richards Bay and Inhaca Island. The highest are concentrated along the Lake St Lucia coast, and immediately south of the Umfolozi-St Lucia estuary where the highest forested dune is 83 m in height (Figure 6). All these are ascending bipolar parabolic dune types formed chiefly by strong north-east anticyclonic winds of the Trades in the St Lucia sector (Plates 79, 80, 109).

2.2.6 Smaller dunes

On a regional scale the pattern of distribution of small coast dunes is clearly divided into four areas, paired opposite each other on western and eastern coasts (Figures 4 and 6). As noted earlier the two southern small dune coasts are coincident with the west and south-east coast monoclines separated to the north by high dune coasts of the Trade Wind sand accumulation areas from the small dune coasts of the tropical and equatorial coasts.

The overall pattern is therefore high dune zone along the Cape south coast, succeeded by small or low dune zones paired on southern sectors of eastern and western coasts, followed in turn by paired high dune areas between the tropic and 28° 45' on the east coast and 26° 30' on the west coast, with a repeat of paired tropical to equatorial small or low dune zone on opposite coasts. On the west coast another large dune sector occurs on either side of the Kunene River mouth between Porto Alexandre (16° S) and Rocky Point (19° S). This does not have an equivalent on the opposite coast.

Monoclinal coasts are downbent continental margins resulting in a linear coastline with irregular edges formed by rocky sections alternating with bays usually formed at river mouths. On these coasts small dunes are confined mainly to river mouth and bayhead positions. Within the high dune zone of the Cape south coast are small dune systems, including hummock, blowout and barrier types, formed by easterly anticyclonic winds on the east-facing deeper curves of zetaform bays.

2.2.7 Roaring and squeaking sands

An amazing phenomenon sometimes encountered in bare dunefields is a sudden loud booming sound which breaks the silence then fades. The sound is so similar to that of a starting aircraft engine, or the brief roar of a lowflying aircraft that the innate response is to look upward. The sound is apparently made by the electrostatic discharges occurring when very dry sand of the leeward slip-face avalanches down the slope due to instability or disturbance (Holmes 1965).

As far as I am aware there are only two roaring dune areas on the coast. In South Africa confined to parts of the Algoa Sand Sea, and elsewhere on some of the seaward dunes of the Namib Desert such as those between Walvis Bay and Swakopmund.

A much commoner related phenomenon experienced on many sandy backshores is the squeaking sound produced when dry sand is walked on or kicked. It seems to be associated with the pure silica sand patches low in carbonate content and where silt influences are minimal. Such sands are characteristic of the south Mocambique and Tongaland coast.

2.3 OLDER DUNES AND CHANGES IN CLIMATE AND SEA LEVEL

2.3.1 Changes in climate and sea level

Older coast dunes comprising oxidized, leached and lithified sands occur inland to about 200 m above present sea level, and the lime cemented cores of drowned dune cordons occur to at least -110 m on the continental shelf (Anderson 1906; Du Toit 1922; Fair 1943; Barradas 1955, 1965a,b; Maud 1968; Ruddock 1968; Dingle 1971; Rogers 1971b; Schalke 1973; Davies 1971a,b 1973; Dingle and Scrutton 1974; Tankard 1976a; Tankard and Rogers 1978; Birch et al 1978; Birch 1980; Siesser and Dingle 1981; Birch (in press b)). From over 300 m above the present sea level about 10 million years ago the sea receded throughout the Pliocene to the Mid-Pleistocene mostly as a consequence of uplift and seaward tilting of the continental margins, and from climoeustatic causes from the Late Pleistocene to recent times (King 1972b; Hays and Pitman 1973; Truswell 1977).

The reworking and reshaping of coast sands and dunes left behind as a succession of shore sediments and exposed to terrestrial weathering and erosional processes took place through the contrasting alternations of glacial and interglacial conditions of the Late Pleistocene. The glacial advances over the last 500 000 years have exhibited regular pulses of 100 000 years duration with intervening short warm interglacial periods lasting for 10 000 years (Nicholson and Flohn 1980).

The Late Pleistocene alternations of marine regressions during glacials and transgressions during interglacials is outlined in Table 3. Dune cordons were probably formed along the shores of each stillstand pause in the overall phases of rising and especially of receding sea levels. At the height of the Würm Glacial 18 000 years ago the greater part of the shelf was exposed, for example a 130 km broad plain off Beira in the Bight of Sofala (Tinley 1971b), and the Agulhas Bank formed a 180 km broad, grass-covered, plain carrying herds of game (Klein 1972, 1980) and traversed by the meandering floodplain drainage of the south Cape rivers (Dingle and Rogers 1972). At this time cave-dwelling hunter-gatherers on the oldland margin subsisted entirely on land animals. From about 11 000 years ago however, the appearance of shellfish remains in the stratigraphic record preserved in the hunter-gatherers' middens showed that sea level had risen as a consequence of the increasing warmth of interglacial conditions and had submerged the shelf plains (Butzer and Helgren 1972).

The return of sea level close to the present coastline 10 000 years ago marks the beginning of the Holocene or Recent geological time. Since the return of sea level to near its present position between 6 000 and 4 000 years ago after the Flandrian Transgression (Table 3) there has been a slow world-wide rise in sea level of 10 cm per century, though from 1860 there has been an equatorward shift in the pressure belts indicating an impending cooler period of climatic activity (Tyson 1977). Refer to summary in Table 3 and to Newell (1961); King CAM (1962); Butzer and Helgren (1972); Tankard (1976a); Tankard and Rogers (1978); Evans (1979); Siesser and Dingle (1981).

The largest dunefields were formed during glacial times when high wind velocity regimes blasted across massive deposits of exposed shelf sediments. These dunefields were subsequently largely destroyed by rising sea level as the Ice Age waned and warm interglacial conditions with slacker wind regimes prevailed and the hardest cemented cores remained underwater as sublittoral ridges. Some of the sand would have been swept up onto beaches recombining with wave eroded and remobilized older dune sands and blown against the remaining landward dunes.

The present day dune sands of the coast landward of the littoral cordon are thus the weathered, and often reworked and reshaped, sands first deposited by a receding sea in the Mio-Pliocene. In contrast, most of the present littoral dune cordons or core remnants must originate from Eem and Würm or later times, their seaward fronts modified by truncation to about five metres above present sea level by the Flandrian Transgression. Modern beige or white (in Cape quartzite areas) sands are largely composed of silica and grains of mollusc shell fragments which have been banked up against the older oxidized sands, or have remantled them by accreting parabolic blowouts. According to Butzer and Helgren (1972) contemporary dune cordons are considered to be younger than 16 000 years, however this, in my opinion, may only apply to cordons in a frontal position. The presence of landward, mid dune to backdune cordons with greater pedological development and the presence of similar remnant dunes in abrupt junction with modern small foredunes and beach sands close to the foreshore indicates that many cordons may have a greater antiquity.

Except where otherwise noted the following scenario on glacial and interglacial conditions in Africa is abstracted chiefly from Nicholson and Flohn (1980) and augmented with data from Cooke (1964), van Zinderen Bakker and Butzer (1973), Street and Grove (1976), van Zinderen Bakker (1976b, 1978), Tyson (1977), Tankard and Rogers (1978) and Deacon (1982). Nicholson and Flohn's (1980) reconstruction shows a parallel shift of climatic and environmental sequences occurring nearly synchronously on both sides of the equator. Hence Sahara environmental changes are included to either backup tentative conclusions from findings in the southern zones, or because little has been said about the moist and wet phases in the interior catchment regions of the main sediment-carrying rivers which traverse southern Africa. Though the zonal shifts of the climatic belts towards and away from the equatorial zone were broadly coeval, local tectonic and orographic factors were of high significance in modifying such changes in different regions (Truswell 1977). These shifts may however be due more to the expansion or contraction of the pressure systems in response to changing intensity, rather than actual changes of their geographical positions (Deacon et al 1983).

2.3.2 Glacial Ice Age environmental conditions

During hypothermal conditions of the Last Glacial for example, 20 000 to 13 000 years ago the drop in the primary base level, the sea, was to about -130 m resulting in incision (rejuvenation) and stripping out of most, if not all, of the sediments which had been trapped by drowning infill of the lower river courses during the previous Eem Transgression. This sediment has accumulated in the deep valleys and river mouths on the oldland margins cut during the Riss Glacial regression. Not only were broad shelf plains exposed but massive amounts of sediments were spread as piedmont fan conglomerates and sands along the footslopes of the oldland.

Concomitant with the changes in coastal sediment availability, the temperate westerly belt and the subtropical high pressure Trade Zone were shifted equatorwards, resulting in the narrowing of the climatic belts with intensified, accelerated, circulation interactions. This brought Roaring Forties conditions closer to the southern coasts of the subcontinent, depressed sea surface temperatures, increased upwelling, and extended the cold Benguela and Canary Currents and the associated coastal deserts towards the Gulf of Guinea. The Namib Desert, for example, expanded north to near Cape Lopez (van Zinderen Bakker 1978).

The stronger high pressure easterly winds will have extended the associated inshore upwelling phenomenon from the south-east coast (Heydorn and Tinley 1980) up the east coast to the tropic near Inhambane, and strengthened the Agulhas Return Current activity. Together these features lowered the surface water temperature of the south Mocambique Channel by 5° C (van Zinderen Bakker 1976b) and must have brought dry summer conditions to this coast sector as cold inshore surface waters inhibit rain development.

Simultaneously there was a greatly expanded area of cyclonic winter rainfall over the Sahara to south of the tropic (about 20° N latitude), and between Bushmanland across the southern tropic to about 20° S from the westerlies. At this time temperate forest trees such as yellowwood Podocarpus sp expanded their range along the western Great Escarpment into Namaqualand. High lake levels in Makarikari and increased springs discharge in the southern Kalahari which occurred during the last glacial, indicate moister conditions from cyclonic winter rains.

In contrast, the northern Kalahari was desert and semidesert to across the Congo River as intense and widespread aridity prevailed in intertropical Africa during the last glacial due to intensification of the Trade Winds and the prevalence of their dry subsiding air masses (Grove 1969; Street and Grove 1976; Sarnthein 1978). At this time an arid corridor linked north-east and south-west Africa (van Zinderen Bakker 1978). South of Bushmanland, and including the shelf plains formed by the exposure of the Agulhas Bank, cold dry Patagonia-like conditions occurred with higher rainfall and periglacial conditions confined to the Cape Fold ranges and along the eastern Great Escarpment to the highlands of east Africa where montane glaciers reached their greatest extent (van Zinderen Bakker 1978).

The equatorial rain forest area was dismembered and shrank to remnant patches along the meteorological equator marked by the position of the intertropical convergence zone (ITCZ) then confined to north of the geographical equator in the east Congo and coast of west Africa. The spread of evergreen Afrotemperate forest to the Cape would seem only to have been able to occur under median conditions, similar to the present, between glacial and interglacial extremes (van Zinderen Bakker 1976b). Tyson (1977) points out that the climatic record shows that cool periods enhance climatic instability with alternations of extremes of drought and flood and extremely hot summers followed by excessively cold winters.

2.3.3 Warm interglacial environmental conditions

In late glacial times some 13 000 years ago as Ice Age conditions waned and contracted polewards, warming, hyperthermic, interglacial conditions expanded outwards from the equatorial region towards the temperate zones and reversed the sequence of changes which occurred during the glacial period. Warming and melting of the ice sheets resulted in a rising sea level which resubmerged the continental shelf and drowned the coastlands causing a repetition of sediment infilling of all river mouths.

With the broadening of the pressure belts and the poleward shift of the westerlies and Trade Wind zones, slack pressure conditions prevailed with median to low wind velocities. The cold currents along the west coasts retracted from the equatorial zone, the warm Angola Current expanded southwards to Namaqualand on the west coast, upwelling was minimal and rising sea surface temperatures were increasingly conducive to rain genesis.

Hyperthermal conditions reached a peak between 12 000 and 8 500 years ago when pluvial conditions returned to the intertropical regions with the ITCZ shifting seasonally to opposite tropics. Rain forest expanded and coalesced between west Africa and the eastern Congo, savannas expanded towards the temperate zones which were desert to semidesert drier than today's conditions. Highest lake levels in the intertropical zone occurred at this time, forming a mega-Chad and mega-Rudolf. A summer rain spill-over occurred into the Sahara from the equatorial zone, leaving the Sahara north of the tropic, including the Marghreb, more arid than today as well as the Horn of Africa and South Africa south of the tropic.

Minor glacial conditions recurred between 8 000 and 6 500 years ago with a partial return of the patterns or conditions noted above, involving strong wind conditions on the South African coasts. Warm interglacial conditions returned between 6 500 and 4 000 years ago resulting in a second intertropical pluvial of lesser intensity with an overlap of summer tropical rains and winter temperate rains - a bimodal rain belt near each tropic.

TABLE 3. Outline of the geomorphic genesis of east and south-east coasts since the End-Miocene (Maud 1982). Compare with the sequence of palaeoenvironmental events interpreted for the south (Butzer and Helgren 1972, Tables 1 and 8) south-west and west coasts (Tankard and Rogers 1978, Table 3)

Years before present BP (approx)		Relative Sea Level Movement	Geomorphic Events
	6 000	Regression	Regression to present sea level, dune formation, soil formation.
Recent or Holocene	9 000 10 000	Transgression (Flandrian Interglacial)	Dune calcarenite and dune formation, 4,5 m beach, river terraces, formation of most soils of region.
	18 000	Regression (Würm Glacial)	Regression to approx 100 m below present sea level, erosion and deposition of extensive colluvium.
	100 000	Transgression (Eem Interglacial)	Dune calcarenite formation, red weathering 18, 12 and 8 m beaches, river terraces.
Late Pleistocene	125 000	Regression (Riss Glacial)	Regression to approx 100 m below present sea level, deposition of Port Durnford formation.
		Regression	Erosion and formation of Pleistocene valley erosion cycles and 70 m, 45 m and 33 m beaches.
		Regression	Erosion and formation of Late Cenozoic 2 erosion-surface (post-African planation 11) and 115 m beaches.
Earliest Pleistocene	2 million		Uplift and tilting.
		Stillstand	Erosion and formation of Late Cenozoic 1 erosion-surface (post-African planation 1) and 170 m beach with laterite.
Mid to Upper Pliocene	6 million	Regression	Uplift and tilting.
Mio-Pliocene	10 million	Transgression	Deposition of Upper Miocene and Pliocene sediments up to $\pm$ 300 m above present sea level. (To base of Lebombo in Tongaland and to near Zimbabwe frontier in Gazaland).

It was at this time that the Saharan Wet Phase or lacustrine period occurred with vast wetlands linked by gallery "forests" harbouring hippopotamus, crocodile, fish and subsistence fishing cultures - environments probably similar to the Chad in its Sahel environment or of the present Okavango Delta in a southern Kalahari setting (Grove and Pullan 1963; Monod 1963, 1973). As the Sahara began to dry out after 4 500 BP Neolithic pastoralists became the dominant culture in the region around 3 000 years ago.

At this time the northern margin of north Africa, the Horn of Africa and in South Africa from south of about the 20° S latitude to the Karoo, hotter and drier desert or semidesert conditions than today developed, as evinced by the hiatus in the Stone Age occupation of the interior of this zone, for the period 9 500 to 4 600 years ago (Deacon 1974). Warmer and wetter conditions than present however occurred on the temperate margins in the south and south-west Cape.

The ripple-like succession of environmental changes shifting or expanding belts towards the equator in glacial times, and reversed towards the temperate zone during the interglacials, indicates that desert conditions did not occur at the same time across the whole of the interior Kalahari region between the Congo and Orange Rivers. The rivers which rise within the tropics such as the Congo, Cuanza, Kunene and Zambezi likely contributed minimal sandy sediments to the coast during glacial times and the opposite during the interglacial pluvials. The reverse of the temperate zone and subtropical rivers which must have made their major sediment contributions during the glacials.

The rivers rising within 5° on either side of the tropic however, such as the Limpopo and Orange, possibly contributed high sediment transfer from the interior to the coast at both extremes due to the overlap of glacial and interglacial wetter conditions than present in this belt.

The proto-Orange, consisting of its present drainage plus the south Kalahari drainage from the combined Auob-Nossob-Malopo, must have provided massive sand loads to feed the Namib Sand Sea on the west coast. A proto-Limpopo composed of the Kunene-Okavango-Kwando-Upper Zambezi (possibly including a Machill-Upper Kafue link) (Bond 1963) was responsible for transporting the fine Kalahari-like sands onto the Gazaland bulge of the Mocambique Coastal Plain prior to the Plio-Pleistocene upwarping, ponding off the interior drainage and its subsequent river capture by headward incision of the Middle Zambezi by the Congo Cycle of erosion during the Pleistocene (King 1962). The eastern coast rivers between the Limpopo and the Tugela all may have been involved in a double peak of sand input to the east coast.

2.3.4 Implications for dune dynamics

A. During glacial periods.

1. Strong wind velocity regimes of both westerlies and easterlies.

2. Colder drier conditions. Cold sea surface temperatures inhibit rain-forming processes, but orographic rainfall probably high.

3. Greatly expanded area and volume of sediments for aeolian transport exposed on the continental shelf and augmented by massive input of fluvial sediments to the littoral from downcutting erosion of river courses in response to the lowered base level, and stripping out of all sediments trapped by drowning during the Eem Transgression. This applies mainly to rivers south of the tropic, the intertropical drainage would have been mainly seasonal or episodic in flow during a glacial.

4. Stronger longshore sediment transport, and greater nett equatorward drift on west and eastern coasts.

5. Major dune building period in size and extent.

B. During interglacials.

1. Relatively feeble cyclonic and anticyclonic flows. Westerlies only reach edge of south Cape coast. Prevalence of easterly winds of median to low force.

2. Submerged shelf and drowned coastline trapping terrestrial sediments as infill to river mouths. Decreased sand input to the littoral active zone.

3. Shelf dunefields destroyed or submerged, and truncated as sea level rises. Landward backdune remnants of once vast dunefields become foredunes and a new littoral cordon is formed by the deposition of new sand banked against or superposed over the older dunes.

4. High river flow and sediment transport by tropical rivers which form laterally coalescing deltaic and fan deposits at the coast as on the Mocambique Coastal Plain between the Zambezi and Mlalazi Rivers. Low seasonal river flow and low sediment volume carried by temperate rivers.

C. Present conditions.

Clearly dune formation has been an ongoing process over the ages with greater or lesser phases of activity and quiescence over the long, medium and short term. Although new parabolic blowouts are formed under today's wind regime, their dimensions are much smaller than the older parabolics they are superposing. When protected from disturbance, these blowouts generally self-stabilize over a 20 to 30 year period as shown by a comparative airphotograph analysis.

The dimensions of the bare linear dunes and giant star dunes of the Namib are reckoned to have been formed by the strong wind regime of the Last Glacial, as it is doubtful that today's winds could have established the major dune patterns of the Namib Sand Sea.

On vegetated coast dunes there is no appreciable migration or growth taking place. Most of the changes are from wind scour destruction of plant cover damaged by undercutting from storm seas and eroding beaches, or secondary factors from human activities resulting in the conversion of parabolic dune types to bare transverse types and their expansion at the expense of wooded dunes. Modification of dune summits by wind and the adjustment of oversteep slopes by gully erosion from rain and gravity slides are the other changes wrought by present-day conditions.

2.3.5 Oxidized and lithified dunes

Transgressive seas reached furthest inland on coastal plains and had their narrowest spread on steep forelands. Similarly during regressive phases the largest exposures occurred on broad continental shelf plains and the least along narrow and steep shelves. For the same rise or drop in sea level, erosional and depositional sequences are more widely spaced on plains and closely packed on steep coasts. The first situation is best exemplified by the wide spread of older dunes on the Mocambique Coastal Plain where conspicuous dune lines parallel to the coast occur to 150 km inland, and the latter by the close, tight sequence of six generations of aeolianites identified on the south Cape coast with ages from 60 000 years to Recent (Butzer and Helgren 1972).

The largest area of older dunes occurs in the Gazaland region of the Mocambique Coastal Plain. Here dune sands, reworked and augmented by fluvial fan processes as the sea receded from its Mio-Pliocene 300 m high level, overlie massive calcretes topped by ferricretes and occur to about 400 km inland. The second most extensive area of red dune sands occurs along the inland half of the Namib Sand Sea. These sands are apparently derived in situ from weathering of much older aeolian sandstone of Pliocene (McKee 1982) or earlier age. This silicified desert sandstone is over 200 m in depth.

Large areas of older dunes occur landwards of the present shoreline, along the west coast between the Orange River and False Bay, and extend in parts to 30 km inland where they lie between the 200 and 300 m contours. Many of these sands, like those in Mocambique, are probably a mixture of fan sands and littoral sands deposited along the piedmont zone of the Great Escarpment and subsequently reworked by wind. In this region the largest area of red sands occurs on eitherside of the Bitter River where they overlie calcretes (from Brak River to north of 30° 45' S).

Extensive areas of older dunes, many of them perched above cliffed aeolianites, also occur at Agulhas, Stilbaai, Wilderness, between Tsitsikamma River and Slangbaai, and on the northern margins of St Francis and Algoa Bays. Where a rising sea level met soft sections in the older dunefields, left behind by the previous glacial regressions, direct access of sand was maintained from the beach onto the older dunes. Where it met lithified dunes, cliffs were cut resulting in perched dunefields severed from their beach-sand source area.

The older unconsolidated dune sands comprise two main types. Orange to red sands enriched by iron-aluminium oxides, referred to on the south-east coast as Berea-type sands (King 1967), and pallid siliceous sands of a greyish-white to beige colour. The largest area of these dystrophic sands occurs within 50 km of the coast on the Mocambique Plain and overlies Port Durnford Beds of Middle Pleistocene Age from which they are derived (Maud 1968). The red and grey sands are both aeolian in origin (Maud 1968), their colour due to the influence of their topo-catenal position on post-depositional weathering and eluviation processes, and there is no evidence that they are of different ages (Rhodes 1968).

Despite the fact that degree of oxidation and lithification is apparently not a valid means of ageing dunes (Pye 1981), younger dune cordons and superposing mobile sands are generally the same colour as the beach sands from which they originate; white from Cape System quartzites on the south-west coast and beige elsewhere. Older dune cordons are generally orange to red in colour (Price 1962; Norris 1969). The increasing free iron oxide content derived from the oxidation weathering process imparts an increasing aggregate stability to the sands. Thus with age, dunes become more compact, requiring higher wind velocities to move them. This has important implications in reconstructing the inferred effective formative winds of the past with those of today.

The Berea-type lateritic clayey sand (Maud 1965; McCarthy 1967; Beater 1970; King 1972b) and their podzolized counterparts in the south Cape (Butzer and Helgren 1972) are the weathered remains of Plio-Pleistocene dunes (Plate 53). Due to the differential weathering and mobility of base-salts and the iron-aluminium oxides in moist and arid environments, either decalcification with deep weathering and kaolinization takes place, or lime cementation of the dune core occurs with or without the later development of an overlying iron hardpan. The former is common on moist tropical and subtropical coasts as best exemplified at Richards Bay, and the latter is typical of the drier coasts or those with strong seasonal contrasts in moisture regimes. These processes have far reaching influences on the subsequent geomorphic development of coast configuration, coastforms and dune and sandplain landscapes.

In deep weathered dunes, lateral underground pipe drainage occurs in or at the contact of the kaolin pallid zone resulting in massive slumping and the development of ravine dongas or amphitheatre-shaped erosion cirques (Buckle 1978). The best examples of this erosion form is in the Richards Bay area (Figure 32; Plates 121-126). Where hardpan horizons develop in dune sands they result in high water-table conditions, and where exposed by incision give rise to a mesaform or stepped landscape as in the Mocambique sector of the Limpopo Valley.

Dunes become cemented by downward percolation of soil water containing dissolved calcium carbonate derived from weathered shell fragments. There is great variation in the degree of cementation from crumbly or friable sand concretions through lime sandstone to crystalline silicified calcretes with a quartzitic appearance. Degree of lithification depends on age, the amount of wetting and drying, and also apparently on exposure where a cementation-front is associated with spray wetting (Marker 1976).

Lithified dunes are identified by their characteristic current or cross-bedding which is fossilized by cementation (Plates 42, 43). In South Africa these consolidated dunes are commonly referred to as dune rock, but are also known as aeolianites, dune sandstone, dune limestones or lime-cemented dunes, coast sandstone or aeolian calcarenites (Bosazza 1956, 1957; De Figuerido 1961; Barradas 1965a,b; Mountain 1966; Maud 1968; Ruddock 1968; Moura 1969; Butzer and Helgren 1972; King 1972b; Siesser 1972a; Coetzee 1975a,b; Hobday 1976; Marker 1976; Birch et al 1978).

Dune rock is distributed at intervals along the subcontinent's coastline from Saldanha Bay south to False Bay, eastwards along the south coast and northwards up the eastern coasts. As far as I am aware, dune rock is absent from the west coast north of Saldanha to the Kunene but reappears on the south Angola coast (Soares de Carvalho 1961). There are two major breaks in the distribution of dune rock up the eastern coasts and they appear to be rare to absent in east Africa where exposures of fossil coral platforms prevail. The first major disjunction of dune rock on eastern coasts is along the monocline crest sector of the south-east coast from north of East London to south of Durban. The second disjunction onshore is made by the Bight of Sofala where the last of the southern dune rock occurrences terminates on Bazaruto Island. Small occurrences reappear nearly 1 000 km to the north near Mocambique Island and Nacala (Moura 1969) where they overlie uplifted, fossil fringing coral platforms which form cliffs three to eight metres in height (Tinley 1971b). The cemented cores of dune cordons from the Last Glacial occur underwater to the edge of the Sofala Shelf in this interval. If exposed, this would form a nearly continuous littoral dune cordon, interrupted by deltas, between Bazaruto and the line of Primeiro and Segundo Islands off Pemba.

The largest, most extensive and massive occurrences of aeolianites occur on the south coast between Arniston and Gouritz Mouth, in the Wilderness Lakes coast sector and again at Woody Cape in Algoa Bay. The curved axes of the onshore nested parabolic dunes in the Wilderness area are continued offshore by the submerged cores of aeolianite ridges truncated by the Flandrian to Recent rise in sea level (Tyson 1971). The larger submerged cordons lie at the -45 m and -35 m isobaths (Birch et al 1978). In the south Cape massive marine calcarenites are overlain by cross-bedded aeolian calcarenites in which the predominant cement is sparry or 'drusy' calcite (Siesser 1972a), and some of these are exposed in clifflines 30-80 m high with sea caves and stalactites (Heydorn and Tinley 1980).

On the southern part of the Mocambique Coastal Plain between Bazaruto and St Lucia, drowned or truncated dune rock forms offshore reefs and the points of half-heart bays where they usually overlie beach rock onshore. Fossil submarine dune rock points and half-heart bay-forms from lower sea level shores can be identified on maps of the south-east coast shelf figured in McCarthy (1967, 1969) and Birch (in press a, b) for example. The relict and recent beach rock platforms often associated with dune rock occurrences do not have a parallel distribution but tend to be confined to warmer coasts (Davies 1980). The beach rock occurrences in South Africa date to nearly 26 000 years in age and have poor correspondence to surrounding littoral sands, whereas those on the Mocambique Coast are more recent of Holocene age and bear a close resemblance in composition to the adjacent sand (Siesser 1974).

The headlands, cliffs and points formed by aeolianites represent the remnant fringe of originally much greater expanses of aeolianites submerged or destroyed by transgressive seas. Their formation and that of beach rock developed in response to phases of dropping sea level (Siesser 1972a, 1974; Birch et al 1978; Birch in press a, b). C14 dates for dune rock on the south Mocambique Coast five metres above sea level gave ages of 2 000 to 4 000 years BP (Barradas 1965a), and the fossil human footprints in dune rock on the Nahoon Point foreshore at East London date close to 30 000 years BP (Mountain 1966).

Dune rock on the foreshore is subject to littoral karst weathering from rain solution and sea spray, forming masses of sharp pinnacles and jagged ridges pitted by honeycomb weathering with intervening potholes and small pools (Plates 44, 45). This jagged supralittoral zone is fronted by a smooth wave-cut platform with pools in the mesolittoral. The junction of the jagged and smooth dune rock erosion stages is typically marked by an undercut notch and visor (Plate 47). Exposed coral rock weathers in a similar manner to form coral rag.

Dune rock is also eroded into stacks, arches, caverns and caves, solution pipes and sink-holes with geyser fountains formed by the uprush of waves from caverns, stalactites and root concretions (Coetzee 1975a,b; Plates 46, 48-51). Larger karst features such as dolines and poljes and dry flat-floored valleys occur in the Stilbaai area as exemplified by Rietvlei, and in the weathered aeolian and marine calcarenites of the Alexandria District immediately north of the Algoa Sand Sea.

The internal geometry of dune rock is used for palaeographic reconstruction (Goldsmith 1971, 1973) but care has to be taken not to confuse locally modified formative wind directions affected by changes in coast configuration with a rising or dropping sea level, from the actual wind direction overhead.

Dune lithification thus has far reaching influences on the evolution of coastal plains, coast configuration and coast forms, affecting wave refraction and sediment transfer and damping erosive processes. Where cliffs and headland or truncated cordons are intersected by the present coastline these preserve a "greater degree of Pleistocene inheritance and perpetuate coastal alignments from previous phases of the Pleistocene" (Davies 1980).

PLATE 1. The true barchan dune migrating (to the left) across desert pavement on the Namib Desert Coast north of the Unjab River mouth (1967).

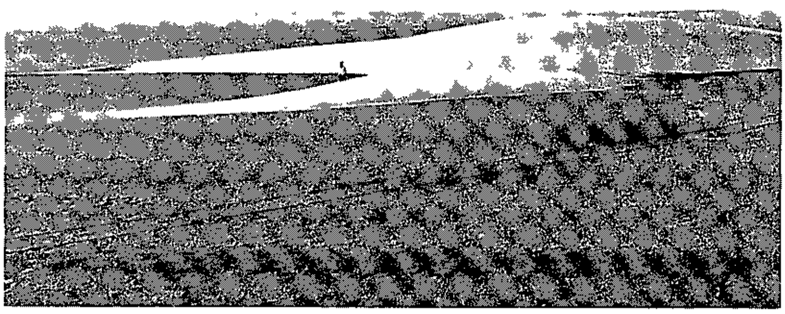


PLATE 2. Barchan dune elongated asymmetrically by strong onshore winds blowing obliquely to the prevailing wind from the right. Area same as above.

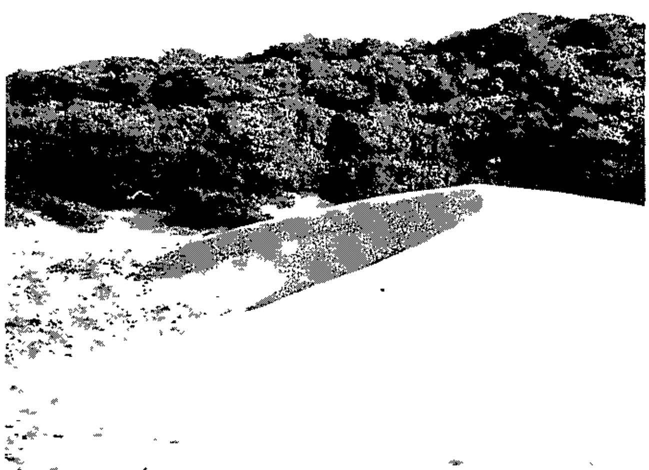


PLATE 3. A barchan dune in a moist setting on the south-east coast near the Nahoon River mouth (av. rainfall 800 mm). Foredune zone of reversing buttress barchanoids.

PLATE 4. Crescentic, sand ripple, micro-dune forms in plan, with the wind blowing from left to right. Illustrating change in dune type as a function of sand abundance and its potential transport. This sequence of barchan, barchanoid and transverse dunes is found in the source area, and its reverse at the dissipatory end of dunefields as shown here.

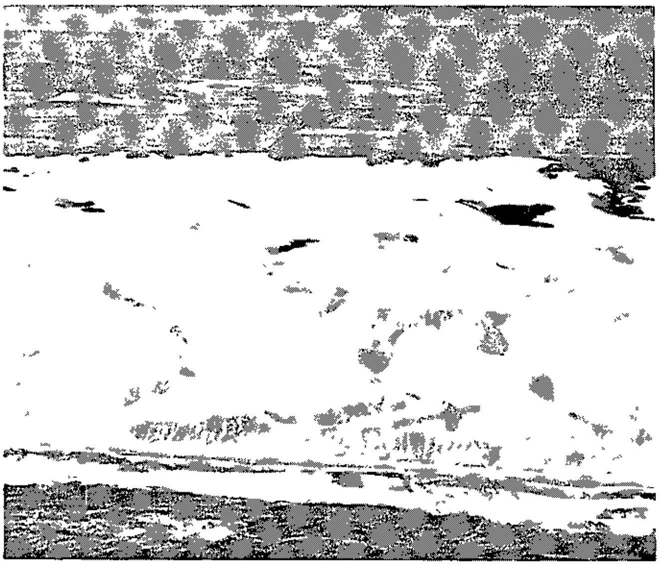


PLATE 5. Part of the Algoa Sand Sea with compound and complex reversing barchanoid dunes. View NNW across the Alexandria karstland towards the Suurberg Range with Grahamstown on the skyline. (photo: A E F Heydorn 1979).

PLATE 6. Reversing barchanoid dunes on the west coast at Elands Bay, downdrift (north) of the Verlorevlei Mouth. In plan all dune plinths in this area are curved away from the predominant southerly winds.

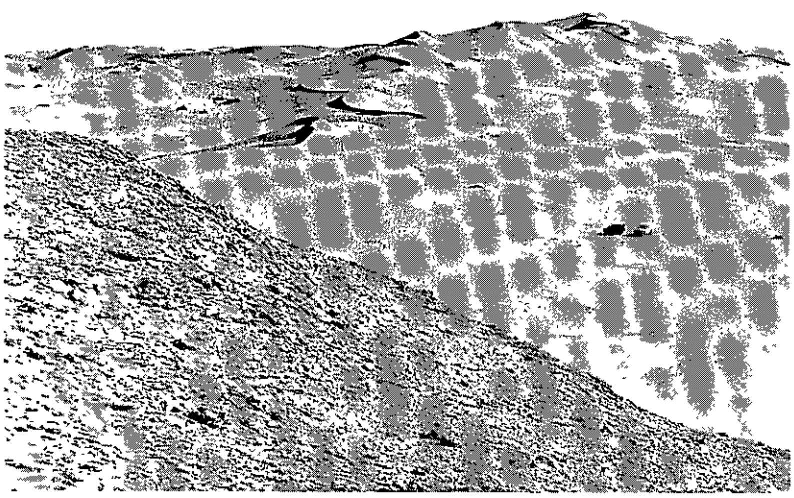


PLATE 7. Linear or longitudinal dunes of the Namib Sand Sea with sinuous reversing crestline. In the foreground fossil alluvial fan debris with Early to Middle Stone Age implements cemented into the calcretized surface. South of the lower Kuiseb River (dark line of riverine trees upper right side).

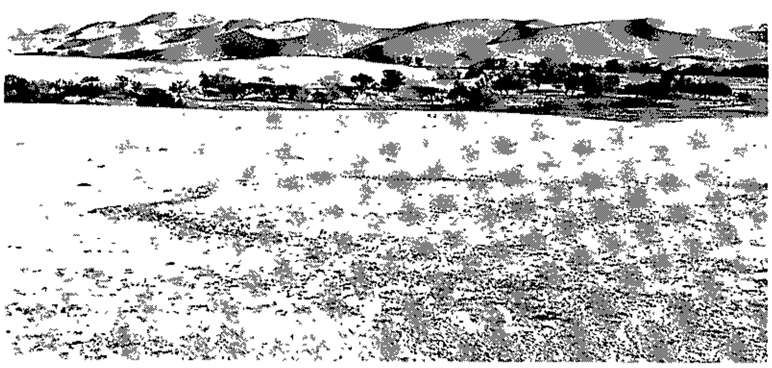


PLATE 8. Terminal area of Namib Sand Sea against the course of the lower Kuiseb River. Barchanoid crested linear dunes with leading slopes avalanching into the river. The trees are chiefly Arid Savanna camelthorn *Acacia erioloba* mixed with *Ficus sycomorus*, *Euclea pseudebenus*, *Tamarix usneoides*. Plains of gravel desert pavement over powdery clay in foreground.

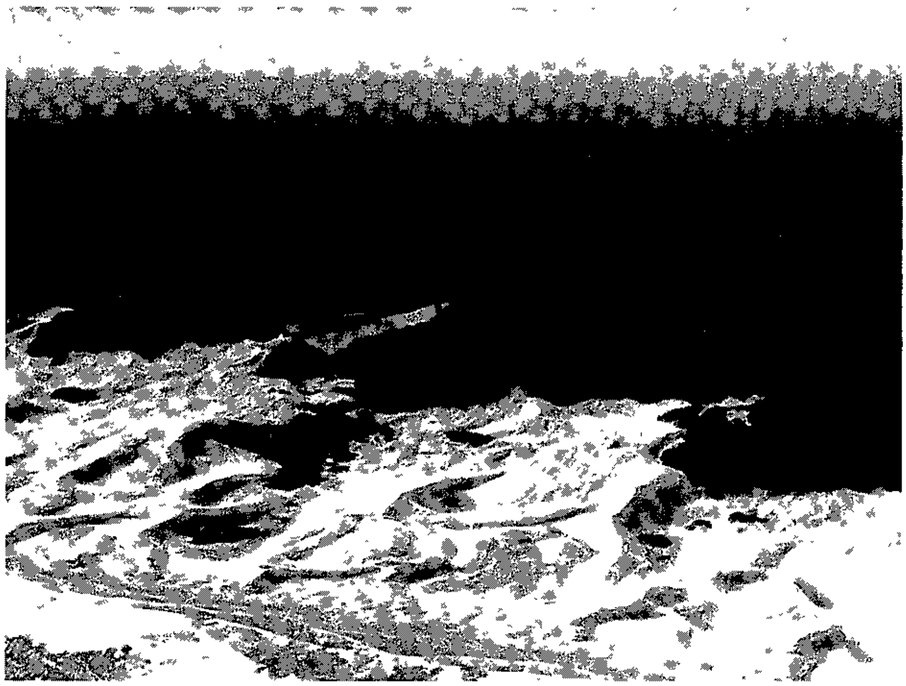


PLATE 9. Buttress reversing barchanoid dunes banked against forested parabolic dunes 7 km south of Port Alfred on south-east coast. Note star and transverse dunes, slacks, dune lake (river mouth sealed off by dunes), relict and initial bush clumps. (photo: A E F Heydorn 1979).

PLATE 10. Buttress barchanoid frontal dune between Nahoon and Quinera River mouths, south-east coast. Note two drift line levels with embryo dunes forming along the upper berm.

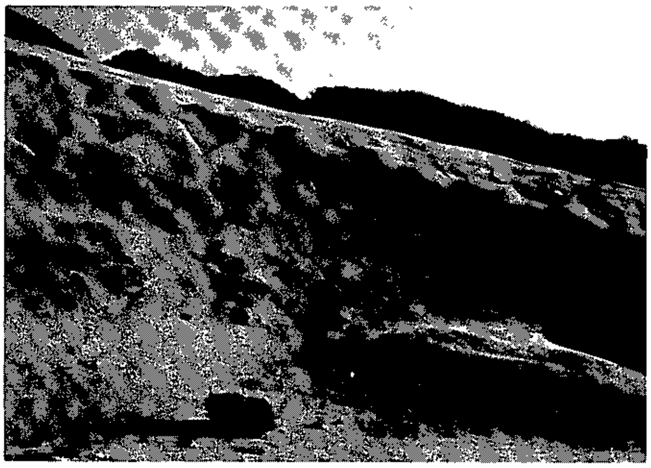


PLATE 11. Close up of buttress dune showing crest reversal with change of wind and exposure of rain moistened core. Outcrop of rubble calcrete from old lime cemented dune core at lower right.

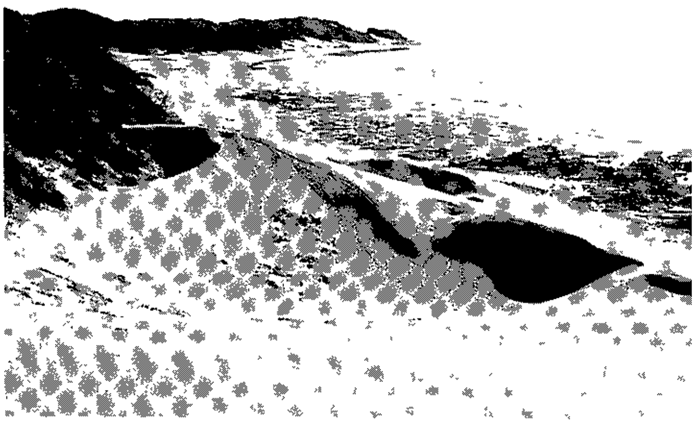


PLATE 12. Star-dune form in buttress dunes at junction of crestlines with rim of scour hollow at retreating edge of dune thicket. Note ephemeral dune pioneer plants colonizing dune plinth.

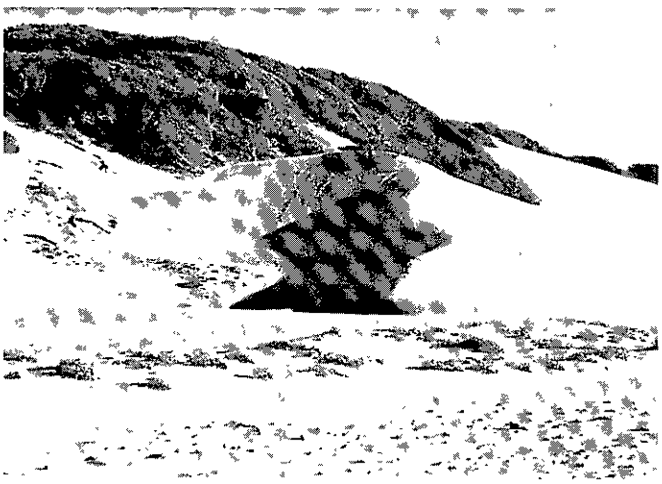


PLATE 13. Buttress dune with exposures of red calcretized dune core at left. Embryo dunes formed by dune cabbage, and in immediate foreground masses of redbait washed up by heavy seas, are in the process of being buried by sand along the upper driftline limit.

PLATE 14. Embryo dunes formed by the strand plant Arctotheca populifolia (dune cabbage) on the highest berm above the driftline. Backbeach sector between Nahoon and Quinera Rivers on the south-east coast.

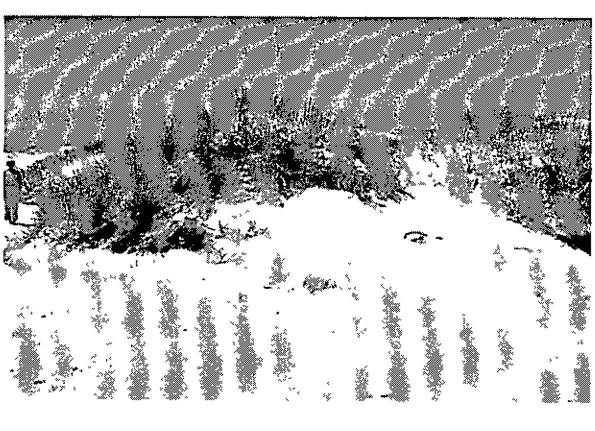


PLATE 15. Hummock dunes on the upper backbeach formed by the temperate grass Ammophila arenaria (marram) on the south-west coast near Cape Hangklip.

PLATE 16. Hummock dunes of the strand plant zone formed mainly by seawheat Agropyron distichum and an endemic legume creeper Psoralea repens in the bay between Cape St Francis and Seal Point, south coast.

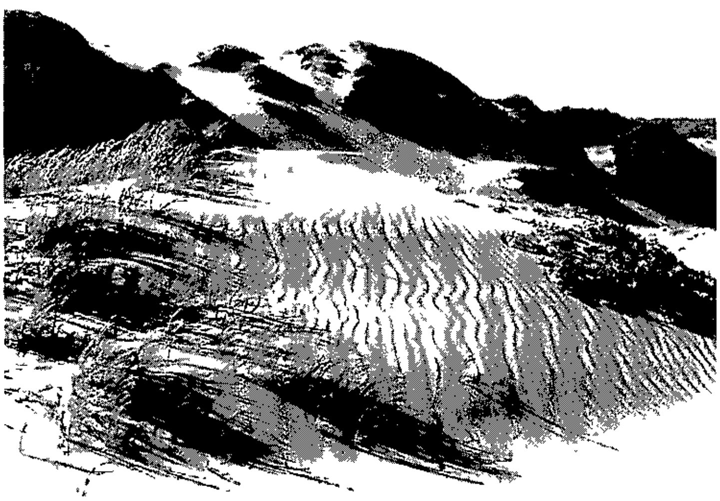


PLATE 17. Formation of hummock dune by seawheat and dune cabbage in the foreground. Fragmentation of scrub-thicket cover on second line of dune hummocks now eroding.

PLATE 18. Steeply rounded hummock dunes formed by Scaevola thunbergii on the Tongaland sector of the east coast. Note parabolic blowout transgressing the zonation.

PLATE 19. Steep scaevola hummock dune rising to over 10 m in height, with slight undercutting and slumping from wave swash. Same area as previous PLATE.

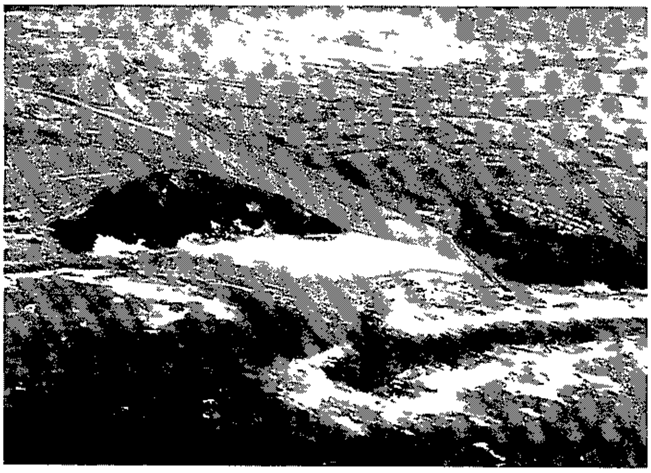


PLATE 20. River mouth precipitation dune built by north-east wind with sand blown off spit. Dune shape is the reverse of a barchan, or linear. Buluga River, east Cape.

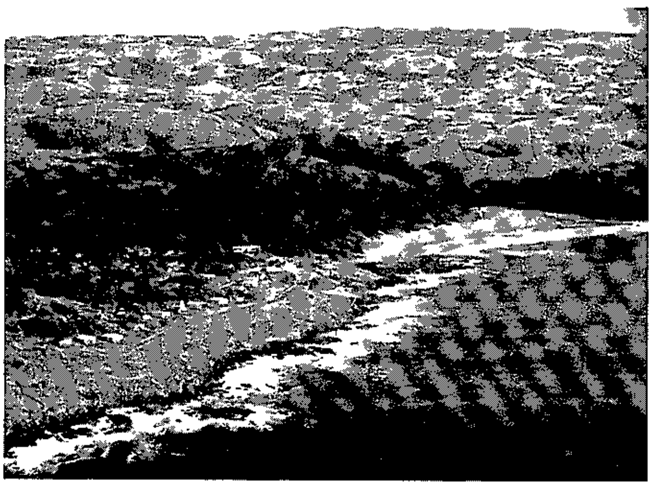


PLATE 21. Composite river mouth-bayhead precipitation dune at Port Edward, Natal South Coast.

PLATE 22. Close-up of a small precipitation dune advancing on a long front at the junction of the strand plant and shrub zone. In the background planted casuarina trees. Pomene Bay, Mocambique South Coast.

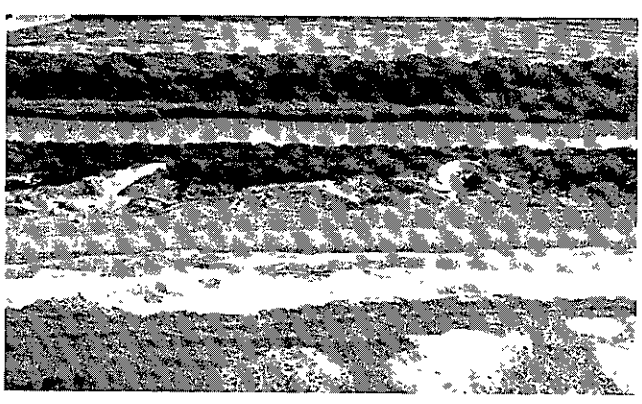


PLATE 23. Parabolic blowout initials transgressing parallel beach ridge hummock dunes. Mlalazi River mouth area, east coast.

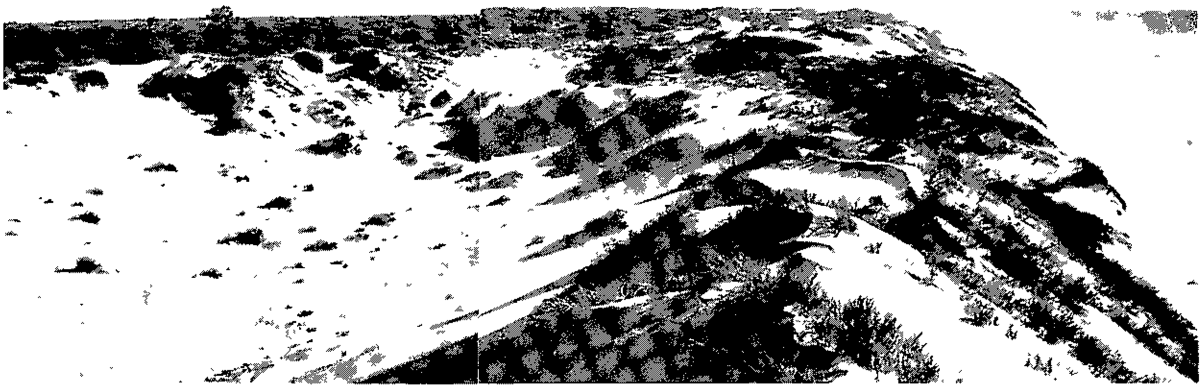


PLATE 24. Blowout in vegetated dune ridges parallel to the shore on the west coast near Rocher Pan. Foredunes on the right colonized by the grass Eragrostis cyperoides and mid to backdune ridges with dwarf scrub-thicket.

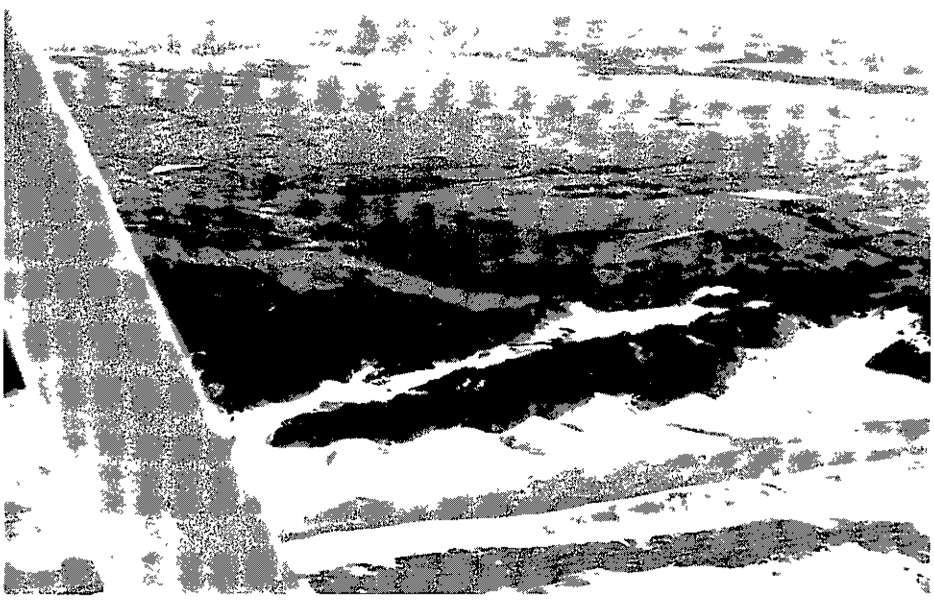


PLATE 25. Mature parabolic blowout in forested dunes of the east Cape near the Old Woman's River. Note buttress dunes, dune lake, and island thickets on termite mounds. (photo: A E F Heydorn 1979).

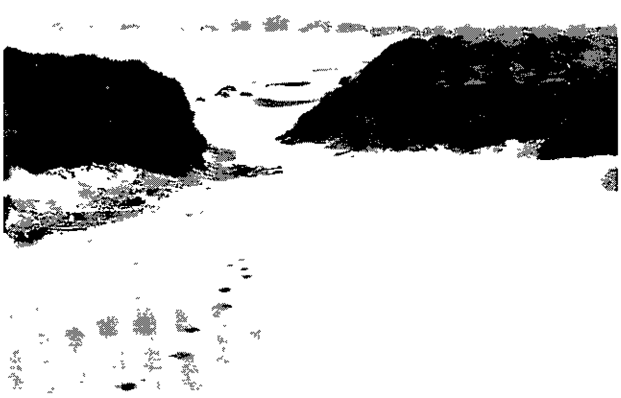


PLATE 26. View down on active parabolic to the backbeach sand source. Cape St Francis, Cape south coast.

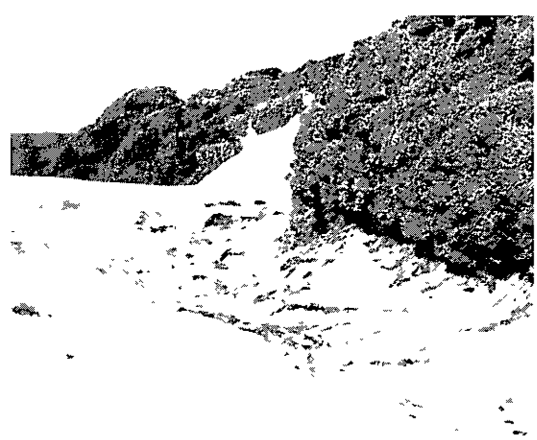


PLATE 27. Breached nose of parabolic in process of being transformed into wind-rift, headland bypass dune (cf PLATE 31B). Wind scour hollow and pruning by sandblasting.

PLATE 28. Superposing parabolics transgressing coastal marshland between Pomene and St Sebastian Peninsula, Mocambique.

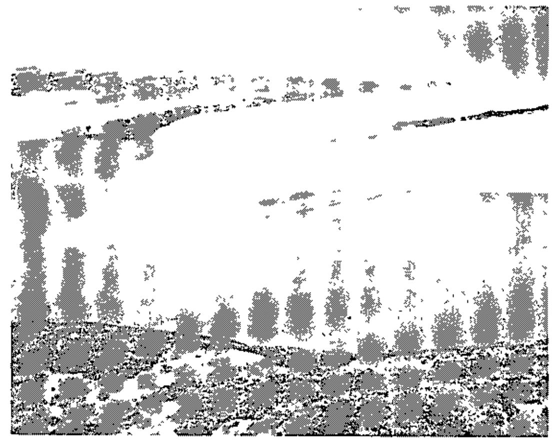


PLATE 29. Barrier lake partially filled by transgressive sandsheet and migrating hairpin parabolic dunes. Lake Llembje on the south coast of Mocambique near San Martinho (see Figure 5).

PLATE 30. West coast migrating hairpin dunes traversing more than 30 km distance between the Bitter and Spoeg Rivers.

1. Typical origin of dunefields on the west coast from the north (downdrift) side of river mouths.

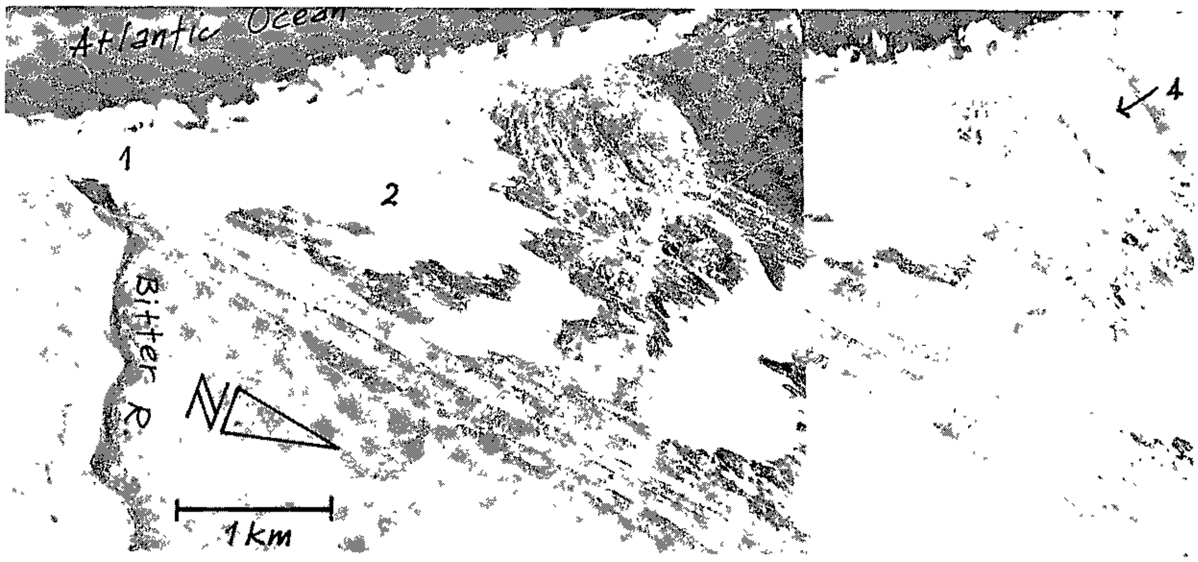
2. Bare, mobile, transverse and barchanoid dunes replacing the vegetated hairpin dunes.

3. Superposition of leading duneroses, and lateral trailing leefaces left as linear ridges parallel to the strong south-south-west to south formative winds.

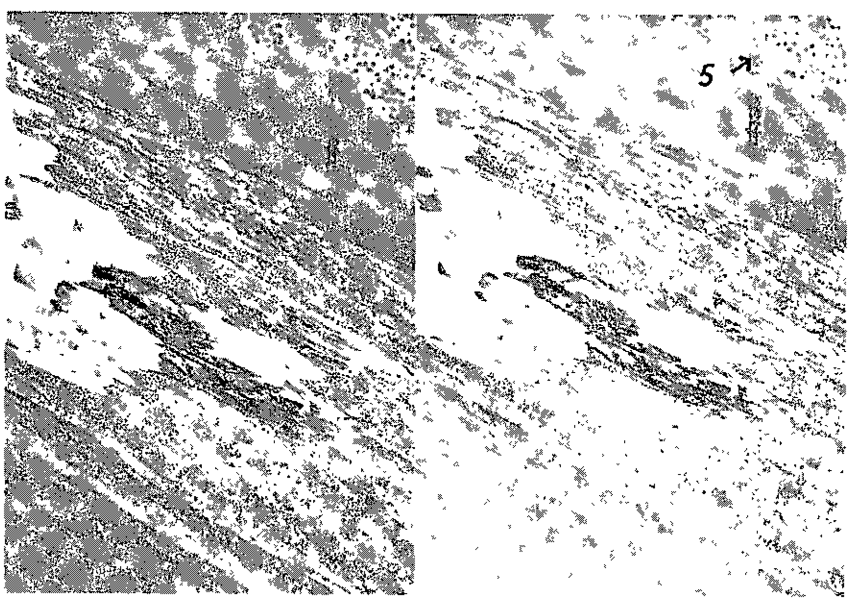
4. Complex of precipitation dune, micro-hairpin blowouts, and coalesced lateral ridge north of the beach dunefield.

5. Rock-marked area at upper right of B are denser patches of vegetation in deflation hollows developed either on dead termite mounds or gilgai soils.

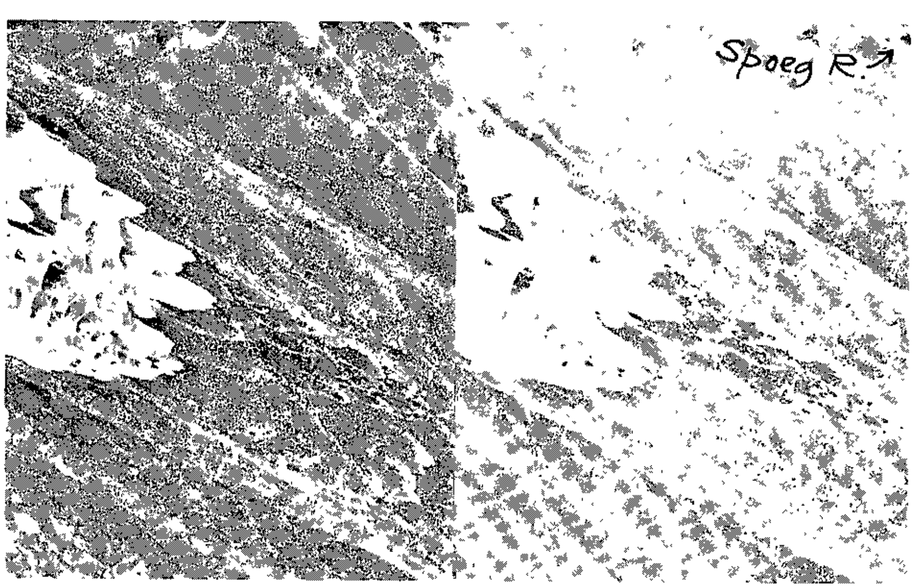
(Airphotography of 1967 reproduced under South African Government Printer Copyright Authority 7811 of 25.5.1982). Use pocket stereoscope.



A. Southern section - origin of dunefield



B. Central section of dunefield



C. Northern section-terminal area of dunes.

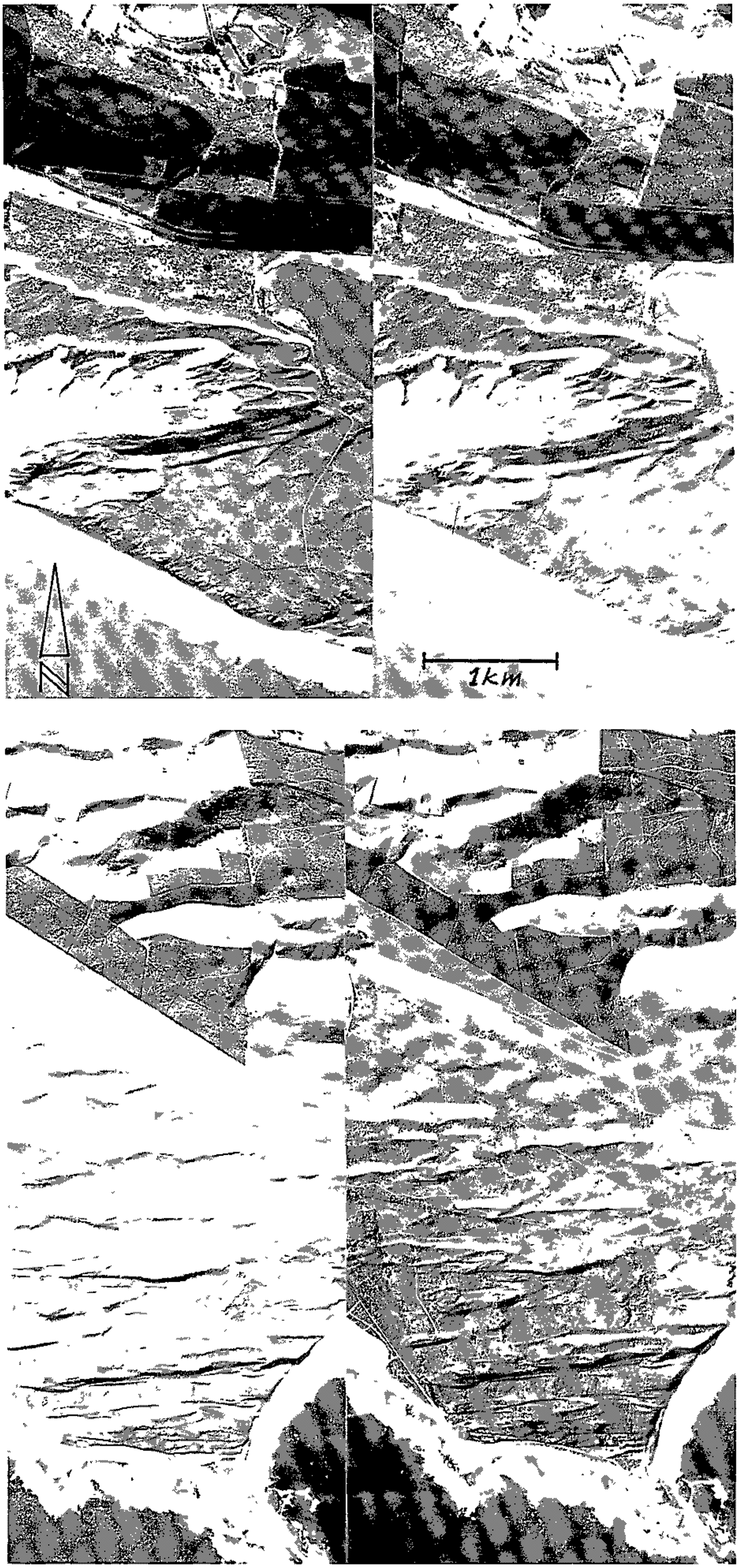


PLATE 31. Compound inbricate parabolic dunes and wind-rift dunes.

A. The best example on the South African coast of compound imbricate parabolic dunes encroaching on western end of Groenvlei Lake in the Wilderness area of the Cape south coast.
1. moisture-vegetation gradient on landward scarp of dunefield, 2. coarse textured dune thicket, 3. fine textured dune fynbos heaths, 4. old oxidized dune cordon covered by plantations (the Sedgefield fossil site).

B. Wind-rift dunes at Buffalo Bay (Walker Pt) east of Groenvlei and the Goukamma River mouth, Cape south coast. Note change in duneform landwards onto old oxidized and lithified dune cordons where rounding of features and karst weathering has taken place. (Airphotographs of 1974 reproduced under South African Government Printer Copyright Authority 7811 of 25.5.1982).

PLATE 32. Landward dunefield scarp above Groenvlei Lake, Wilderness area, Cape south coast. The highest vegetated dunes in South Africa rising to 201 m alt. Note moisture gradient on scarp slope depicted by change in vegetation height, density and type.

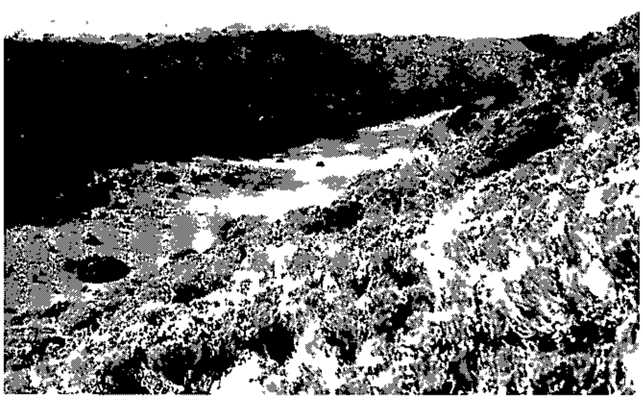


PLATE 33. The largest and best example of wind-rift dunes on the coast, Langekloof near Slangbaai. View eastwards towards St Francis Bay. Steep, high, east-west trending ridges with marked slope aspect contrasts in vegetation.

PLATE 34. View eastwards across Groenvlei Lake from the nose of the active parabolic shown in PLATE 31A. Dune scarp at right, old dune relief behind, and colonization of the slipfaces and nose by pypgras Ehrharta villosa and waxberry Myrica cordifolia.

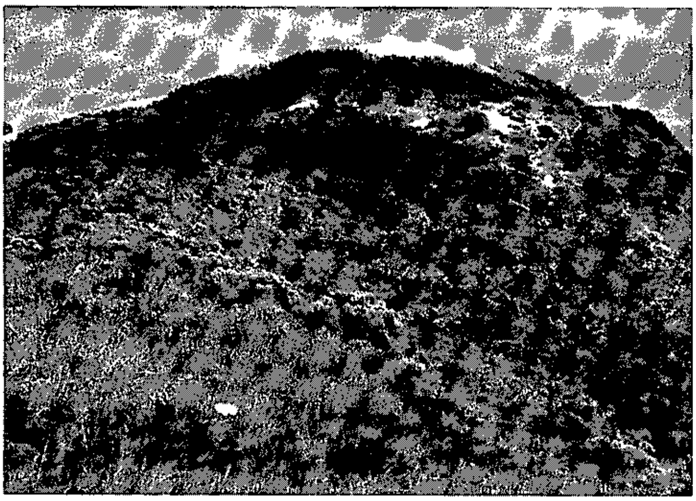


PLATE 35. View from below of parabolic nose shown in previous PLATE. Slipface colonized mainly by waxberry and dune taaibos Rhus crenata. Heaths in the foreground.

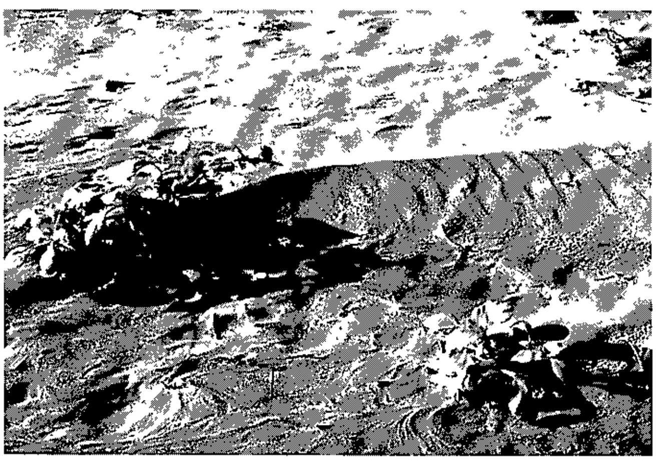
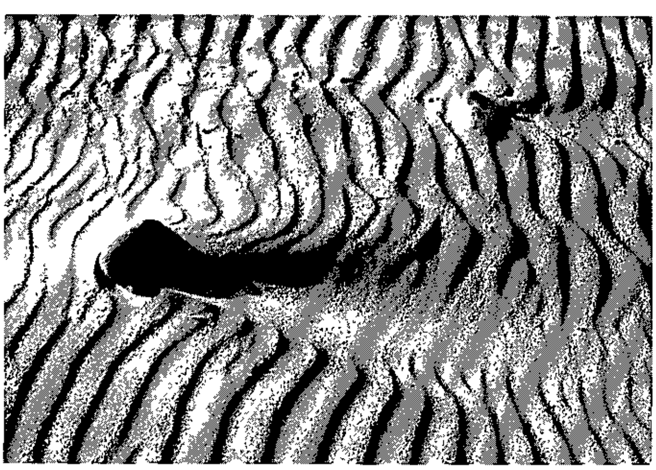


PLATE 36. Microscale barrier-related dunes with the wind blowing from left to right in both examples.

A. Lee dune.



B. Lee trough.

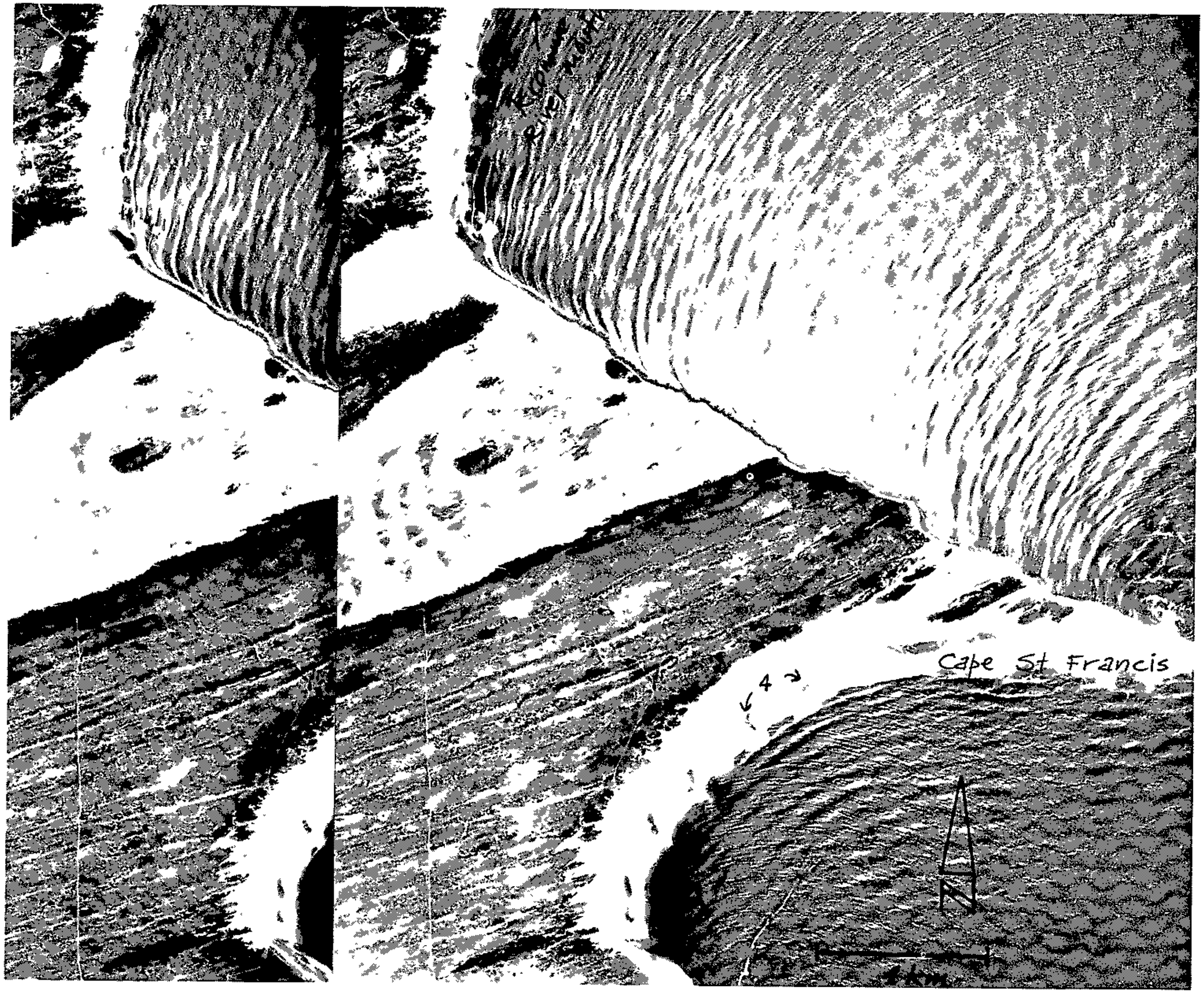


PLATE 37. Westerly-formed headland bypass dunefields on the Cape south coast, entering St Francis Bay. 1. Bare, white, barchanoid dunes on high water-table substrate, 2. parallel dune ridges formed by lateral trailing edges of hairpin parabolic dunes (cf PLATE 30), 3. blowouts formed by easterly winds overriding westerly ridges (rip current) gullies in the surf zone, 5. the wind-faceted rocks and stones shaped from sandblasting by westerlies, occurs in the small headland bypass dune on Cape St Francis, 6. boulder or cobble fan formed by convergence and seaward flow of longshore currents in corner of larger bay, 7. light, fine texture is dune heath, dark, coarse, texture is dune thicket. (Airphotography of 1961 reproduced under South African Government Printer Copyright Authority 7811 of 25.5.1982).

PLATE 38. Steep hummock dunes formed by Lycium sp. Shrub on estuarine flats at the Olifants River mouth, west coast. Embryo dunes in the foreground formed by succulent salt plants (Arthrocnemum sp).

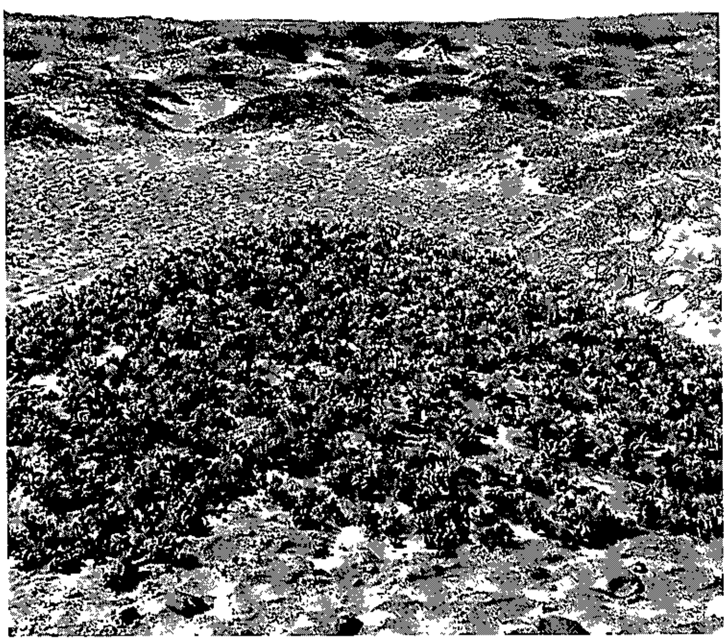


PLATE 39. Hummock dunes formed by Merremia multisecta on river mouth flats of the Namib Desert coast.

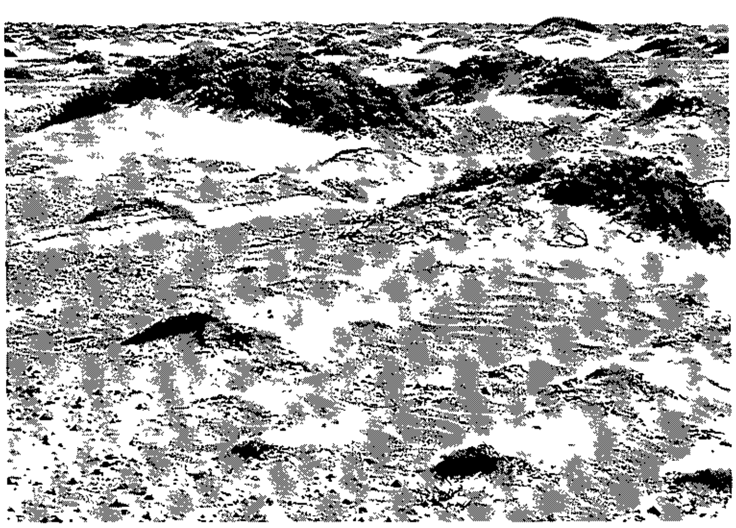


PLATE 40. Hummock dunes formed by Salsola nollothensis on desert washes in the Namib.

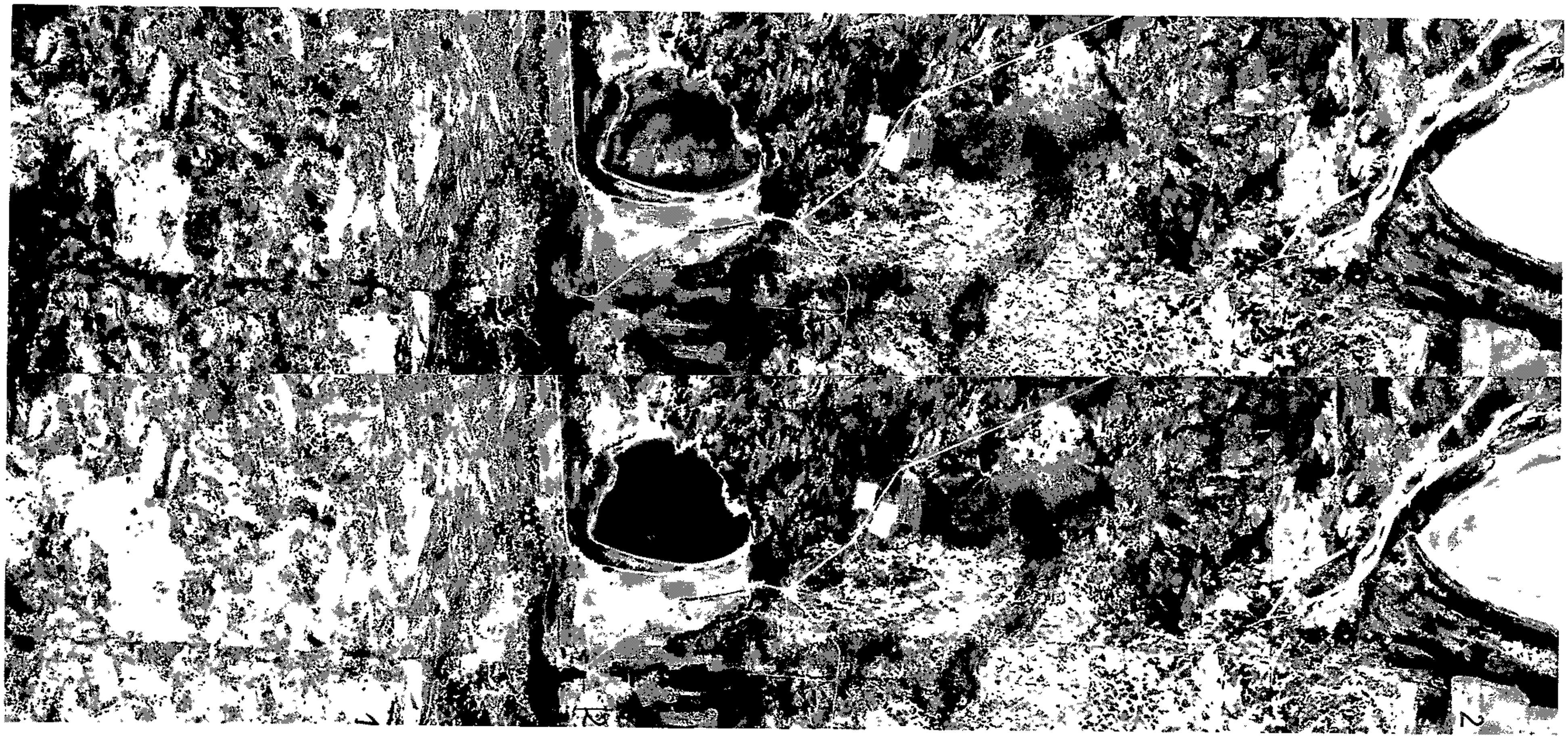


PLATE 41. Hummock-blowouts and playa lunette dunes on the Agulhas Plain between Soetanysberg and Sandberg immediately west of Cape Agulhas. 1. unique dune-type confined to this area, examples of which occur south of (below) the smallest playa known as Renosterkop pan. The whitish strips are fire scars burnt in dune heath vegetation. Dark patches are dune thicket clumps. 2. lunette dunes on the downwind, east side of the playas with smaller linear shoreline precipitation dune. Corner of the larger playa shown is Soutpan. (Airphotography of 1961 reproduced under South African Government Printer Copyright Authority 7811 of 25.5.1982).

N

1 km

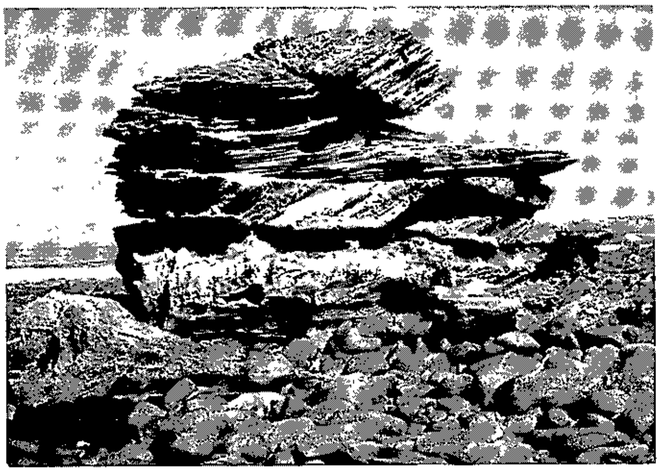


PLATE 42. Dune rock stack at Nahoon Point, east Cape coast. Upper cross-bedded aeolianite with major unconformity along junction with basal water laid beach rock cemented to spheroidally weathering boulders of dolerite sill.

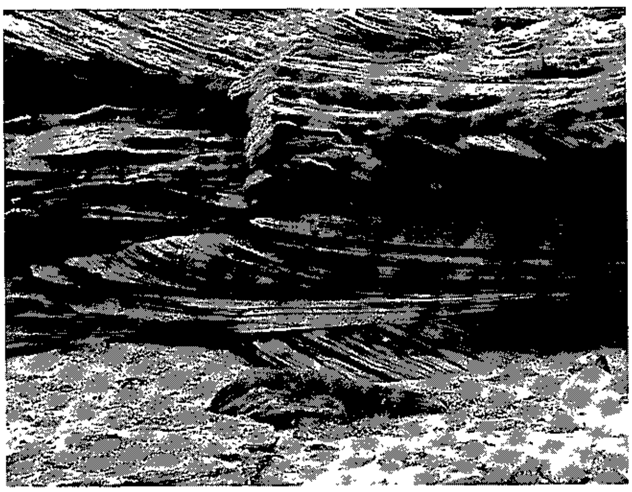


PLATE 43. Classic example of cross-bedding in dune rock at Nahoon Point.

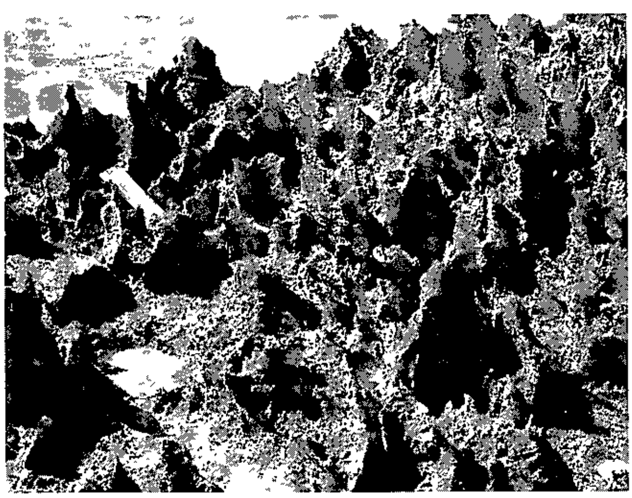


PLATE 44. Jagged pinnacle weathering of dune rock in the higher supralittoral zone affected by sea spray.

PLATE 45. Smoother honeycomb and pothole erosion of dune rock at the junction with the mesolittoral.

PLATE 46. Pipe connections and small stalactites along highest edge of dune rock cliff.

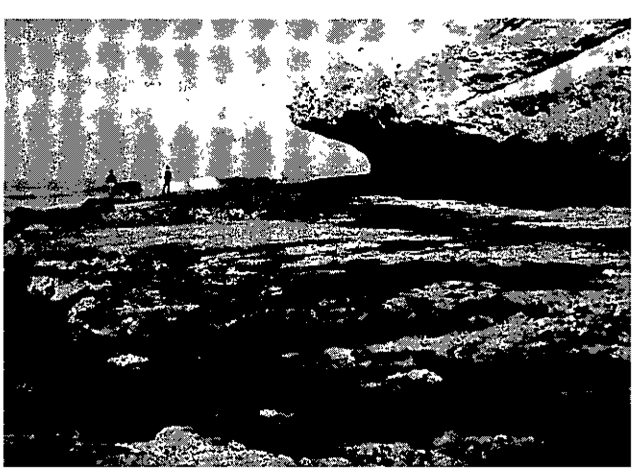


PLATE 47. Smooth wave-planed platform and undercut notch with visor cut into dune rock.

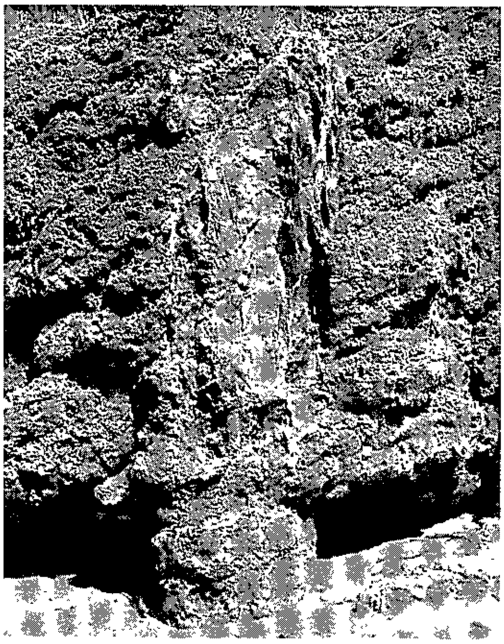


PLATE 48. Calcretized tree stem channels in dune rock at Barra Falsa, Pomene, on the South Mocambique Coast.

PLATE 49. A field of solution pipes formed by weathering out of the softer calcretized tree stem channels leaving the harder aeolianite (Pomene).

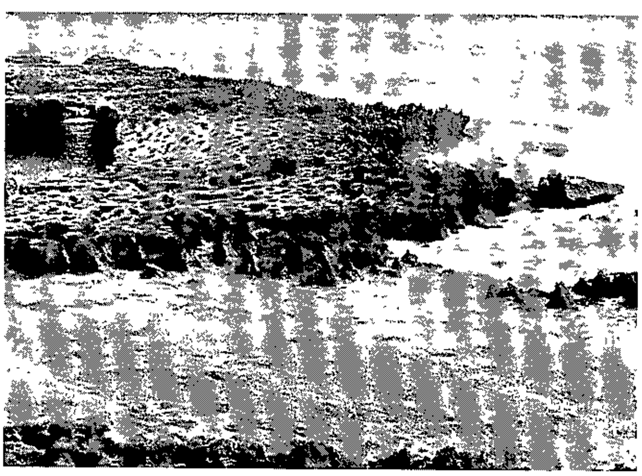


PLATE 50. Caverns, solution pipes, and pinnacle stacks left where adjacent pipes break through in dune rock.

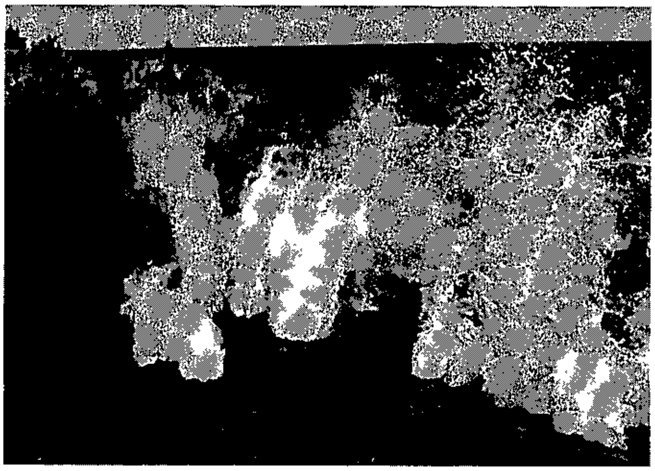


PLATE 51. Geyser fountains formed by uprush of wave in cavern beneath the solution pipes (old tree stem passages).

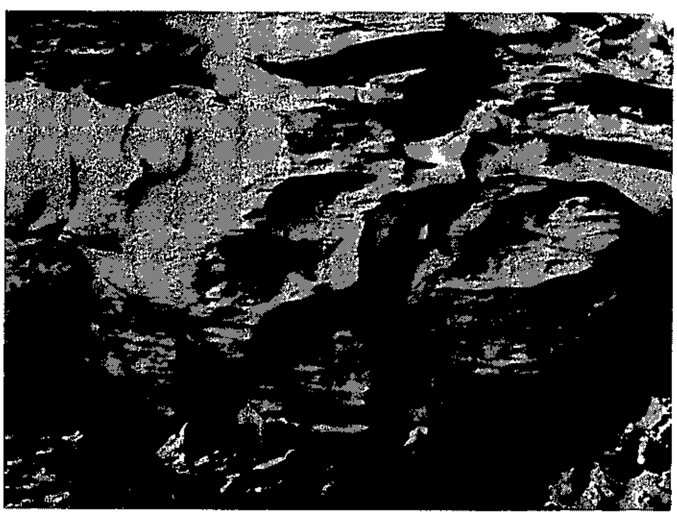


PLATE 52. Wind-faceted stones shaped by sand blasting, cut into silcrete-capped rock floor of headland bypass blowout at Cape St Francis.

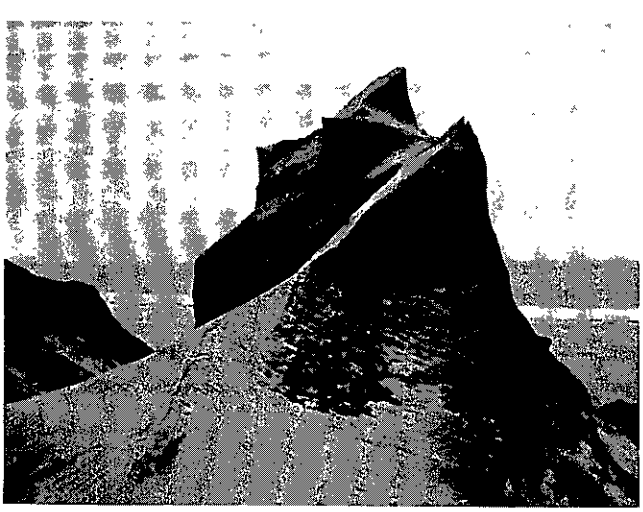


PLATE 53. Yardang cut by wind and rain in compact clayey red dune (Berea-type) at Xai-Xai, South Mocambique Coast.

3. ECOLOGICAL FEATURES

3.1 PHYSIOGRAPHY AND THE TERRESTRIAL SOURCES OF SAND

The basic surface form of southern Africa is similar to that of an inverted saucer, comprising three major physiographic units: (1) the broad interior continental plateau, characterized by extensive planation surfaces with a mean altitude of 1 200 m, separated peripherally from (2) the seaward sloping, relatively narrow (50-150 km) continental margins, by (3) a nearly continuous mountain escarpment rim, rising, generally to between 1 400 and 2 000 m altitude, and separated into sectors or massifs by deep valleys of the rivers which originate from the interior.

3.1.1 The continental plateau

The greater part of the interior continental plateau is mantled by Cainozoic desert sands of the Kalahari Basin, now covered by savannas of various kinds. The Kalahari Sands cover a vast region which extends over 3 000 km between the Orange and Congo Rivers. South of the Orange-Vaal drainage the greater area of South Africa is a stepped mesaform landscape eroded out of alternating sequences of sandstones, mudstones and shales of the Karoo System. These, mostly horizontal, Upper Palaeozoic to Mesozoic strata abut the coast only in the south-east between the Great Fish River and Mendu Point in the Transkei.

Whilst a large area of the southern Kalahari is either drainless or endoreic (Okovango and panveld regions), the characteristic feature of this physiographic unit's drainage is for a few large rivers to traverse the interior from nearly opposite sides of the subcontinent, rising off the backslopes of the Great Escarpment rim (Orange, Zambezi) or the Great Rift Valley (Congo).

In the northern Kalahari the rivers rise on high water-table sands of the Kalahari Basin's dambo country, and the remainder of the interior originate on Precambrian metamorphic, volcanic, sedimentary and granitized rocks. These are exposed on the rim and periphery of the Kalahari Sands in the tropics, and between the Kalahari and Karoo Systems in the south, diagonally across from the Eastern Transvaal to the Lower Orange River and Namaqualand. The remainder of the interior drainage is derived from the radial perennial flow off the high Lesotho massif of Drakensberg basalts and sandstones, which is also the major source area for the rivers of the south-east seaboard.

3.1.2 The continental margins

In the south and south-west these are boldly defined by the Cape Fold Belt ranges and northwards on both west and eastern coasts by the crest of the Great Escarpment or its outliers.

The coastal belt is generally stepped, with a lowland zone rising from sea level to about the 150 m contour. This merges upward into a deeply dissected upland zone between 150 and 300 m where footslope pediment surfaces merge with raised coastal plain surface remnants on the interfluve spurs.

The width of the coastal lowland is highly variable, non-existent where steep plunging forelands meet the sea as on part of the south-west, south and south-east coasts, and over 400 km in width at the other extreme in Mocambique.

The continental margins are segmented by numerous river valleys draining the seaward slopes and from inland. These have their highest density along the south and south-east coasts where coincidence of high rainfall with high mountain catchments results in perennial river flow. A low river density is characteristic of both the desert west coast due to lack of rainfall, and again on the Mocambique coast where highly porous low rolling sandy plains, with high rainfall, confined to the immediate coast, has resulted in areic or local endoreic conditions.

A. West coast.

The Trade Wind desert coast has a curvilinear north-north-west trend with numerous rocky inlets and half-heart bays backed by a diversity of landforms. These include low dunes with raised beaches and terraces, saltpans and deflation surfaces, marshes, inselbergs, high mobile dunes or undulating red sand plains vegetated by dwarf shrubland mantling subsoil calcretes. Over large areas of the compact red sands on the west and adjoining south-west coast plain the vegetation has a clumped appearance due to denser growth on regularly spaced termitaria hillocks. This pocked landscape is most conspicuous near the Olifants River and also in the Saldanha area where the majority appear to be dead or fossil (calcretized) (Plate 54). On the inland margin of the coastal plain vast areas of pocked landscapes near the Richtersveld and in the van Rhynesdorp district, are formed by the bare living hillocks of Microhodotermes viator.

Between Walvis Bay and Luderitz the Namib Sand Sea, which extends 120 km inland to the base of the Great Escarpment, abuts directly on the coast forming sliding sand scarps 150 m high where they are undercut by wave action. This sand is transported northwards alongshore to form prograding coastal outgrowths such as those at Sandwich Harbour and Walvis Bay.

Due to the abundance of sand, from sand slides and offshore Berg Winds, actively prograding shorelines occur at intervals along the Namib Coast at Walvis, Sandwich, Conception, Meob Bays and between Luderitz and Hottentotsbaai. These growing coast areas relate in most cases to sites of former river estuaries from pluvial times (Bremner in press). Progradation is by the northward growth of large spits enclosing either open water as at

Walvis Bay, or backwaters with salt marshes, salt pans, hummock dune plant communities and parabolic dunes. South of Luderitz the only prograding shoreline on the west coast is in St Helena Bay north of the Berg River mouth at Dwarskersbos (Heydorn and Tinley 1980). South of the Orange River to the shores of False Bay the coast lowland is generally about 50 km broad. The greater part of this lowland is composed of reddish-brown sands overlying calcretes of various kinds, but where the south-west coast region is approached larger areas of white and whitish-grey quartz sands predominate.

The coastal sands are underlain by Precambrian metasediments of the Damara System north of Luderitz and by the Nosib (Gariep) System for a considerable distance on either side of the Orange River mouth, and southwards to near the Olifants River by granite-gneiss of the Namaqualand-Natal belt. Between the Olifants River mouth and Elands Bay the first outcrops of the Cape Fold Belt rocks occur on the coast. Characteristic features of this sector are large, north-trending, dune plumes which originate at the larger seasonal river mouths. Cliffed shorelines occur at intervals, and the only inselberg coast in southern Africa occurs from 140 km north of Luderitz (Uri-Hauchab Mountain) south to near Port Nolloth (photograph B1 in Heydorn and Tinley 1980). Except for inselbergs and lesser outcrops, exposures of country rock are confined mostly to river valley sides and the seashore. No aeolianite or beach rock apparently occurs on this coast. In this sector and southwards salt pans and deflation floors are common near the coast.

B. South-west coast.

From St Helena Bay southwards the coastal sands and calcareous sediments overlie Late Precambrian Cape granites and Malmesbury metasediments of the Nama System. The granites outcrop at Saldanha where a large indented bay and lagoon occur and again on the Cape Peninsula where they are overlain by Table Mountain Sandstone to form a steeply plunging mountainous foreland.

The coastal lowland of the western coasts is separated from that of the southern coast by the seaward abuttment of the high Cape Fold Mountain area of syntaxis which terminates at Cape Hangklip. A 'backdoor' lowland link however, has been available since the Early Cretaceous (Truswell 1977), along the tectonic valley formed by the 480 km long Worcester fault, through which thicket (valley bushveld) elements occur patchily between the two lowlands.

From False Bay eastwards to Danger Point a low, narrow foreshore is formed by a raised coast platform merging into the footslopes of high mountain forelands. The platform supports dense fynbos vegetation on high water-tables, with a number of blackwater lakelets. This is interrupted at intervals by broad lagoons in the embayments formed by the synclinal valleys of softer shales such as at the Bot River and in Walker Bay.

C. South coast.

The outstanding large scale feature of the south coast is the series of large asymmetric half-heart embayments and their east-jutting promontories, notably at Struisbaai, St Sebastian Bay, Stilbaai, Vleesbaai, Mossel Bay, Plettenberg Bay, St Francis Bay and Algoa Bay. These are backed by high west-east trending subparallel ranges of quartzites which form giant catena sequences alternating with shale valleys or flat floored basins.

The south coast lowlands are discontinuous, being confined to the embayments noted above and their associated river valleys. The bays are tectonic and synclinal troughs of shales filled in by Cretaceous to Recent sediments. The low embayments are separated from each other by sectors of raised coast plateaux with steep or cliffed shores. The cliff coast cut in ochre to orange coloured coast limestones between Potberg and Mossel Bay rises to over 100 m, exhibiting all the typical features of limestone weathering, and is surmounted by orange coloured sands. Where the coast plateau fronts the Outeniqua Range it is only 10 km broad and deeply incised by narrow gorges along dip joints in the folded Table Mountain Quartzites. This plateau ends in spectacular cliffs over 200 m high. The break in coast sands and limestones made by Table Mountain quartzites outcropping on the foreshore brings podsols, leached grey sandy soils and skeletal or rocky acid soils directly onto the coast.

Active and fixed dunefields are most extensive against the long curve of the half-heart bays and across their promontories.

The south coast is fronted by the broad continental shelf of the Agulhas Bank of 120 km width (to the -100 m isobath) which was exposed by the -130 m lowering of sea level during the Würm glaciation between 20 000 and 11 000 years ago (Rogers 1971b).

D. South-east coast.

Like the west coast it is a linear rocky coastline but indented by a much greater number of small bays at river mouths.

The south-east monoclinal coast is characterized by deeply dissected spur and valley landscape with a rounded convex foreland rising steeply or gently to the 70 m contour on interfluve spurs, where remnants of the raised coast plain occur to above the 300 m contour (Board 1962). Buried soils occur up to three kilometres inland where they are overlain by windblown sands and calcareous Cainozoic deposits (Board 1962). Older Berea-type clayey red sands, covering areas of varying dimensions, occur at intervals along the coast. These are banked up over older formations and extend landwards up to about the 100 m contour. There is a general increase in the altitude to about 150 m north of the Tugela River. From the Mlalazi River northwards the red sands form cordons which swing away from the present coast to follow the inland margins of the Mocambique Coastal Plain in Tongaland.

The high density of the seaward drainage with deeply incised meander courses, form quiet forest-enclosed lagoons at the river mouths, many of which are sealed off by sandbars in the low-flow period of the winter dry season. High forelands alternate with pocket beaches and small dunes at the bayheads of each river mouth. These coast forms reach their greatest development on the Wild Coast of the Transkei where the monoclinal axis meets the sea in a steep cliffed foreland of exposed Table Mountain Quartzites where waterfalls drop directly into the sea. In this area and the adjoining Natal South Coast, granite-gneiss of the Namaqua-Natal mobile belt reappear and with the Table Mountain Quartzites extend northwards obliquely inland on a divergent line with the coast, terminating in KwaZulu, close to the southernmost outcrops of older Precambrian granite-gneiss of the Eastern Transvaal Lowveld.

South of the Kei River a high nearly continuous dune cordon occurs along the coast. It is only in this sector and north of where the monoclinal axis meets the sea that aeolianite (dune rock) forms headlands on raised shorelines. The south-east coast is thus a sector characterized by relatively small dunes and rare Cretaceous and Cainozoic sediments. Generally the south-east coast is fronted by a steeply shelving shoreline and a narrow continental shelf scarred by submarine canyons (Flemming 1982).

The predominant soils of the south-east coastal region are shallow to deep gley-like podzols which are temporarily waterlogged in summer (van der Merwe 1962). These soils of the interfluves support acid grasslands. Large areas of non-humic red and yellow fersiallitic soils derived from dolerite occur in Natal and the Transkei. In the lower rainfall areas of KwaZulu and the eastern Cape these are black and red fersiallitic clays interspersed with extensive areas of solonetzic soils covered in savanna and thicket.

E. East coast.

The southern seaboard of Mocambique is characterized by an extremely broad low coastal plain, mostly below 100 m altitude, composed predominantly of Quaternary Sands and fronted by a high, narrow, forested dune cordon enclosing a chain of barrier lakes. It is a composite plain composed of laterally coalesced giant pediment fan deposits off the oldland intercalating with coastal marine, estuarine and littoral dune facies.

The coastline has a zigzag trend with alternating north and north-north-east linear coast sectors, the north-trending sectors irregularly toothed by remnant dune or beach rock points in the lee of which shallow asymmetric half-heart bay indentations have been formed by refracted predominant south-south-east swell. Nett northward longshore transport of sand has formed peninsula spits surmounted by parabolic dunes which have built out enclosing large bays as at Delagoa Bay, Inhambane, and Dahu Bay behind the peninsula islands of Bazaruto. This mirrors Pelican Point at Walvis Bay and Peninsula dos Tigres on the west coast. The major bights of Sofala, the Limpopo and Mlalazi Rivers are formed at the inset junction of the zigzags.

The Mocambique Coastal Plain is between 40 and 80 km broad in the south (Tongaland Region) where it is bounded on its inland margin by the highest section (between 600 and 700 m) of the narrow north to south trending cuestaform Lebombo Mountain spine which extends to just short of the Limpopo River. Seaward of the 200 km wide gap in the eastern Great Escarpment rim formed by the lowland between the Limpopo and Save Rivers the coastal plain attains its greatest width of more than 400 km to the coast at Inhambane. This region is known as Gazaland.

The coastal sands which are yellowish-brown and reddish-brown calcareous or greyish-white leached, acid, sands form an undulating surface of old dune cordons forming linear rises alternating with sedge peat dambo and swamp drainage, or shallow flat-floored elongated basins of old barrier lagoons and estuaries. These were left in alternating sequences parallel to the present coastlines by a receding Pleistocene sea with the onset of the Würm glaciation.

Narrow beaches of silica quartz sands are interposed between a steep forested parabolic dune cordon and shallow littoral waters which wash over an extremely narrow continental shelf. Its edge plunging to -200 m between four and eight kilometres offshore, narrowest off Lake Sibayi and Sodwana, and again at Cabo dos Correntes near Inhambane, and off the peninsula islands of Bazaruto where the -200 m isobath is only 1,5 to 4,5 km out. From Bazaruto the -100 m break in the shelf cuts straight across the Bight of Sofala where the edge is 160 km distant off Beira (Tinley 1971b).

The coastal sands are underlain by a mosaic of Middle Pleistocene white and grey consolidated sands, clays, calcretes and limestone, marls and diatomite of the Port Durnford Beds with a predominance of clayey calcareous sediments of similar age in Gazaland. These are in turn underlain by Cretaceous calcareous sediments, both these underlying formations dipping seawards in which direction the sand mantle is deepest. All these formations thin landwards where the Cretaceous outcrops at the surface. Most of the pallid sands of the plains thus appear to be derived from reworked white and grey sands of the Port Durnford Beds (Maud 1968; King 1972b).

3.1.3 Major terrestrial sources of sand

The Kalahari, Karoo, Cape and Precambrian rocks all provide an abundance of fines and especially sandy sediments, and the associated heavy minerals derived chiefly from the intrusive and extrusive rocks, are stripped off and carried by the rivers via sandbank stages to the sea. At the coast the sands are deposited at or near river mouths from where they are transferred by currents and wind alongshore to feed beaches, spits and dunes. River catchments such as that of the Zambezi arise on predominantly migmatitic granite-gneiss intrusive rocks and carry a sufficient superabundance of titanium and ilmenite to form "black beaches" north of the delta, and a sand volume sufficient to prograde the coast on the delta front where parallel sequences of chernier (dune-slack) ridges have been formed (Tinley 1971b, 1977).

In summary:

1. Kalahari Sands are carried onto the west coast by the Orange, Kunene, Cuanza and Congo Rivers and onto the east coast by the Limpopo and Zambezi River.

2. Intrusive granite-gneiss derived sands reach the west coast between the Olifants and Orange Rivers and again only in northern Namibia and Angola between the Hoarusib and Cuanza Rivers (10° to 19° S); and on the east coast between the Zambezi and Usutu Rivers, with relatively minor, though important, input in Natal and the south-west Cape.

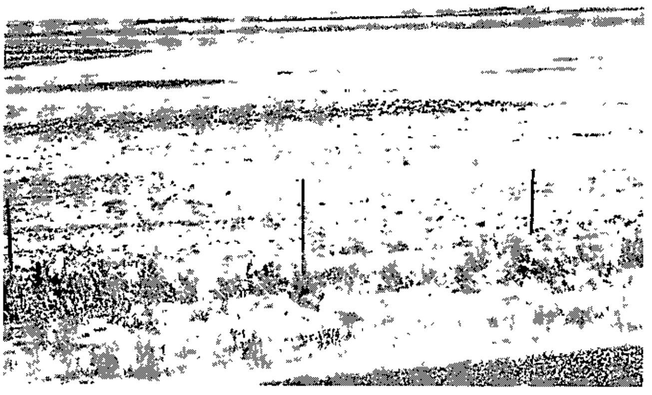


PLATE 54. Fossil termite hills flattened by repeated ploughing, many calcretized and some with ferricrete as well, between Vredenburg and Cape Columbine, south-west coast.

PLATE 55. Dust storm in the subdesert zone of the Namib with strong Berg Wind blowing seawards from the Interior (photo: E Nink).

PLATE 56. Guttation by the dune cabbage Arctotheca populifolia at night and in the early morning.

3. Karoo Sandstone derived sands reach the west coast by way of the Orange River, the south and south-east Cape, Transkei and Natal coasts.

4. Cape quartzite derived sands chiefly along the south-west and south Cape coasts and with a relatively minor input in Natal.

5. Precambrian metamorphic derived sands chiefly onto the west coast by the Orange River, and northwards from the Kuiseb River at Walvis Bay to the Congo. On the east coast chiefly the whole of northern Mocambique from the Zambezi to the Rovuma Rivers.

Generally the Kalahari Sands, Karoo Sandstones and Cape Quartzites furnish fine sands to the coasts, and the Intrusives and Precambrian rocks provide coarse sands and heavy minerals.

3.2 CLIMATE

3.2.1 Classification

The coastal zone of southern Africa traverses six climatic regions which conform closely to the five major changes in coast trend across 12° of latitude from Cape Agulhas (35° S) to the tropic. In addition to latitudinal influences each change in trend exposes the coast to different sets of influences from the same pressure systems and contrasting effects of cold and warm seas. These coast regions are defined above in section 1.6.

According to the various climatic classifications assessed by Schulze and McGee (1978) the maritime zone is divisible into a varying number of types depending on which parameters and indices are used. These include the classifications of Köppen, Thornthwaite, Holdrige's Life Zones and Poynton's (1971) moisture regions.

Köppen's classification identifies only four main types along the coast, (1) a west coast desert climate (BWk), (2) warm temperate climates along the south-west (Csb), south (Cfb) and south-east (Cfa) coasts, interrupted by (3) a steppe climate (BSk) between Cape Agulhas and Groot Brak, and (4) the equatorial winter dry season type (Aw) of the Mocambique Coast. Northern Mocambique has a tropical monsoon climate from about 17° S northwards, on the east coast and north of 10° S on the west coast and falls within the bimodal equatorial climatic zone (Miller 1959; Thompson 1965; Meigs 1966; Griffiths 1972).

Though little used in modern literature, de Martonne's Index of Aridity (P/T+10) has the merit of simplicity, is a rapid means of identifying biome-type (Tinley 1975a), and can be used to construct a drought index for a particular area using the monthly means correlated with the occurrence of leaf discolouration (Tinley 1977). The coast stations are listed below according to this index and their biome-types.

Walvis Bay	0,3	Extreme arid (desert to subdesert)
Luderitz	0,7	
Port Nolloth	2,5	

Mossel Bay	15,0	Arid
Cape Agulhas	16,6	
Port Elizabeth	21,1	Mesic
Cape Town	23,0	
Maputo	23,5	
East London	28,2	
Inhambane	28,3	
Durban	33,0	Moist
Port St Johns	39,0	
Cape St Lucia	41,0	

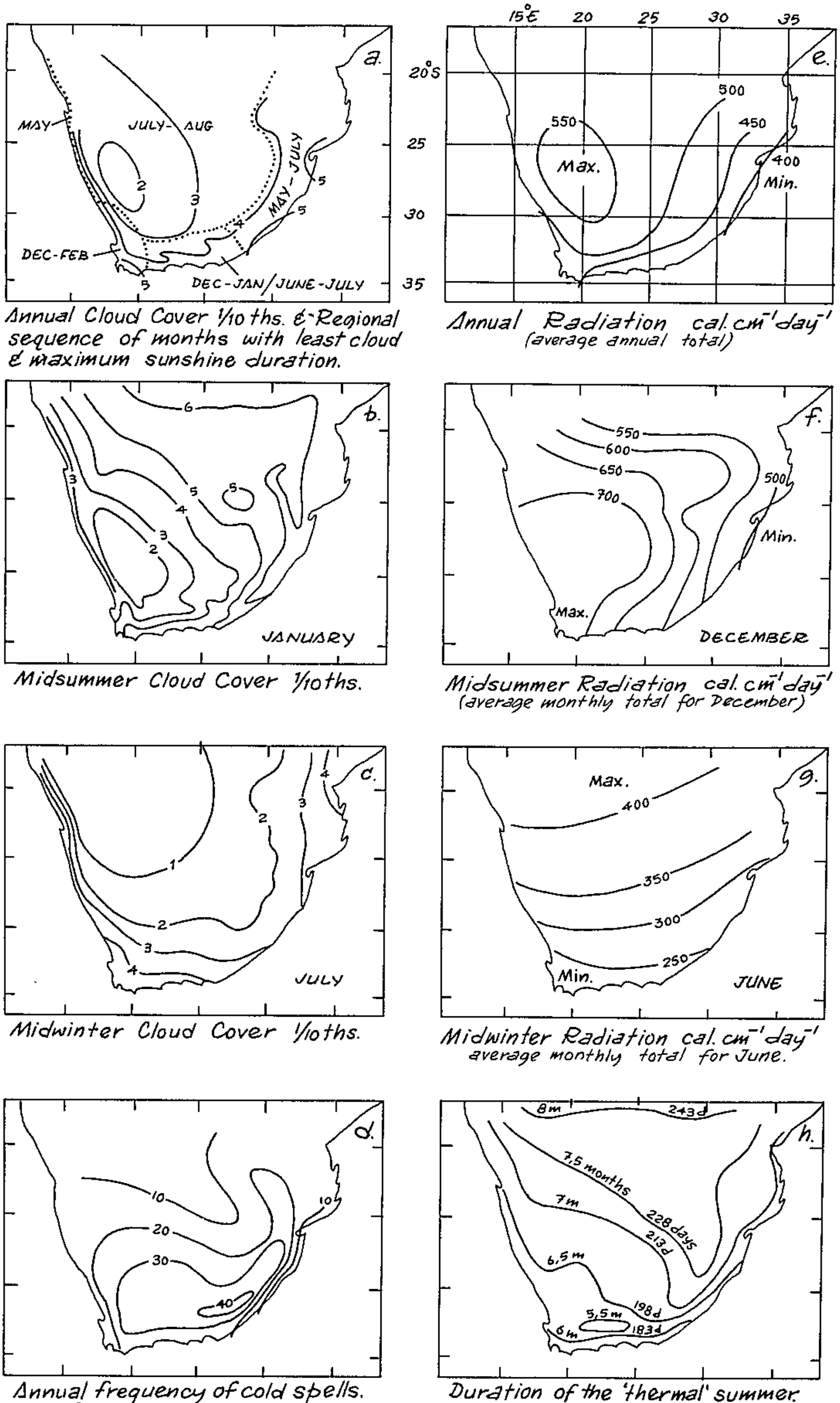
3.2.2 Controls of climate

The climates of southern Africa are dominated by the semi-permanent subtropical anticyclonic high pressure cells, centred over the southern oceans on either side of the subcontinent. These interact with successions of eastward moving cyclonic low pressure systems of the circumpolar westerlies, and the waxing and waning of an anticyclonic inversion over the interior continental plateau. The predominance of particular weather patterns and local or mesoscale processes are in turn strongly influenced by the build of the subcontinent, the asymmetric disposition of nearshore cold and warm seas and the differential heating of these by the seasonal march of the sun.

The Great Escarpment and the first line of the Cape Fold Belt ranges cause a marked discontinuity of climate between interior continental and coastal maritime types. The gaps cut in this barrier by valleys of rivers rising in the interior act as two-way ducts for conveying either marine air to the interior or continental air seawards. There is a strong orographic control of local circulations and of precipitation all around the South African coast.

In response to the solar control there is a seasonal shift of the main pressure belts between five and ten degrees equatorwards in winter with a return polewards in summer. The low sun shift results in the predominance of westerly low pressure frontal disturbances confined mostly to the southern and eastern coastal margins by the simultaneous establishment of an anticyclonic inversion over the interior continental plateau which precluded all except the most strongly developed cold fronts from penetrating to the interior. Such cold snaps occur between three and five times every winter with a maximum in August.

Both anticyclones, including the landward extension of the South Indian High over the eastern Transvaal (the 'Limpopo High'), most strongly developed in winter, fluctuate in position and are responsible for fine dry weather over the greater part of the subcontinent at this time. The oceanic highs ridge in south of the subcontinent particularly in summer where they cause easterly winds to blow. In winter the fluctuating position of the continental high is responsible for hot dry Berg Winds which descend from the interior blowing seawards on one of the coasts depending on the synoptic situation. These scorching winds are experienced most frequently on the west coast.



Annual Cloud Cover 1/10 ths. & Regional sequence of months with least cloud & maximum sunshine duration.

Annual Radiation cal. cm⁻¹day⁻¹ (average annual total)

Midsummer Cloud Cover 1/10ths.

Midsummer Radiation cal. cm⁻¹day⁻¹ (average monthly total for December)

Midwinter Cloud Cover 1/10ths.

Midwinter Radiation cal. cm⁻¹day⁻¹ average monthly total for June.

Annual frequency of cold spells. (total T° drop > 5°C)

Duration of the 'thermal' summer.

Fig 8 SEASONAL CLOUD COVER & RADIATION PATTERNS IN SOUTHERN AFRICA.

In summer, with the return of high sun conditions and the southward shift of the pressure belts, a heat low develops over the interior continental plateau between the northern Cape and Zambia. This undercuts and replaces the continental anticyclone at the surface permitting the influx of anticyclonically advected moist marine air from the Indian Ocean, and of recurved South Atlantic anticyclone air moistened by its trajectory across Angola and the Congo. These notes on climatic controls are summarized from Thompson (1965), Tyson (1969) and Griffiths (1972).

3.2.3 Elements of climate

A. Cloud cover.

The degree of cloud, seasonally or on a daily basis, directly affects radiation and insolation values, diurnal temperature variations, evaporating power and thus air and ground moisture content.

The more complete and lower the cloud cover the greater the 'greenhouse' effect it imposes. Either dank conditions as occur with advective sea fog, off cold seas, or sweltering as in the equatorial region and east coast tropics. The less the cloud cover, especially where afternoons and nights are clear, the greater are the extremes and ranges of the above parameters. These relationships are especially important in sand dune areas for several fundamental reasons:

(a) Low stratiform cloud such as advective sea fog or coastal drizzle, can sufficiently wet the sand surface so that any closed cloud cover thereafter directly affects sand mobility as the sand is kept wetter longer and a far greater wind velocity is required to move the sand. This feature becomes increasingly important on dune coasts where higher rainfalls occur, as for example in Natal where strongest winds are seasonally coincident with the rains and increased cloud cover (Figure 12). In such regions the effect of storm winds as dune builders is much reduced.

(b) As the greater proportion of air spaces between soil particles occurs in sands and the least in clays, the diurnal variation of temperature with clear skies is greatest in sandy soils. Where such drops are below dew-point in bare sands this leads to internal dew formation in dunes (Chapman 1964) which has far reaching geoecological implications (see Section 3.3).

The annual pattern shows persistently higher cloud cover values to be a feature of the coasts (Figure 8a,b,c). As can be expected, the major seasonal patterns of cloud density on the coasts are related to the particular rainfall regime which pertains in each sector, ie highest values between September and February in the summer rainfall eastern coasts, bimodal equinoctial peaks on the southern coast and a winter peak on the south-west coast. The bimodal peak, however, remains a feature of the west coast (eg Alexander Bay) and is still discernible in the monthly curve for Cape Town (Schulze 1965).

The seasonal change in cloud cover is least along the southern Cape coast, whilst the southern south-east coast (eg East London) experiences the largest day to day changes in cloudiness (Schulze 1965). Cloudiness is at a maximum on west, south-west, and south coasts in the mornings, and in the afternoons along most of the eastern coasts due to the development of convectional cumuliform Trade Wind clouds. From Natal northwards these are typically cumulo-mediocris and cumulo-congestus, and southwards, as at East London, stratocumulus prevails throughout the year (pers data). In both types maximum drying out of sands from noon onwards is coincident with the maximum diurnal velocities of the effective predominant winds (refer to section on Wind).

Where orographic highs abut close to the coast, the cloud cover maximum build-up is in the afternoons (eg at George) whereas the adjacent coast (eg at Mossel Bay) has its maximum in the mornings (RN and SAAF 1941/44; Schulze 1965). These clouds are typically fair weather cumulus which clear towards sundown.

B. Radiation.

As the total radiation received at the earth's surface varies inversely with the degree of cloudiness, contrasting seasonal patterns are experienced in southern Africa between the western winter rain and desertic regions and the eastern and northern summer rain region.

The summer radiation isoline patterns parallel those of cloud cover, and thus of the isohyets, with a maximum of more than 700 cal cm^{-2} day^{-1} in the winter rain and subdesert region where skies are predominantly clear in summer (Figure 8e,f,g).

In winter the pattern of incoming radiation is chiefly zonal with the maximum of more than 400 cal cm^{-2} day^{-1} between the tropic and the equator when least cloud pertains over the greater part of the interior of the subcontinent. At this time the southern minimum is due not only to the latitudinal effect of low sun but also to coincident increased cloudiness along the southern and south-west coasts where winter rains occur (Figure 13).

At most coast stations highest radiation values occur between 11h00 and 14h00 (Schulze 1965). Some of the highest radiation values on the continent have been recorded at the west coast stations of Cape Town and Alexander Bay where average daily values have exceeded 800 units (Schulze 1965; Thompson 1965). In fact the radiation recorded at Alexander Bay of 522 total average units per annum is one of highest values known for any coastal region in the world (Schulze and McGee 1978).

The coincidence of highest incoming radiation values during the southern summer with clear skies over the winter rain and subdesert region of the subcontinent is of intrinsic biological importance. The annual range in these regions is close to 80% of that received outside the atmosphere, contrasting with only some 30% in the summer rainfall region at the same time (Schulze 1965).

C. Temperature.

On coasts extremes in temperature are generally damped by the moderating influence of marine air, increased cloud cover, high atmospheric humidity and the cooling effect of land and sea breezes.

Four features along the South African coastline, however, results in anomalous temperature regimes: (1) the asymmetric disposition of cold and warm currents off the coast, (2) some of the coldest nearshore sea temperatures occur in summer particularly on the west and south-west coasts and to a lesser extent on south and south-east coasts at the time of strong anticyclonic wind predominance (Heydorn and Tinley 1980), (3) the occurrence of scorching Berg Winds in winter which result in some of the highest absolute maxima of the year being experienced, and (4) the greater activity of cold frontal lows confined to the coastal zone (Schulze 1965).

The annual variation of mean temperatures is retarded on the coasts so that maxima tend to occur in February and minima in August (Schulze 1965) during the same months when sea surface maximum and minimum temperatures occur. Amplitudes in diurnal variation are damped, and minimum temperatures tend to be stable while maxima show large fluctuations due to intervention of cold fronts, Berg Winds and high variability of cloud cover (Schulze 1965).

The intrinsic asymmetry imposed by the two major ocean currents results in a negative temperature anomaly on the west coast, which is greatest in summer (6° C) and least in winter (2° C). The parallel crowding of low isotherms along the Namib coast is due to the chilling influence of the Benguela Current which affects the west coast for some 3 000 km and through more than 20° of latitude. In this coast region least temperature variation is recorded as it is out of reach of cold fronts and mean summer temperatures are comparable to those of montane areas of Lesotho above 2 300 m (Shulze 1965). On eastern coasts the presence of the tropical Agulhas Current results in a positive anomaly of 2° C in winter (Schulze 1965).

Port Nolloth has the lowest mean annual temperature on the entire coast (14° C) increasing northwards to 21° C at Mocamedes in Angola, and south and eastwards around the coast to 24° C at Inhambane (Figure 13). Mean monthly temperatures are depicted by the climographs in Figure 13. The extreme temperatures experienced along the coast show the majority with absolute maxima of 40° C or more and four stations on the western and south coasts with rare frost recorded (Table 4).

TABLE 4. Extreme temperatures recorded along the coastline of southern Africa (° C)*

Station	Alt m	%Abs Max	%Abs Min
Mocamedes	13	39,0	5,0
Walvis Bay	3	40,0	-4,0
Luderitz	23	38,0	3,0
Port Nolloth	7	42,0	-1,0
Cape Town	12	40,8	-2,0
Cape Agulhas	19	39,0	3,9
Cape St Blaize	60	40,0	3,3
Cape St Francis	8	40,6	1,1
Port Elizabeth	58	40,2	-0,3
East London	125	41,3	2,8
Port St Johns	47	41,1	5,6
Durban	5	42,0	4,1
Cape St Lucia	111	39,0	5,7
Maputo	59	45,0	7,2
Beira	9	43,0	8,0

*Statistics from Africa Pilot 1963.

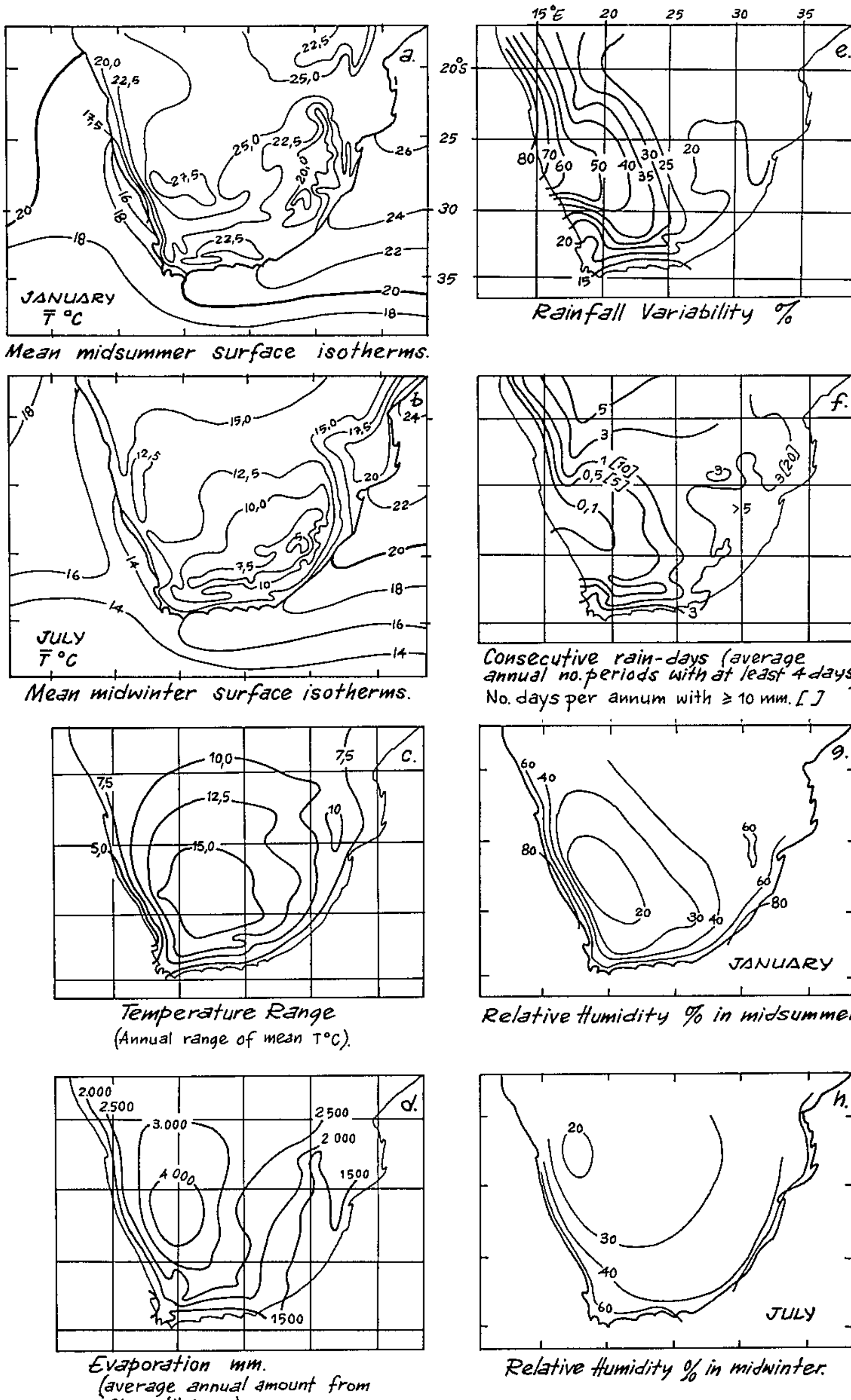
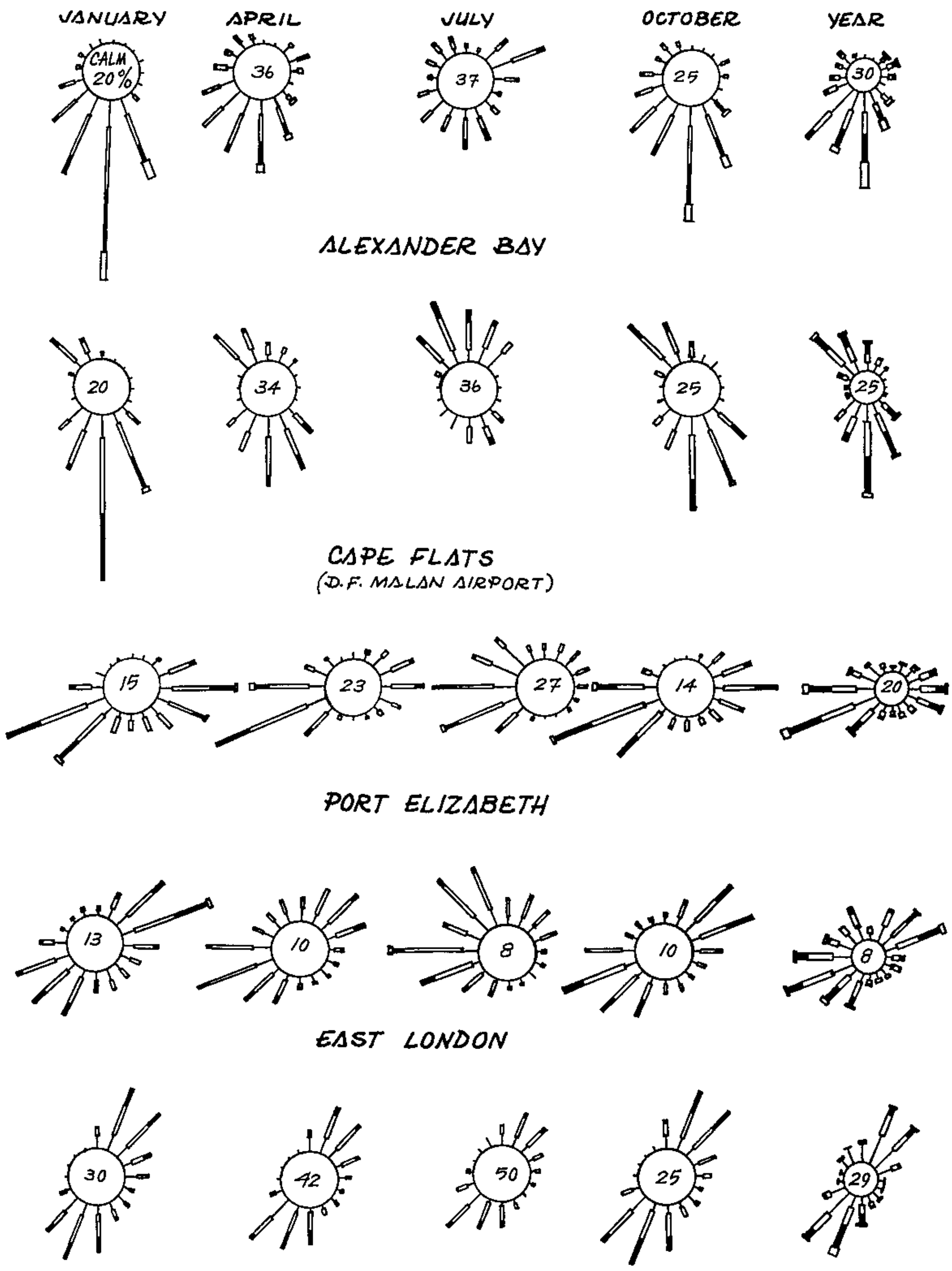


Fig 9 SEASONAL TEMPERATURE & MOISTURE PATTERNS IN SOUTHERN AFRICA.
(FROM SCHULZE 1965).



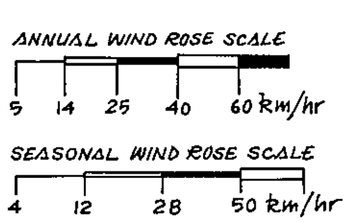


FIG 10

SEASONAL & ANNUAL WIND ROSES FOR SOUTH AFRICAN COAST STATIONS.

D. Wind.

1. Introduction. Around the coastline of southern Africa the directions of the strongest winds are coincident with the predominant winds. Except for the constant Trade Wind coasts on the west and east seaboards where diurnal changes in wind direction occur, the remainder of the coastline, between approximately the Olifants River and Richards Bay, experiences a strongly bidirectional wind regime with the predominant winds blowing in alternation from opposite quadrants throughout the year. On the west, south and eastern coasts, an increase of offshore landwinds becomes a major component of the autumn and winter night and morning air flows.

Except for the offshore landwind component and the directly onshore trajectory of the Trades on alternating sectors of the zigzag east coast, the predominant winds conform obliquely to the trend of the subcontinent's coastline, ie they blow obliquely onshore or offshore along the coast. Local coast configuration is the most important feature along each coast trend determining which areas are exposed to or protected from a particular wind. Where there is an adequate sand supply this is a key factor in coast dune genesis.

The local relief along the coast also modifies winds, steep forelands result in winds being deflected alongshore and increased somewhat in speed (Africa Pilot 1963), and low foreland results in a much broader area being affected by the stronger winds. The entire coastal belt is characterized by strong winds which are less extreme inland and beyond 20 km seawards (Africa Pilot 1954, 1963).

2. Seasonal wind predominance. Wind roses for five stations on the South African coastline are shown in Figure 10. These depict the quarterly and annual values of wind direction frequency for given speed intervals. It was not possible to construct similar diagrams for any other stations as the data for these unfortunately showed either direction frequency only or frequency for given speed intervals without direction.

On the west coast predominant winds throughout the year are southerly (south-south-west to south-south-east), on the south-west coast they are south and north-west, on the south coast west and east, on the south-east coast south-west and east-north-east/north-east, and on the southern east coast east and north-east in Delagoa Bay, and east and south-east north of Inhambane. The westerly low pressure cyclonic winds are predominant in winter and the easterly high pressure anticyclonic winds in summer. The monsoon coast is unusual in that the seasonally opposing winds prevail for six consecutive months at a time.

3. Diurnal variation in wind. Regular diurnal variation of wind speed and direction is a characteristic of all coasts, due to the seasonal, periodic or irregular day and night contrasts in land and sea surface temperatures. On all coasts the strongest wind velocities occur in the afternoons at the hottest and driest time of the day (Table 5).

TABLE 5. Average speeds of afternoon winds around the coast of southern Africa: The most effective* sand transporting winds in the 24 hour cycle.

Locality	Latitude° S	Average Wind speed km/h at 15h00	
Mocamedes	15° 12'	12	
Walvis Bay	22° 56'	24	
Luderitz	26° 38'	38	Western
Alexander Bay	28° 34'	26	Coasts
Port Nolloth	29° 14'	22	
Cape Town	33° 54'	22	
Cape Agulhas	34° 50'	24	
Mossel Bay	34° 11'	16	Southern
Port Elizabeth	33° 59'	26	Coasts
East London	33° 02'	26	
Durban	29° 50'	20	
Maputo	25° 58'	20	Eastern
Beira	19° 50'	16	Coasts
Mossuril	14° 57'	10	

*Threshold for effective transport of dry sand is from 16 km/h upwards (statistics from Africa Pilot 1954, 1963).

(a) West coast. The force and constancy of the Trades decreases from south to north, from an average of 36 km/h between the latitudes 30° and 25° (Port Nolloth - Luderitz) to 24 km/h between 25° and 20° (central Namib) to eight km/h between 20° and 10° (Angolan Namib). It is thus no coincidence that the source area of the Namib Sand Sea is along the coast directly opposite the core of the South Atlantic High where high average wind velocities are most consistent. At Luderitz for example the average wind force is 45 km/h and gales are common. In this sector morning winds are southerly in summer with an easterly landward component averaging 16 km/h, which is replaced in the afternoons by a southerly wind with a westerly seaward component blowing with a mean force of 45 km/h (RN and SAAF 1941/44; Africa Pilot II, 1963; Rogers 1977).

In early mornings a light northerly breeze is common and this backs during the course of the day to the strong sea wind which develops at 14h00 from the south-south-west. After sunset the wind drops gradually and backs throughout the night traversing all easterly directions reaching north at dawn, completing the circuit in 24 hours (RN and SAAF 1941/44).

In winter the Trade Wind belt is between 5° and 10° further north than in summer and in this low sun season offshore northerly, and easterly land winds are important. Of these the scorching Berg Winds are the most important, five per cent of which reach gale force carrying large volumes of sand into the surf zone and dust plumes several hundred kilometres seawards. A unique example of this is seen on the Meteosat photograph of Africa on 13 June 1979 which shows two dust plumes being simultaneously blown by gale Berg and Harmattan Winds off the desert coasts at opposite ends of the continent. One with a plume reaching over 500 km over the South Atlantic from south of the Orange River mouth, and the other blowing to 1 000 km over the North Atlantic from off the west, Mauritanian, coast of the Sahara (Map 11 in Hurry and van Heerden 1981).

On the Namib Coast, however, even these gradient winds are usually interrupted in the afternoons by the south-south-west sea breeze between 14h00 and 20h00, the Berg Wind resuming at 06h00 the following day (RN and SAAF 1941/44; Logan 1960).

Dust and sand storms occur in practically all months of the year (15 days/year) with their highest frequency from May until October, and are associated with both the easterly Berg Wind and the south-west onshore Trade Wind (Plate 55). The west coast is thus unique as a region in which considerable transfer of sediment from the land to the sea is affected by deflation.

Due to strong seaward flowing air at the level of the plateau over the west coast air is removed from above the coastal region resulting in a pressure drop and the formation of a low pressure cell. These lows temporarily replace the Trades causing north-west onshore winds to blow at right angles to the prevailing Trades direction. They bring sea fogs with light drizzle and a rise in sea surface temperature, up to 23° C recorded at Walvis Bay (RN and SAAF 1941/44) due to the resultant southward spread of the warm Angola Current (Bremner 1977).

In summary the strongest onshore winds on the west coast occur at the hottest and driest time of the day all year, but particularly in summer when the pressure gradients are strongest, providing optimal dune forming conditions.

(b) South-west coast. Unlike the west coast which has a prevailing strong unidirectional Trade Wind predominance throughout the year with periodic interruptions from Berg Winds and coastal lows, the south-west coast and the seaboard eastwards experiences a strongly developed bidirectional wind regime with predominant winds blowing seasonally from opposing quarters. The principal changes in wind direction are due to alternating successions of depressions and the anticyclones which follow them.

Although winter is less windy than summer (Figure 11) prefrontal north-west gale winds brought by depressions, are followed by southerly gales when the wind backs and anticyclonic high pressure winds blast in behind the front as it moves eastwards. The summer dry season is the windiest season of the year particularly in December and January with an average wind velocity of 24 km/h of predominantly strong south and south-east winds normally accompanied by fine weather though orographic cloud often develops on the mountain summits. August is the calmest month of the year with an average wind speed of 11 km/h.

Unlike all the other coasts the nocturnal and early morning land breeze circulation is weakly developed in this region due to the inhibiting effect of cold nearshore waters (Fuggle and Ashton 1979). In summer at Cape Columbine for example 56% of winds in the morning (08h00) are from the south-east and south, and in the afternoons (15h00) 70% are from the south and south-west. Northerly winds tend to back to north-west and west, and southerly winds, which are generally stronger, tend to veer to south-west (RN and SAAF 1941/44).

Light winds often blow from opposing sides of the Cape Flats during periods of warm weather associated with prefrontal conditions. This is due to the development of a light north-west sea breeze on the Atlantic side and a southerly sea breeze on the False Bay side which entrains the south-easter freshening in the afternoons (RN and SAAF 1941/44). Some 20 km offshore the frequency and force of the south-easter decreases and its highest occurrence and force is between Danger Point and Cape Columbine (Africa Pilot II 1963).

In winter average wind speeds are 14 km/h in the mornings increasing to 20 km/h, and in summer from 20 km/h to 28 km/h. Strong dune-forming winds occur in the summer dry season as evinced by the series of climbing dunes along the east-facing False Bay coast of the Peninsula. By comparison north-west formed dunes are rare, confined to only two sites on the entire coast, at the Bot River mouth and in Walker Bay.

In dune building terms the unique feature of this winter rain coast sector is the coincidence of the windiest season of the year with the parched conditions of the summer dry season.

(c) South coast. On the Cape south coast westerly winds occur throughout the year, the main seasonal differences being the higher frequency of easterlies in spring and summer (Figures 10 and 11). Strong south-east winds which give clear dry conditions on the south-west coast tend to bring unsettled weather to the south coast with low cloud and drizzle (RN and SAAF 1941/44). In this region there is a slight sea breeze throughout the year, with a moderate to strong land breeze component from the north-west quadrant. Land breeze development is influenced by the local topography and is strongest below the Langeberg and Outeniqua ranges and particularly down the main river valleys, such as the Gouritz, which breach the mountain barriers acting as air ducts for the katabatic wind which impinges the coast from the north-west quadrant.

Where plainsland backs the coast as at Cape St Francis the land breeze is weakly developed, but appears again more strongly at Jeffreys Bay around the northern margin of St Francis Bay to Port Elizabeth. The alternation of sea and land winds is most frequent from June until August with cloudless nights and when warm Agulhas water is closest to the coast. The land breeze begins typically at 21h00 and backs during the course of the morning to the prevailing west and south-west winter wind direction.

The windiest season on the south coast is from midwinter to spring with strongest winds in the afternoons. Cape Agulhas at the western end of the south coast is the windiest area year round along the South African coast with the least per cent calms, (4%), increasing to 17% calms at Mossel Bay (Cape St Blaize) and 20% at Port Elizabeth at the east end of the region (Figure 10).

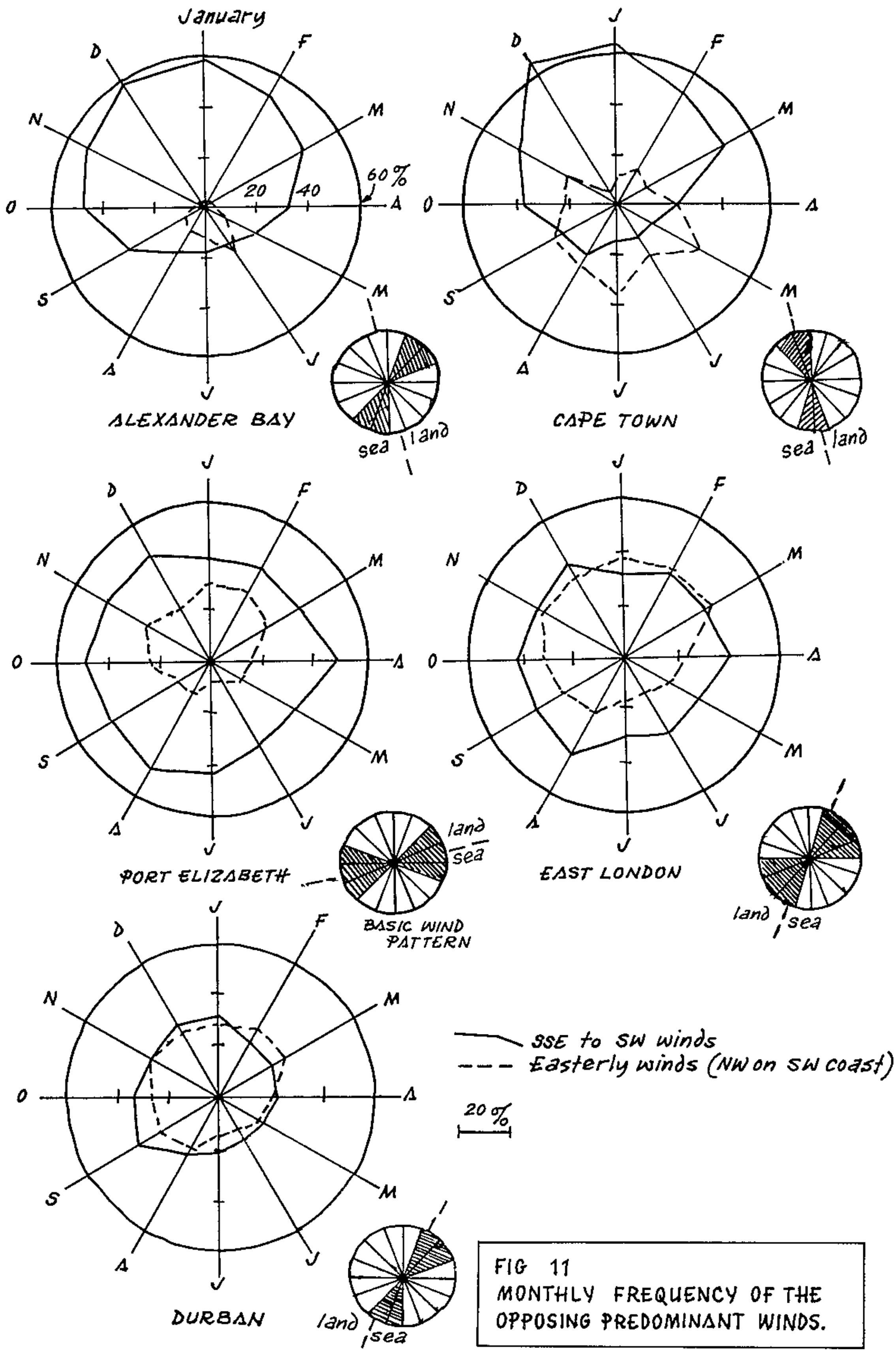


FIG 11
MONTHLY FREQUENCY OF THE OPPOSING PREDOMINANT WINDS.

At Cape Agulhas mean morning wind speeds in January are 18 km/h and in the afternoons freshen to a mean of 26 km/h. In winter mean speeds are 18 km/h all day. The lowest average wind speeds at Cape Agulhas between 21h00 and 10h00 are equivalent to Cape Town's highest between 12h00 and 19h00 (RN and SAAF 1941/44).

The Mossel Bay area experiences the lowest recorded wind velocities along the south coast. At Port Elizabeth mean morning wind velocity in January is 18 km/h in the afternoons whilst in July the change is from 14 km/h in the afternoons.

(d) South-east coast. The southern sector of this region is similar to the regime recorded at Port Elizabeth with high wind velocities all year round, East London having the second lowest frequency of calms after Cape Agulhas. The autumn is the calmest period and spring and early summer the windiest. At the northern end of the south-east coast in Natal winter days are warm and dry with long periods of light winds, whereas at East London westerly winds predominate.

There is a regular diurnal variation in wind direction and speed depending on the steepness of the pressure gradients. In the summer when the easterly wind is strong it backs slightly to north-north-east or north at night and veers back to north-east (Durban) or east-north-east (East London) in the day. When south-west frontal winds occur they back at night to west and return to south-west during the day. As the front passes the south-west wind backs to a strong south wind, which moderates and backs around to the north-east quadrant.

The seasonal predominance of winds in this region is north-east onshore winds in spring and summer and south-west offshore winds in autumn and winter. The contrast in the diurnal wind regimes at the two ends of the south-east coast is illustrated by comparing the mean wind speeds and precentage calms for East London and Durban at the same time (Figure 10; Table 6).

These data show a drop in the mean afternoon wind velocity regime in Natal with increased percentage of calm weather particularly in the dry season which correlates with the small dune region of the monocline coast. Wind velocities increase again northwards on the Zululand to south Mocambique east coast sector where the lowest percentage calms recorded on the entire southern African coast at Maputo is coincident with a dramatic increase in coast dune dimensions.

In September, the windiest month, afternoon mean wind speeds are 32 km/h at East London, and 22 km/h at Durban, coincident with the arrival of the first rains. In the calmest months at the two stations, East London has a higher mean wind force than Durban in its windiest month, ie East London 24 km/h in May and Durban 14 km/h in July (Africa Pilot III, 1954; South African Weather Bureau 1960, 1975).

When clear skies at night coincide with slack pressure gradients, land breezes can form at any season but have their highest frequency and velocity in the autumn and winter. At this time the gradient wind drops by sunset and the land breeze is initiated earlier in the evening and lasts later in the mornings until about 10h30. In summer the land breeze is only initiated between 21h00 and midnight and is replaced by the gradient wind at dawn or by 06h30 at the latest.

TABLE 6. Wind values at eastern coast stations: Comparison of mean morning and afternoon wind speeds and per cent calms for summer, winter and the year

Lat S	Station	JANUARY am	JANUARY pm	JULY am	JULY pm	YEAR am	YEAR pm
14° 57'	Mossuril	4(60)	8(42)	8(46)	12(35)	6(56)	10(38)
19° 50'	Beira	12(18)	18(6)	12(11)	14(10)	12(17)	16(6)
25° 58'	Maputo	14(3)	22(0)	16(1)	16(1)	16(2)	20(1)
29° 50'	Durban	14(21)	22(2)	8(38)	18(5)	10(30)	20(3)
33° 02'	East London	16(15)	28(1)	18(5)	22(4)	16(10)	26(2)

Wind speeds in km/h, per cent calms in parenthesis (data from Africa Pilot III, 1954).

(e) East coast. Though the diurnal wind speed pattern is similar at Durban and Maputo in mid-summer, there are less calm periods particularly in the later mornings at this time in the latter area. In dune forming terms the southern Mocambique Plain winter dry season wind velocity regime is more conducive to effective sand transport due to higher mean speeds all day and only one per cent of calm weather (Table 6). The more active wind regime in southern Mocambique is a direct result of stronger pressure gradients from the close proximity of the landward extension of the south Indian Ocean anticyclone (the 'Limpopo High'), and the strengthening of the Trades in winter in response to their entrainment into the south-west monsoon.

This more active sand transporting sector gives way in central Mocambique (Beira data) north of Bazaruto Island to decreasing mean wind velocities and increasing periods of calm weather reaching a maximum on the monsoon coast (Mossuril data) where dune development is minimal (Table 6).

In Delagoa Bay the predominant winds are either longshore (south-south-west 14%) or obliquely onshore (east-north-east 13,4%; south-south-east 13,0%), of these the highest percentage of stronger winds above 20 km/h are those from the south-south-east (7,3%), easth-north-east (6,9%) and south-south-west (6,7%) (Mocambique Meteorological Services 1968). On Inhaca Island at the point of the peninsula enclosing Delagoa Bay all parabolic blowouts on the seaward dune range are aligned from between south-east and south-south-east.

Not only are winter dry season winds generally stronger and more persistent in this sector, but the first effectively wetting rains (50 mm or more), which arrive at the same time as the strongest winds in Natal, only arrive here in November after these winds have occurred.

From the Bight of the Limpopo northwards the north-east component of the Trades diminishes as the south-east component becomes increasingly dominant all year towards Beira and the Zambezi Delta (eg at Beira east-south-east 16%, south-east 12%, east 11%, from Correia 1969). North of this is the monsoon coast where the windiest season is in winter, when south-east trades freshen as they become entrained to recurve past the equator as the south-west monsoon (da Rocha Faria and da Mata 1965; Tinley 1971b).

The nocturnal and early morning land breeze component is a characteristic feature of the whole of the Mocambique Coast and is strongest in the extreme south (including Tongaland), centre and north (Tinley 1971b, 1977).

On the Gazaland coast sector the land breeze is weakly developed due to the wide gap in the eastern Great Escarpment between the Limpopo and Save Rivers. Whilst the land breeze may not be of any dune building importance this component of the diel cycle is a valuable source of moisture in the dry season. This is derived from the accompanying katabatic fogs and coastal rains produced by the interaction of the Trade air with the underlying land breeze air (Preston-Whyte 1970).

4. Gale winds. Gale force winds transport the largest volumes of dry sand over the shortest period of time, except if the winds are rain-bearing or where the sands have been previously wetted by rain. Figure 12 illustrates the patterns of effective gale occurrence on the long term. Except for the hurricane coasts of Madagascar and northern Mocambique (Tinley 1971b) gale wind frequency increases southwards from the tropics with increasing latitude to a winter maximum of over 30% between Cape Agulhas and East London (Africa Pilot III 1963). This conforms with the overall wind power increase towards the Roaring Forties belt of westerlies. Despite their seasonality, gale frequency is highly variable from year to year in all coast sectors. Some Berg Winds, particularly on the west coast, also reach gale force.

TABLE 7. Winds of 50 km/h and greater strength (lasting from one to 18 hours duration)

Locality	Gale Months	Av Freq/yr
Luderitz	Oct - Jan	70
Alexander Bay	Oct - Jan	81
Cape Town	Dec - Jan, July	11
Port Elizabeth	Oct - Dec	21
East London	Oct - Jan, June-July	21
Durban	Sept - Dec	12
Maputo - Inhambane	Sept - Dec	8

(data from Africa Pilot III 1954, II 1963 and South Africa Weather Bureau Publication No 26, 1960).

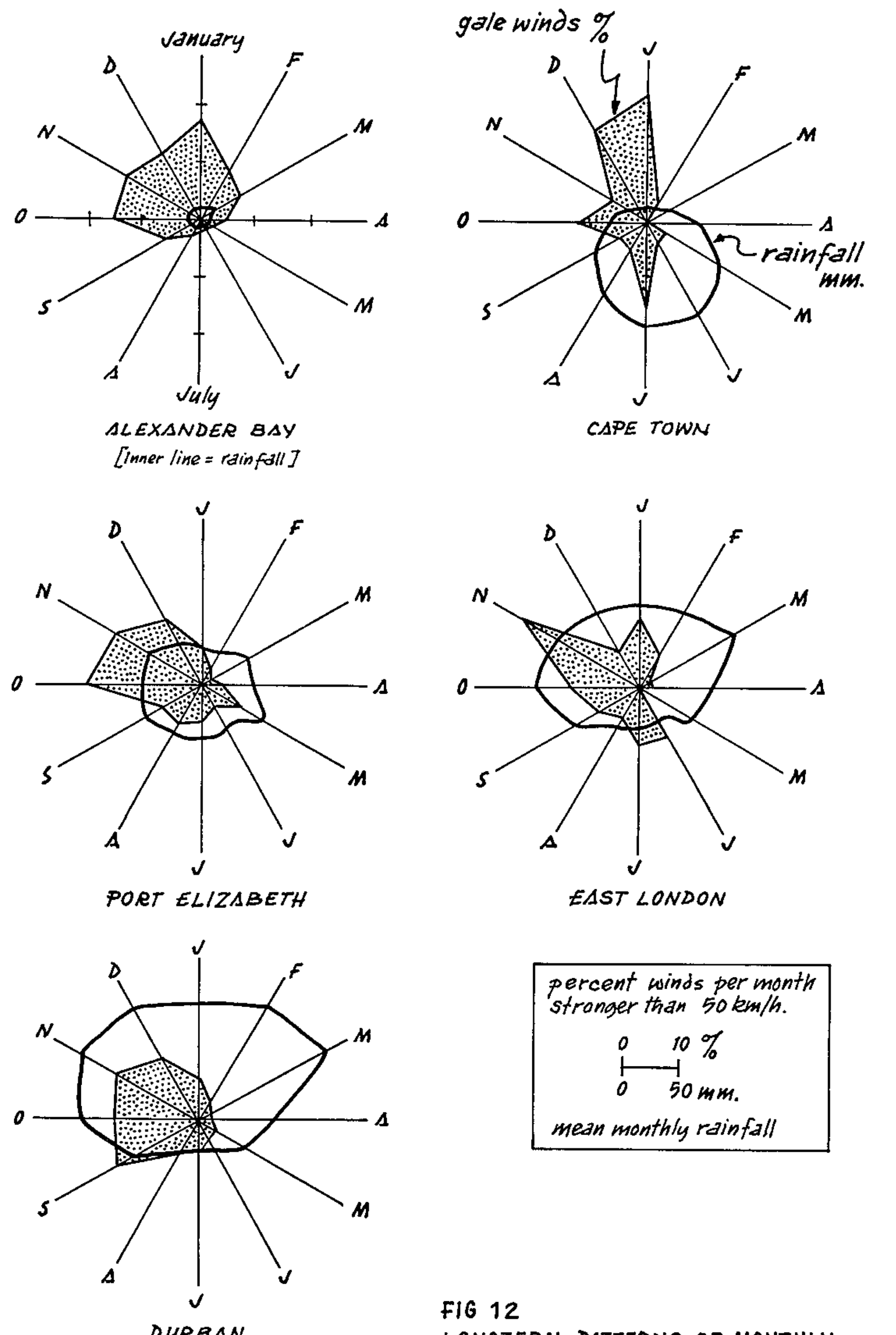


FIG 12
LONGTERM PATTERNS OF MONTHLY GALE WIND FREQUENCY & RAINFALL OCCURRENCE.

The most effective strong wind regimes along the subcontinent's coastline are where these coincide with a summer dry season, as in the south-west Cape and Namaqualand Coast, or with desert conditions, as in the Namib north of the Orange River. The prevailing Trade Wind direction on the west coast reinforces the direction of south-west swell originating in the "Roaring Forties" and is thus a multiplier factor in the nett transport of sandy sediments northwards up the coast. On the other coasts with their bidirectional wind regimes the overall east and northward nett longshore and dune transport of sand is interrupted and reversed when strong easterly anticyclonic winds persist. On the south coast summer and winter periods are driest, on the south-east coast between June and August, and on the east coast from winter to the end of October.

Table 7 indicates the average annual frequency of the stronger winds around the coast with two peak areas. The highest by far between Port Nolloth to north of Luderitz, and a second lesser, but significant, gale area between about Cape St Francis and Kei Mouth. This is related to a separate summer gale generating region south-east of Port Elizabeth in the area of the Agulhas Current return gyre (Davies 1980). The attainment of strong to near gale force velocities by the Trade Wind during the afternoons is a unique feature of the Orange River to Luderitz sector of the South African coastline. The only other area nearby where such a phenomenon occurs is on the north-east coast of Madagascar at Diego Suarez where the south-east Trades regularly attain force seven and eight on winter afternoons (RN and SAAF 1941/44).

Hurricane tracks generally follow the eastern margin of the Mocambique Channel and recurve to the south-east on a dissipatory path into the open ocean south of Madagascar (Tinley 1971). On occasions they stray sufficiently close to the south Mocambique and Zululand coasts to effect massive damage of dunes. This occurred in 1970 when large-boled dune milkwoods and other trees littered the length of the Tongaland sector, precluding any movement by vehicles along the beaches (Ron McDonald pers com 1980). Hurricanes or tropical cyclones are a summer phenomenon with their highest frequency between January and March. Hurricanes erode dune coasts in three ways (a) turbulent gale force winds, (b) torrential rains which cause massive donga slumping of the steeper forested dune slopes, and (c) extensive undercutting of frontal dunes by storm surf.

5. Berg winds. Extremely hot, dry and turbulent subsiding air formed by anticyclonic winds blowing from the continental interior seawards. They are experienced on all coasts from the Namib around to Delagoa Bay. Occurring chiefly from the autumn until spring, they have their highest frequency on the west coast (50 per year) where they can occur for up to 10 consecutive days at a time (RN and SAAF 1941/44). Berg Winds are most common in winter but they may occur whenever the pressure patterns are favourable. Berg Winds are responsible for the anomaly of some of the highest temperatures on the coasts being recorded in the winter (Table 4).

With the arrival of a Berg Wind the increase in temperature, day or night, can exceed 10° C, and the drop in temperature when the winds back to south-west with the arrival of the cold front which replaces the Berg Wind at the coast, can exceed 15° C (Tyson 1964).

The Berg Wind's low absolute humidity results in tinder dry conditions and dangerous veld fires often occur in the fynbos of the south-west and south coasts, and the grasslands of the eastern coasts. On the south-east and southern east coasts strong Berg Winds are responsible for carrying devastating fires from the landward savannas into mature forest and thicket of the dunes.

Their prevalence in winter results in a bimodal fire hazard in the winter rain region of the Cape, where a summer dry season fire peak is followed by winter rain season fire peaks associated with Berg Wind conditions. Hence a bimodal phenology is imposed on the fynbos ecosystem quite apart from the out-of-phase influences of the rainfall and the thermal regimes (Heydorn and Tinley 1980).

E. Precipitation.

Two main kinds of precipitation occur along the South African coastline: (a) rains resulting from the interaction of macro- and mesoscale processes characteristic of the greater part of the subcontinent's coast, and (b) the fine drizzle derived from advective sea fog characteristic along the desertic west coast and from orographic fog where high forelands abut the shoreline.

1. Rainfall. The patterns of mean annual rainfall, moisture region distribution and rainfall regimes are depicted in Figure 13. In the same figure climographs constructed for coast stations show the monthly sequence of wet or dry periods against the march of the mean monthly temperature curve through the year.

On the west coast the rare showers of measurable rain are from thunderstorms that are able to penetrate coastwards over the desert from the Great Escarpment.

The climographs also show the severity and duration of the arid period or dry season which occurs all year on the desert coast, in summer in the winter rain region, in midsummer and midwinter in the bimodal rain areas and in winter and spring up the eastern coasts.

The south-east coast and southern east coast to about Kosi Bay show relatively mild dry seasons on the long term. From Delagoa Bay northwards to the Save River the dry season is more pronounced again especially in the pre-rain spring when the strongest wind velocities are usually experienced. Midsummer droughts remain a feature of the east coast stations due to the persistent re-establishment of the Limpopo High, and to the interruption caused by the centripetal airflow from all surrounding regions to tropical cyclones (hurricanes) passing seaward of the coast (Griffiths 1972; Tinley 1977). Quite the opposite condition results, however, when a hurricane approaches or crosses the mainland coast producing torrential flood rains driven by gale force winds. The catastrophic impact of these tropical cyclones on landscapes and soft coasts is well exemplified by the recent passage of hurricane Demoina when it crossed the south Mocambique Coast during the first week of February 1984.

In southern Africa cyclonic frontal rains begin in the south-west in autumn, and progress eastwards along the south coast in winter and spring as the winter rains of the south-west Cape tail off, and spread further in a northerly and north-easterly direction in spring reaching the Natal coast in September and the Transvaal Highveld in November (Schulze 1965). At this time due to the development of the heat low over the interior, the tropical anticyclonic rainfall regime takes over advecting moist marine air from off the Indian Ocean across the east coast, escarpment and interior. This regime develops progressively south and westwards with maximum rains over the eastern margins in January and later in March over the western interior to Bushmanland (Taljaard 1982).

Some of these rain-bearing winds penetrate to the west coast desert but are usually blown back by the westerly winds recurving from off the South Atlantic anticyclone's predominantly south and south-west winds.

Over the greater part of southern Africa there is typically an abrupt cessation of rains in April just as winter cyclonic rains are beginning in the south-west Cape where they reach a maximum in July. This coincides with the equatorward shift of the pressure belts with the sun, bringing the westerlies and their successions of polar fronts closer, and causing the dissipation of the heat low over the interior at the time of the autumnal equinox.

From the south-west Cape to the south-east coast near Kei Mouth, where inshore sea temperatures are generally cold, low rainfall occurs where the coastlands are low, and higher rainfall only where abrupt relief occurs on the foreshore (eg Cape Peninsula, Tsitsikamma, Transkei Wild Coast). Further north up the eastern coast where warm seas abut the shore, high rainfall becomes associated with the land-sea junction with an increasingly drier hinterland where it is low (eg Gazaland) and the recurrence of a second rain peak on any escarpment or range. The high rain zone along the immediate coast is enhanced considerably wherever local abrupt relief is afforded by high coastal dunes, as along the coast of the Mocambique Plain. Here the dune range is generally more than 60 m high with sectors over 100 m where the highest rainfall is experienced, but where concomitantly markedly drier leeward 'shadow zones' bring the lower isohyets closer to the coast. Where there are gaps in the dune range at river mouths the higher isohyets curve landwards (Tinley and van Riet 1981).

Another important source of coastal precipitation in winter on the warm water coasts with steep hinterlands, are the land breeze-associated rains reported from Natal (Preston-Whyte 1970) and central Mocambique (Tinley 1971b, 1977). These are nocturnal and dawn drizzle or showery rains, from cumulo-congestus and cumulonimbus cloud formed at the interface of the cool saturated wedge of land breeze air flowing seawards beneath warmer marine air moving inland. A flat hinterland slackens the land breeze such that it acts almost as a "standing front" at the coast, rather than a seaward moving wedge of cold air, and rains are then confined to the shoreline zone.

Another rain source on the eastern coasts in summer, notably in Natal and central Mocambique, is that from thunderstorms carried seawards by the upper westerly wind from their area of genesis in the afternoons along the Great Escarpment with ascending sea winds. These rains can affect large areas of the hinterland as well as the coast.

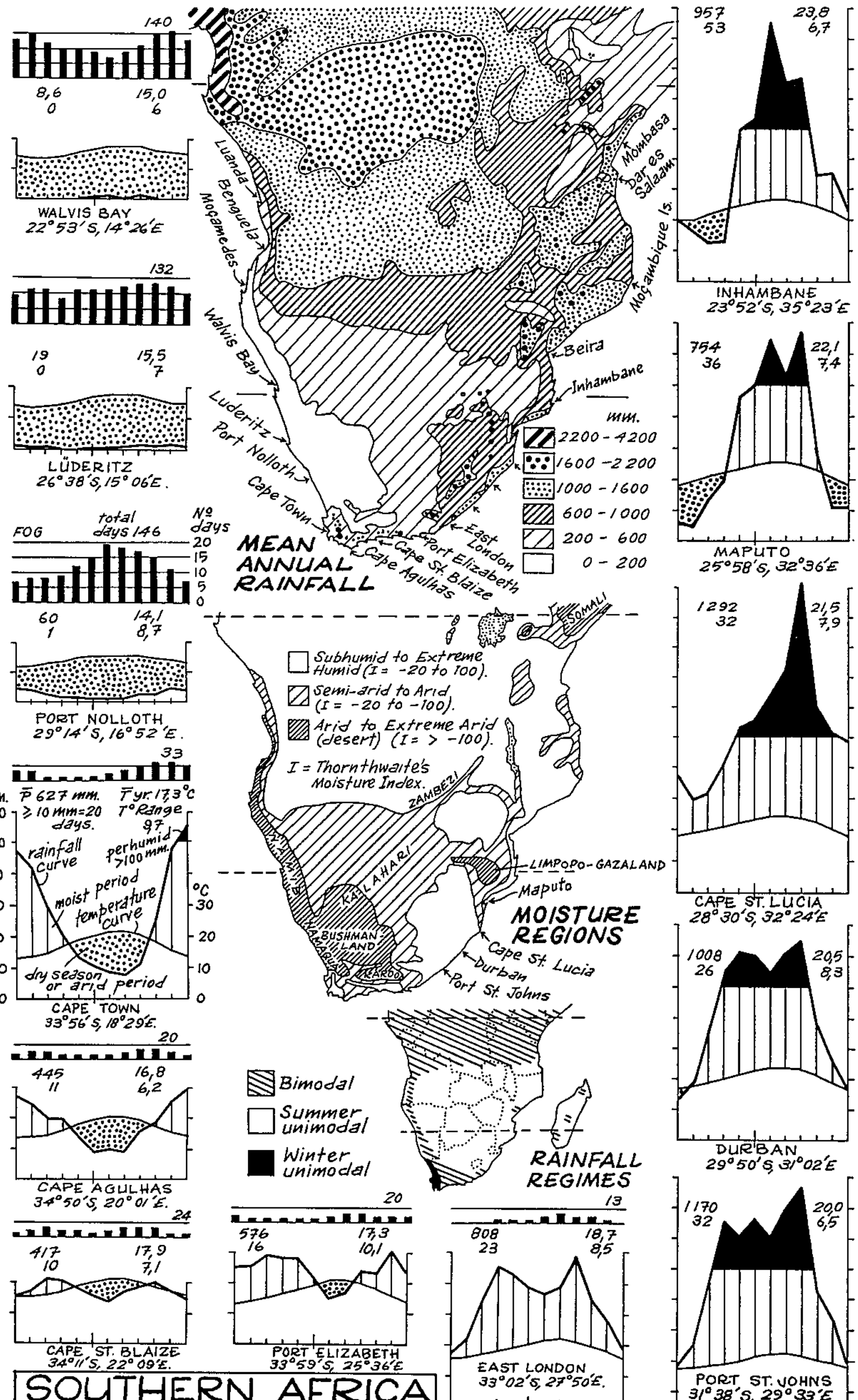

MEAN ANNUAL RAINFALL
mm.
2200 - 4200
1600 - 2200
1000 - 1600
600 - 1000
200 - 600
0 - 200
Luanda
Benguela
Moçamedes
Walvis Bay
Luderitz
Port Nolloth
Cape Town
Cape Agulhas
Cape St. Blaize
Port Elizabeth
East London
Beira
Inhambane
Mombasa
Dar es Salaam
Moçambique Is.
MOISTURE REGIONS
Subhumid to Extreme Humid (I = -20 to 100).
Semi-arid to Arid (I = -20 to -100).
Arid to Extreme Arid (desert) (I = > -100).
I = Thornthwaite's Moisture Index.
SOMALI
ZAMBEZI
KALAHARI
NAMIB
BUSHMAN LAND
KAROO
LIMPOPO-GAZALAND
Maputo
Cape St. Lucia
Durban
Port St. Johns
RAINFALL REGIMES
Bimodal
Summer unimodal
Winter unimodal
WALVIS BAY 22°53′S, 14°26′E
LÜDERITZ 26°38′S, 15°06′E.
PORT NOLLOTH 29°14′S, 16°52′E.
FOG total days 146
No. days
CAPE TOWN 33°56′S, 18°29′E.
P 627 mm. T yr. 17,3°C
≥ 10 mm = 20 days. T° Range 9,7
rainfall curve
perhumid >100 mm.
moist period
temperature curve
dry season or arid period
CAPE AGULHAS 34°50′S, 20°01′E.
CAPE ST. BLAIZE 34°11′S, 22°09′E.
PORT ELIZABETH 33°59′S, 25°36′E
EAST LONDON 33°02′S, 27°50′E.
INHAMBANE 23°52′S, 35°23′E
MAPUTO 25°58′S, 32°36′E
CAPE ST. LUCIA 28°30′S, 32°24′E
DURBAN 29°50′S, 31°02′E
PORT ST. JOHNS 31°38′S, 29°33′E
SOUTHERN AFRICA
RAINFALL & COAST CLIMOGRAPHS

FIGURE 13

Drought on the coast is associated mainly with the establishment of prolonged anticyclonic activity with their dry descending air masses (Schulze 1965; Tyson 1969; Jackson and Tyson 1971; Hurry and van Heerden 1981). These also affect the winter rainfall areas where outflow of high pressure airstreams from the continental interior result in offshore parched Berg Wind conditions. The rainfall inhibitory features along the coast are thus (a) cold coastal waters, (b) lowlands abutting the coast ie absence of relief, and (c) persistence of high pressure influences.

One of the most important features affecting sand mobility and transport is the coincidence of strong winds with dry or wet periods. (Figure 12 shows these relationships over the long term for various parts of the coast).

2. Fog. Four fog types of quite different origin occur along various sectors of the South African coast. These are (a) advective sea fog, (b) anabatic orographic fog or drizzle, (c) nocturnal and dawn radiation and katabatic valley mist or fog, and (d) foreshore salt spray mist.

(a) Sea fog. Advective sea fog is a characteristic feature of the desertic west coast where an average of 146 fog days per annum occur over the long term. At Swakopmund up to 215 "mist rain" days have been recorded (and as few as 95) with their greatest frequency at the equinoxes (RN and SAAF 1941/44). Fog days decrease southwards and eastwards to 13 at East London where they have an increasingly higher year to year variability and are a summer phenomenon. South of Luderitz fog frequency is highest in summer and at the equinoxes with the onset of strong easterly winds. At Walvis Bay a greater fog frequency occurs in spring and autumn (Figure 13) and the heaviest fogs are associated with coastal low conditions with the wind from the north-west. The heavier fogs are advected as far inland as the base of the Great Escarpment or first orographic line on the southern coast. On the south-west coast the most persistent fog conditions are from the south-east quarter (RN and SAAF 1941/44).

On all coasts experiencing sea fog, the fog is usually associated with the development and longshore movement of coastal lows after cold water upwelling inshore has occurred following a period of strong easterly winds. The lows entrain warm moist air from offshore surface waters which cools and condenses when advected across the cold inshore waters.

The most favourable condition for formation of sea fog is the passage of damp air, with a dewpoint between 18° and 24° C over a cooler sea surface at the time of light winds (RN and SAAF 1941/44). The importance of near-shore sea surface temperature in fog formation is highlighted by their low occurrence in False Bay (about five per year) which is generally some 6° C warmer than the sea on the Atlantic side where between December and May Cape Columbine is enveloped in fog one day in five (RN and SAAF 1941/44).

Whilst this form of precipitation is confined to surface wetting of the ground any obstacle such as stony outcrops or plants concentrate runoff to their bases. This interception by plants has been measured on the Namib Coast where it is estimated that in a three kilometre broad coastal strip, fog precipitation equivalent to 150 mm per annum may be trapped by plants and up to 300 mm on the Namaqualand Coast.

(b) Orographic fog. Ascending saturated sea air which is banked against orographic lines such as escarpments and mountains occurs with the passage of coastal lows and the anticyclonic airstream sucked in behind the low. These are formed on all coasts and are especially common from Namaqualand southwards against the Great Escarpment (eg at Spektakelberg), along the first orographic line of the Cape fold belt, around the southern coast, and against the steep forelands and stepped scarp topography of the south-east coast, northwards past the Zambezi River into south-east Malawi. Along the Lebombo Mountains and the Great Escarpment on either side of the Limpopo-Save gap they occur most frequently in summer from spring until autumn, with a peak from January to March when pressure gradients are at their strongest between Durban and Beira, and least from May to August when the pressure gradient is slackest. During the periods of highest frequency orographic fogs occur from 7 to 10 days apart and last for about 3,5 days in the rainy season and for 2,5 days in the dry season (Kreft 1973).

In the Natal mistbelt, fog occurs on about 10 days per month in the summer, and in the Drakensberg contributes an additional 403 mm moisture per annum (Schulze and McGee 1978). In the south-west Cape 5 664 mm of fog is intercepted per annum from the orographic cloud blanket which pours over the crest of Table Mountain.

(c) Valley fog. This is a radiation fog formed by valley inversions on clear nights, augmented by cold air drainage and intensifying at dawn over some areas of the coast especially at river mouths and in foreland valleys below uplands. Although radiation fogs occur at any time of the year except at the height of the dry season (Tinley 1977), they are a feature of the autumn and winter months in the summer rainfall region. They are reported from all coasts from near the equator southwards and can be carried more than 10 km seawards by the land breeze, only clearing by mid or late morning in autumn and winter (RN and SAAF 1941/44; Africa Pilot 1954, 1963; Tinley 1971).

(d) Foreshore salt spray mist. This type of fog forms frequently over the surf and foreshore zones in late afternoons after strong onshore winds have abated. Dewpoint or condensation is reached first earlier in the afternoons in the shadow inversion formed by a high foreland, such as a dune range. The fog thickens and spreads towards sunset with the development of the evening inversion, banking up against the seaward slopes of the foreland and extending through gaps into estuaries and other low ground.

Such shoreline fogs have only been recorded on the south and east-facing coasts and are sufficiently significant that dune forest epiphytes occur in greater abundance on sea-facing aspects of tree trunks and branches.

3. Guttation and dew. Due to the high year round moisture content of the air on the coasts, heavy dews within several kilometres of the coast are encountered in all months of the year. As can be ascertained by direct observation, however, much of this 'dew' is in fact guttation (Plate 56). Guttated moisture is exuded by plants at specialized pores termed hydathodes. This occurs when soil moisture is near field capacity at night

or in the early morning when no evaporation by sun or wind is taking place. The occurrence of radiation or valley fogs is associated with the pumping out of soil moisture by plants. When guttation stops there is coincidently an abrupt termination of valley fog occurrence, except where high water-table conditions pertain (Tinley 1977).

Heavy dews are therefore generally a post-rain related phenomenon, heaviest deposits occurring in autumn and early winter in the summer rain region and in spring in the winter rain region. Along the Trade Wind Desert of the west coast heavy dews are common throughout the year within several kilometres of the coast with equinoctial peaks related to fog drizzle maxima (RN and SAAF 1941/44).

The attainment of dewpoint and thus of condensation is, however, related to the development of a nocturnal inversion when pressure gradients are slack, hence on gusty, windy nights and especially when Berg Winds occur, excess moisture is removed and little to no guttation or dew is to be found the following morning. Otherwise dew formation in the coast dune zone can be expected on almost every morning of the year, even under drought conditions as experienced in the east Cape during 1982/83.

In the canopy of dune forest and thicket, condensation is sufficiently heavy that birds are able to foliage-bathe in the early mornings of most months of the year. The wetting-drying sequence of dew is similar to that of rain. Westward and especially poleward aspects remain wettest longest, and eastward and especially equatorward slopes dry out quicker (refer to Section 3.3 Soils).

F. Relative humidity.

Due to their position at the land-sea junction, all the coasts have a high year round humidity with a mean annual relative humidity at 14h00 of more than 70% (Schulze 1965). This high humidity is not only from the direct permanent influence of moist marine air, but the coasts are areas of vapour convergence from other sources such as onshore winds, advective sea fog, shoreline rains, moist land breeze air with valley fog and heavy dew formation, and greater cloud cover values than inland.

The mean morning and afternoon relative humidity values for coast stations show that the moisture of the air is highest on the west coast fog desert and relatively lowest where low coastland abuts the coast or where offshore winds, other than the land breeze, prevail for a large part of the year (Table 8). The mean annual range of relative humidity is least on west, south-west and east coasts where it is less than 10%, and greatest on the south-east coast between the Great Fish and Kei Rivers where it is from 20 to 25% (Schulze 1965). Night-time and early morning humidity values remain at a high level everywhere along the coast throughout the year.

At all localities, however, drops in humidity to less than 10% are caused by the intervention of Berg Winds, as occurred on 11 June 1979 at East London where a 3% humidity was recorded at 14h00 with a strong Berg Wind gusting to 108 km/h.

TABLE 8. Relative humidity at coastal stations* (mean values morning and afternoon periods)

Locality	RH% 08h00	RH% 14h00
Mocamedes	81	72
Walvis Bay	89	70
Port Nolloth	88	79
Cape Town	83	60
Cape Agulhas	87	73
Cape St Blaize	82	69
Port Elizabeth	81	63
East London	72	65
Durban	86	70
Cape St Lucia	84	70
Maputo	70	63
Beira	75	65
Mossuril	70	65

*(data from Africa Pilot 1954, 1963).

The annual variation of relative humidity on each coast conforms closely to the rainfall regime, or to sea fog occurrence in the case of the west coast. Although the diurnal variation generally shows an opposite curve to the diurnal temperature curve, lowest humidity on the coast is generally between 09h00 and 12h00 before the freshening sea breeze raises the moisture content of the afternoon air (Schulze 1965). The monthly mean relative humidity at 14h00 for South Africa is mapped in Schulze (1965) and for the continent near sunrise and midday for each quarter by Thompson (1965).

G. Evaporation.

The average annual evaporation from a free water surface is highest in the summer dry region of the south-west Cape and along the desertic west coast, where the lower values are on the coast itself (just above 2 000 mm) increasing to 3 000 mm in the coast hinterland (Schulze 1965).

A second high evaporation area on the coast occurs at the junction of the south and south-east coasts between Algoa Bay and the Great Fish River (eg Port Elizabeth 1 956 mm). Lower values are recorded up the remainder of the south-east coast, rising again to 1 868 mm near the tropic on the Mocambique Coast (Table 9; Schulze 1965).

The zone of lowest year round evaporation (1 500 mm) occurs along the south coast, coincident with the region of least rainfall variability (Schulze 1965).

TABLE 9. Evaporation from a free water surface at coastal stations (average mm)*

Locality	January	July	Year
Alexander Bay	297	130	2464
Cape Town	323	71	2141
Port Elizabeth	249	79	1956
East London	198	94	1727
Durban	203	89	1755
Maputo	125	108	1419
Inhambane	179	126	1868

*(data from Schulze 1965; Tinley 1971. Readings from Class 'A' (American) evaporation pans)

Seasonally the highest evaporation on all coasts is in midsummer, when more than 30% of the average annual moisture loss occurs, with a maximum of more than 40% in the winter rain region. Least evaporation occurs in autumn and winter with a minimum of less than 15% in the winter rain region. Spring is intermediate with highest values along the desert coast and the east tropical coast where rains only arrive in November (Schulze 1965).

The evaporation values relate closely to the increasing and decreasing cloud cover values related to various rainfall-dry season sequences along the coasts as well as to the seasonal march of the thermal regime (compare Figures 20-27 and 32-35 in Schulze 1965). The higher levels of solar radiation on the desert west coast and the tropical east coast are reflected in the high rates of evaporation experienced in these regions.

3.2.4 Implications of large scale sea surface temperature - atmospheric interactions

Long-term historical temperature and rainfall fluctuations have been found to vary inversely over the last 100 years of record, reflecting similar persistent oscillations in the general circulation over South Africa (Schulze 1965; Tyson 1978). Periods of higher temperature with lower rainfall likely resulted from the predominance of anticyclonic systems over the subcontinent with their dry subsiding air masses favouring clear skies, dry air and high radiation (Schulze 1965; Tyson 1978).

Conversely low temperature - high rainfall periods in South Africa are likely related to the predominance of cyclonic low pressure systems of the westerlies belt which have their greatest activity in winter and spring, favouring increased convergence and cloud cover-over with decreased radiation (Schulze 1965; Tyson 1978).

Some of the weather processes which have characterized the recent 1982/83 drought conditions in the summer rainfall region are:

(a) The prevalence of strong negative pressure anomalies in the westerlies south-west of the Cape, resulting in a strong zonal air flow with a greater number of fronts, in a more northerly position than usual, bringing above average rains confined to the south-west and south Cape, (b) dearth of strong high pressure systems south of the continent in the westerlies belt which are normally responsible for bringing cool moist air over the east and interior of the subcontinent, (c) stronger than normal high pressure (positive pressure anomalies) over the interior and above in the upper air resulting in aridity and higher temperatures than normal, (d) high pressure system of the South Atlantic and South Indian Oceans stronger than usual, the former centred further north and the latter further south (blocking high) than usual deflecting the fronts south-eastwards away from the eastern margins, and (e) associated with these features is typically the low frequency of trough development over the land in the easterly Trade Wind flow (Schulze 1965; Tyson 1969, 1978; Hurry and van Heerden 1981; Schulze 1983). Drought conditions in the summer rainfall region thus have many features in common with winter synoptic conditions.

Exceptionally wet summers over the eastern and central parts of the subcontinent are associated with (a) a deeper continental trough (negative departures in pressure over the interior) due to the strong development of a heat low, incursions of tropical Congo air and a greater frequency of trough development in the easterlies over the land (upper air lows), (b) stronger anticyclonic activity south of the subcontinent in the westerly belt of frontal genesis, (c) more southward position of the South Atlantic high and prevalence of easterly winds over the south and south-west Cape where dry conditions pertain in summer (references as above). Summer synoptic conditions which occur in winter are responsible for the failure of rains in the south and south-west Cape.

These irregular fluctuations of flood and drought conditions, when synoptic patterns resembling those of the opposite season prevail, are linked to the change in predominance of high or low pressure conditions which last for several years in one ocean region then fade in favour of the same condition in another ocean. This is a global-scale see-saw phenomenon referred to as the Southern Oscillation (SO) which apparently occurs in response to large-scale anomalous changes in sea surface temperatures (SST's) (eg Boucher 1975). In studying recent papers on this subject (Schulze 1983) the clear impression obtained from the data is that a reciprocal relationship exists in the SO between strength and position of the pressure systems, wind regimes and SST's.

The SO has a low (negative) and high (positive) phase, and associated with the low phase of the SO have been the following events: (1) incursions of warm surface water (positive SST anomaly) off the Peruvian coast resulting in flood rains in the Atacama Desert (El Nino phenomenon), (2) a simultaneously occurring spread of cold surface water (negative SST anomaly) across the Atlantic from the Namib Coast towards north-east Brazil followed by extreme drought in north-east Brazil several months later (Markham and McLain 1977), (3) drought in southern Africa and Australia coincident with the El Nino phenomenon, as well as in India due to the weak development of the south-west Monsoon, and (4) the low frequency of easterly wave development (troughs) in the Trade Wind air stream is associated with the low SO phase (drought in the tropics), and high frequency with the high SO phase (Schulze 1983).

By analysing the SST's across the Atlantic between 5° N and 30° S Markham and McLain (1977) were able to identify an indicator quadrant that showed the highest correlation with subsequent rain (warm SST's) or drought (cool SST's) conditions that could be expected in north-east Brazil within certain confidence limits. The rainiest periods in this region did not occur when the Trades were strong, but when the South Atlantic high was weak or retreated to the south allowing flows with a northerly component to penetrate landwards. A hallmark of the recent drought conditions in South Africa has been the prevalence of negative pressure anomalies south-west of the Cape with the south Atlantic high either further north or stronger than usual, which fits the synoptic conditions causing drought in north-east Brazil as well. It would seem that the singular research done by Markham and McLain (1977) should be extended to cover the rest of the South Atlantic and Indian Ocean to try and track down an SST indicator quadrant using satellite imagery that could possibly be used for forecasting droughts in southern Africa and Australia.

The SO and the global circulation is strongest during the southern summer when the high pressure Trade Wind systems are at their strongest. Of all the Trade systems those of the Indian Ocean maintain the highest year round velocities (Crowe 1971). A continuous band with a negative SST anomaly extends north-west across this ocean in winter and spring following the path where the South-East Trades have their highest constancy in direction and strength (Crowe 1971) and recurve across the equator near Africa to form the south-west Monsoon (Prell and Hutson 1979). Despite the seasonal contrasts in SST changes and the overall stronger Trade Wind regime in the Indian Ocean, it is suggested that the SO may have its origin in the South Atlantic where the SO occurs simultaneously with the mean zonal change in SST, or precedes it by the shortest time lag.

The long-term oscillatory variations in rainfall across South Africa occur in patterns related to the regional distribution of particular rainfall seasonality regimes (Tyson 1978).

Four regional rainfall variation patterns are recognized:

(a) Summer rainfall region: oscillations of 16 to 20 years with quasi 10 year periods of high rainfall followed by similar periods of low rainfall.

(b) Southern Cape all-seasons rainfall region with equinoctial peaks: a quasi 10 year wave occurs with five year high rainfall periods alternating with similar periods of low rainfall. This region, however, also experiences the 20 year temperature oscillation.

(c) Winter rainfall region: exhibits complex fluctuations with periods greater than 20 years.

(d) Bimodal rainfall region: an oblique trapeze-shaped region which lies between the winter and summer rainfall regions, extending from south Namibia across Bushmanland and the Karoo to the eastern Cape. Two rain peaks occur, one in early summer and the other in autumn, each separated by a dry season. Two to four years of higher rainfall alternate with the same number of drought years (Tyson 1978). There are, however, lesser sets of oscillations occurring within larger fluctuations of up to nine consecutive years' rainfall above the mean and up to 18 consecutive years below or close to the mean as shown for example by the 200 year record for Prieska.

As southern Africa lies wholly within the influence of the high pressure belt it is significant that the shift in the mean axis position of this belt is 19 years, which corresponds to maximum (northernmost) or minimum (southernmost) declination of the moon that occurs at 18,6 year periods, referred to as the Rawson Cycle (Louw 1982). Drought or arid years tend to occur in southern Africa when the high pressure axis is at each extreme of the north to south shift, and rain years with the median position of the axis at 30° S (Louw 1982). These fluctuations and the interacting air mass patterns responsible for them, and of particular wind and swell regimes, are fundamental components effecting changes in the sediment budget and the correlation of erosion or accretionary phases in the littoral active zone.

The basic relationships and past to present ecological implications which emerge from this precis in the context of coastal dune ecosystems included the following features. Though a change in frequency and velocity regimes of the major winds occur seasonally and at longer periods, the overall interactive pattern of high pressure easterly winds alternating with low pressure westerly winds prevail through drought and rain cycles as well as the longer term glacial-interglacial shifts in the Quaternary (refer to Section 2.2 above). In other words both winds retain an alternating codominance without one occurring to the total exclusion of the other over the long term.

Thus sea level changes and the resulting change in shape of the coast remains the most important feature governing dune occurrence and orientation. But the phases of massive dune building appear to be related to whether one or other of the codominant winds was ascendent in an onshore direction, with a superabundance of sand supply, on a particular coast sector.

As the precis attempts to provide a frame of interactive, reciprocal relationships as an aid to unravelling past to present dune dynamics, some of the significant aspects of rain-drought cycles are presented in summary form below, and these can be compared with those for glacial and interglacial times (Section 2.3).

Rain Years

- higher frequency of more intense pressure gradients; generally stronger wind velocities,

- stronger swell and longshore drift conditions,

- higher rainfall, greater erosion in river catchments, greater input of sediment to all South African coasts (unless winter and summer rain regions experience opposite conditions as exemplified by the recent drought in the latter region),

- wet sand conditions inhibiting sand mobility and thus dune growth on summer rain coasts. Enhanced dune growth on winter rain coasts where highest wind velocities are coincident with the summer dry season,

- greater donga erosion and slumping of dunes,

- more rapid plant colonization and succession towards closed woody cover. Reproductive phenology high (especially following an extended drought),

- minimal disturbance by fire.

Drought Years

- relatively slacker pressure gradients and wind velocities,

- slacker swell and longshore drift conditions,

- greater aridity, minimal erosion in river catchments, greatly decreased sand supply from land onto the coasts,

- dry sand conditions, greater sand mobility, greater possibility for dune growth on all coasts,

- greater drying out of dunes on crest and north to north-west facets. Die-back of woody plants on these sites, increased sand slides and creep, openings remain bare or are colonized by pioneer plants and fynbos (on south-west and south coasts).

- greater susceptibility to devastating fires into or through the dune vegetation, very slow regrowth and change. Reproductive phenology low, with increased leaf fall in what is essentially an evergreen habitat.

Other Aspects

Palaeoecology including aspects such as: dune building and erosive phases; genesis of playas and lunette dunes; pedogenesis; archaeology; biogeography and shifts in biomes and ecosystems (expansion, contraction and recombination); dispersal, particularly of strand plants whose distribution and occurrence are affected by ocean currents and prevailing inshore sea surface temperature conditions.

3.3 DUNE SOILS

3.3.1 Classification and form

On the 1:5 million soil map of Africa coastal dune sands are grouped with the juvenile weakly developed soils of recent deposits (D'Hoore 1964). In South Africa they are classified as littoral sands of the arenosol order of soils (van der Merwe 1962; MacVicar et al 1977; Harmse 1978).

The common topo-catena sequence in dune sands is with orange (yellow-brown) to red sands on dune ridges, beige to yellow in low undulating areas and foredunes, and pallid or whitish-grey sands in bottomland sites or areas subject to waterlogging from impeded drainage. In terms of the South African binomial soil classification system (MacVicar et al 1977) this topo-sequence is characterized by Hutton Form fersiallitic sands followed in turn by the dry then wet series of the pallid Fernwood Form sands. In geological terms coast dune sands are referred to as quartzose shelly well-sorted sands (Rogers 1971b).

Coast dune sands are composed chiefly of the lighter quartz minerals and calcite from shells. Their high calcareous content from shell fragments is the characteristic feature which separates coastal dunes from most continental dunes which are acid sands (Mabbutt 1977). (Alkaline sands also occur amongst the acid Kalahari Sands in the continental interior where they are affected by dolomites, calcretes or calcic-sodic clays). The quartz is derived chiefly from orthoclase and plagioclase feldspar silicates, which comprise up to 50 per cent of present beach sands in Natal (Maud 1968). Heavy mineral occurrence in coast dune sands is usually between 0,2 and 3 per cent, but in Natal is 4,5 per cent with extremes of 10 or 17 per cent (Fromme 1980). In Natal the following heavy minerals are recorded, all of which contain ferromagnesian compounds except for the last three: augite, biotite, eustatite, garnet, hornblende (brown, green), hypersthene, ilmenite, magnetite, olivine, rutile, tourmaline (dark, light) and zircon (Fromme 1980).

Aerobic weathering of the feldspars and heavy minerals results in ferruginization of the dune sands and an increasing aluminium content with the development of clay minerals composed essentially of hydrous silicates of aluminium. The dominant clay mineral in the Berea Red sands for example is kaolin with some geothite (Maud 1968). Under poorly aerated, acid, waterlogged conditions the ferromagnesian compounds are more soluble and are leached out and deposited in the subsoil as mottling, concretions, or hardpan resulting in the development of groundwater laterites or podzols (Klinge 1969; Brady 1974; Tinley 1982).

On the coast a mosaic pattern of acid and calcareous sands occur depending on the accumulation or hiatus in shell fragments or lime sediments. As coast dunes are derived from beach and river mouth sands their calcareous content is affected by the inshore availability of calcareous material from seashell fragments or from erosion of lime-rich Cretaceous and Tertiary rocks and reworked coast dune sands on the one hand and their dilution by terrigenous sediments from rivers on the other. Beach sands with a low calcium carbonate content occur on the east and south-east coasts south to the Kei River, and those with a high calcareous content from East London to the Orange River (McLachlan et al 1981). On the downdrift side of the Orange River (northwards) the beach sands are again poor in calcium carbonate (Rogers 1971b). The inshore wave swept zone of the Agulhas Shelf containing sediments of high calcium content occurs at the sediment divide on the south coast between Quion Point and the Duiwenhoks River (Rogers 1971b; Dingle and Rogers 1972; Siesser 1972b).

On a regional basis two broad groups of littoral sands are recognized, (a) a western low rainfall, sand-over-calcrete group from Mossel Bay to the west coast, and (b) an eastern higher rainfall group of fersiallitic dunes from Mossel Bay to Bazaruto Island (van der Merwe 1962).

3.3.2 Processes, characteristics and properties

Despite their singular unifying characteristic of loose silica or quartz sand grains, dune arenosols comprise a large variety of forms and series depending on the particular combinations and sequences of soil forming processes to which they have been subjected, and to the intensity and duration of these. These processes include leaching (eluviation) with decalcification and ferruginization (both lateritic and podzolic), accumulation of carbonates and later the iron and aluminium oxides (illuviation) in the subsoil, cementation-duricrust or hardpan formation, acidification and alkalization, truncation or burial of older humus surface horizons, and the influence of shell, heavy mineral, and humus content.

Examples of the kinds of soils formed by these processes include the following: deep, pallid horizonless sands (Fernwood Form), oxisols of both lateritic (Hutton Form) and podzolic genesis with a ferri-humic horizon (Lamotte Form), which becomes cemented as ortstein in groundwater podzols, duplex forms with a loose sand surface over a compact clayey subsoil or with cemented pan horizons (including calcrete, ferricrete and silcrete), sedge peat sands over an impervious horizon (eg Westleigh Form of gleyed sands formed on the Port Durnford Beds in Tongaland).

A. General properties of sands.

Sand particles are loosely packed with intervening air spaces. The result is that they are well aerated and exhibit a seasonal and diurnal temperature change from warm to hot in the day and in summer, to cool or cold at night and in winter. Due to their open structure sands are poor conductors of heat, thus temperature drops rapidly from the surface inwards. They are excessively porous to rainwater percolation and are thus rapidly permeable to excessively drained (ie have a low water holding capacity). Sands are thus a dry and droughty habitat. As there is no surface runoff sands entrap any and all the rain that falls, and the deeper soil moisture is protected from evaporation by the loose sand surface. Due to their structureless profile and porousness sands are easily leached and thus tend to be acid dystrophic substrates. Sands are typically poor in all nutrients, in origin, from leaching, or both (Malherbe 1962; Brady 1974). Their productivity is tied almost exclusively to the nutrient level derived from humus in the top 20 cm).

B. Properties of coast dune sands.

There are five features which characterize coast dune sands:

1. They are typically alkaline due to their generally high calcareous content from finely divided shell fragments. They are thus single macronutrient dominated in the formative and early stable stages prior to modification by leaching and deep weathering process.

2. Like desert dunes they are wind formed and the aeolian winnowing selectively sifts the finer and lighter particles from the heavier. Hence finer sands and light shell detritus compose backdunes as they are carried further inland, and coarser sands occur in foredunes (Mabbutt 1977).

On high dune cordons it is likely that a gradient of particle sizes from fine near the crest to an increasing proportion of larger particles occurs with depth into the plinth or dune core.

3. Coastline soils, particularly within one kilometre of the sea, are subject to repeated deposition of salt from spray aerosols carried by onshore winds. The stronger the wind the greater the salt load deposited.

4. The weathering potential is kept high year round by warm moist conditions (high humidity and mild to hot temperatures).

5. Unlike desert dunes, those at the coast receiving more than 50 mm mean annual rainfall become stabilized by plant growth. The mature cover on dunes above about 100 mm is a deep-rooted closed woody plant community.

The stabilization of dunes by plants allows pedogenesis to proceed resulting in many co-related consequences which have reciprocal influences over time (Olson-Seffer 1909; Salisbury 1925, 1952; Oosting and Billings 1942; Burges and Drover 1953; Oosting 1954; Wright 1955a,b; Wilson 1960; Price 1962). These include: (a) leaching of the carbonates, mainly calcium, and increasing acidification on the topsoil enhanced by solubilization of the calcium by hydrogen ions from humic acids, (b) build up of humus in the topsoil, (c) loss of calcium maybe offset by its high content in rainwater next to the sea, and deep rooted woody plants return between 55 and 95 per cent of their calcium to the ground in litter fall. But heath vegetation reinforces leaching and increases acidification (Trudgill 1977), (d) accumulation of plant waxes in the topsoil resulting in the formation of a water repelling, hydrophobic layer, (e) either accumulation of lime in the subsoil resulting in cementation of dune sand, or deep lateritic weathering with complete decalcification of dune sand and the development of non-calcic kaolinized sands (lateritic ferrosols and red podzols), (f) change in texture and consistency with build up of clay mineralization, profoundly altering the nutrient status and soil moisture balance of dunes. Stabilization of pH under thicket/forest where all the bases have been leached out, (g) increased resistance to erosion due to a high free iron oxide content which maintains a high aggregate stability (van der Eyk et al 1969). Ferruginization converts the dune from a loose sand body to a compact coherent soil (Plate 53), (h) in the case of increased calcium carbonate saturation (calcretization) of dunes this results in mineral deficiencies particularly of the micronutrients which become unavailable due to their increasing insolubility (Malherbe 1962), (i) influence of these changes on the growth, structure and species content of the plant cover.

On the Mocambique Coastal Plain a high, densely forested, littoral dune cordon, with abundant calcicole trees and shrubs on the calcareous sands gives way abruptly at their landward base to open acid grasslands and savannas on grey to orange leached sands where there is an associated change in soil moisture balance (Tinley 1982).

1. Typical soil profile of vegetated dune ridges. The characteristic profile of vegetated dune cordons along the South African coastline as revealed by soil pits and auger sampling on flat summit areas comprises (1) a surface humus layer 2 to 15 cm deep underlain by (2) a humus stained topsoil ("grey zone" - including fine charcoal where the cover is frequently burnt) to a depth of 10 to 30 cm under grassland and between 60 to 100 cm under a closed woody cover of fynbos heath or thicket/forest, with a gradual transition to (3) a "clean" beige to orange (yellowish-brown) coloured sand subsoil beyond 80 to 100 cm depth.

Despite the uniform texture and loose to compact consistence, horizon differentiation is indicated both by the above colour change and in particular by a characteristic reverse concentration of sodium in the topsoil and calcium in the subsoil (Table 10).

This feature is responsible for the high pH throughout the profile, though a lower pH is apparent in the transition between the topsoil and the subsoil (see Table 10, Samples 2 and 7). The topsoil is typically decalcified (leached) and the origin of its salinity is probably salt-spray.

In the Alexandria area deforested old dune sands now covered in grassland had the following profile sequence: (1) topsoil of 60 to 70 cm of compact grey (black when wet) humus-rich sand with a relatively sharp change to (2) calcareous nodule layer of 5 to 10 cm width, and a relatively sharp change to (3) a red sandy loam Hutton Form (oxisol).

The contrasting calcium and/or salinity values on different aspects of the same dune ridge is exemplified by Samples 4 a,b,c, and of the closely juxtaposed acid heath-bracken soil and alkaline thicket/forest soil on the same dune slope by Sample 5 a,b (Table 10).

An interesting phenomenon encountered on the west coast dunes were the drip salt-patches formed on the surface beneath succulent mesems during a drizzle rain. The sodium appears to have been leached from the leaves or had been excreted and subsequently washed off by the drizzle. A drip salt-patch collected beneath the foliage of a dwarf mesem tree Rushcia frutescens had a pH of 9,2 and a high salinity of 220 ohms. The surrounding dune surface has a pH of 8,7 and less, with a slight salinity of 525 ohms. High NaCl accumulation in plant cells is a characteristic of the Mesembryanthemaceae (Meidner 1963; von Willert et al 1979).

2. Effects of high calcium content in dune sands. Due to their seashore and water-washed origin, coast dune sands alkaline and low in micronutrients, and the high calcium carbonate content further induces deficiencies in nine elements, including aluminium, cobalt, copper, iron, manganese, zinc and in boron, phosphorus and potassium either by making them insoluble or inhibiting their availability (Malherbe 1962; Brady 1974). Except for the last three elements the remainder are most soluble in acid soil conditions where some may assume proportions toxic to normal plant growth. Waterlogged conditions in dune slacks for example significantly increase exhangeable iron and manganese, and iron oxide is precipitated in the vicinity of plant roots (Jones 1972).

On the south and south-west coasts there is a deficiency of copper in calcareous dune pastures which causes swayback disease in sheep (Malherbe 1962). Dune pining disease in stock due to cobalt deficiency also occurs on the coast, as well as stiffsickness (aphosphorosis) from phosphorus deficient pastures which, however, is not confined to the coast (Malherbe 1962). Vegetables and legumes grown on the calcareous sands of the Cape Flats remained small and chlorotic due to a chronic deficiency in manganese. This was resolved by applying heavy amounts of stable manure or compost with manganese sulphate and copper sulphate added (Malherbe 1962).

High calcium content reduces the toxicity of sodium (also of potassium and manganese) where this occurs in excess amounts, enabling plants to tolerate more brack conditions (Malherbe 1962; Brady 1974). Low available nitrogen which is typical at least of the younger coast dunes has also been found to increase the tolerance of plants to salt spray. Both features would be advantageous to plants growing on dunes next to the coast.

Added to the obvious advantage of deep root systems in colonizing dunes, if the seeds of the woody plants on dunes have large reserves of nitrogen and phosphorus they would also be almost independent of a nutrient supply from the soil in the initial stages (Lloyd and Piggott 1967).

Extremely slow growth and recovery after fire or clearing is a characteristic feature of the woody plant growth on coast dunes. A Berg Wind driven veld fire burnt into the landfacing slope of tall dune thicket near the Nahoon River on 4 August 1979. It took over three years for coppice growth to reach one metre in height, compared to the rapid recovery to this height in a single summer by woody plants on adjacent heavier soils. The same feature is noted between sand and clayveld vegetation elsewhere in southern Africa as in the northern Kalahari (Tinley 1966). Phosphorus is involved mainly in the growing, meristematic parts of plants and in the mature stages in the seeds (Malherbe 1962) and its deficiency is probably responsible for slow growth and regeneration of plants on sands.

Though high lime content of coast dune sands induces deficiencies in many nutrients, the abundance of dune fungi and the close attachment of endomycorrhizal fungal hyphae between the roots of pioneer seedlings and sand grain coatings of sesquioxide containing phosphorus, suggests that these fungi play an important role in dune colonization (Webley et al 1952; Nicholson 1960; Jehne and Thompson 1981).

Lime-induced chlorosis, which closely resembles symptoms caused by iron deficiency, is a widespread phenomenon of plants growing on calcareous soils (Grime and Hutchinson 1967). Relatively few woody plants exhibiting chlorotic symptoms have been noted on calcareous dunes in South Africa during this survey. This may be for two reasons, first most of the thicket species are calcicoles and secondly chlorosis seems to occur in individual plants at different times. It has been noted in Cassine papillosa, Acokanthera oblongifolia, a Senecio creeper, and saplings of Podocarpus falcatus, but is most conspicuous amongst alien plants grown on lime-sands. It is suggested that the seasonal periodicity of chlorosis recorded on calcareous soils in England for example, is related to a cycle of phosphorus absorption and release (Grime and Hutchinson 1967). The same authors found that acidicolous species growing on calcareous soils were more susceptible to chlorosis, and suggest this may make them more liable to desiccation.

3. Soil and nutrient turnover. Gravity slips, rain-formed gullies and landslides, blowouts and burial of the topsoil humus layer and vegetation by advancing slipfaces of superposing mobile dunes (Plates 58, 59), restabilization by plant colonization and development of a new humus topsoil at another level, wave erosion of vegetated frontal dunes, frequent burning of dune heaths, grassland and savanna by veld fires are the main physical changes or perturbations of soil-forming processes in dunes

affected by the elements. Similar disturbances are affected by many human activities as exemplified by dune mining.

The atmospheric supply of nutrients to coast dunes from aerosols carried by onshore winds, especially copious during stormy periods, and those from rain bearing winds are especially important in areas with nutrient deficient quartz sands. The main nutrients supplied in this way next to the sea are Ca, Na, Cl and to a lesser extent Mg, K, P and hydrogen ions (Etherrington 1967; Clayton 1972; Yaalon and Lomas 1976; Trudgill 1977). Deep rooted woody plants use up nutrients and moisture from the soil profile and these are in part recycled to the surface from leaf leachates and by leaf fall (Trudgill 1977).

The source of nitrogen in the strand plant embryo duneline (Zone I) along the uppermost reach of wave swash is chiefly from detritus of the driftline (Chapman 1964). On South African beaches wherever they are fronted by rock platforms or reefs within the surf zone the most conspicuous input of nitrogen is from the masses of seaweeds and tunicates Pyura stolonifera (redbait) broken off by heavy seas. These are washed up in the driftline and are covered with sand by succeeding tides and wind action. In tropical waters sea grasses are an important detritus source.

The remainder of the coast sands are typically devoid of nitrogen except that tied up with the topsoil humus of vegetated dunes. It is probably due to its self-sufficiency in nitrogen fixation in rhizobial nodules on its roots that the alien rooikrans is an extremely successful invader of disturbed coast dune vegetation and where it is planted or seeded for drift sand reclamation (Roux and Warren 1963).

Burrowing animals are a particularly important component of sand habitats (Callan 1964). These animals vary from the size of an antbear down to the herbivorous mole-rats (Bathyergidae) and insectivorous moles (Chrysochloridae) to beetles, termites, wasps and bees. The main action common to most of these animals is in bringing subsoil to the surface. Where the subsoil is derived from beyond 80 cm depth it is usually base saturated and sometimes slightly more textured.

Antbear activity is absent from most forested dunes but occurs widely scattered in open plant communities on dunes wherever termites are available. Mole-rats are apparently the most important agents of soil turnover in dunes on the south and south-west coasts. Their underground tunnelling, mound formation, and storage of bulbs by two species must have important influences on soil development, particularly as these activities are highly concentrated (Davies and Jarvis 1982). As the large Cape sand mole-rat Bathyergis suillus is mainly a grazer of grass roots and stems, the advent of fire in the dunes, temporarily eliminating the aerial portions of the vegetation, results in greater digging activity to obtain sufficient food (Davies and Jarvis 1982). In the south-west Cape these mole-rats are most active in the winter wet season and least active in February at the height of the dry season (Davies and Jarvis 1982). In one burnt dune area about 12 m^3 of soil was pushed to the surface in an area of about 9 000 m^2. If evenly spread this would represent a complete covering of the ground surface every 15 years (Davies and Jarvis 1982). In the high imbricate parabolic dunes at Groenvlei mole-rat mounds were only observed on the floors of dune hollows.

On the south and south-east coasts a solitary, but common, small hymenopteran burrows to beyond 80 cm depth and brings subsoil to the surface in heath and thicket covered dunes. Termites are important in the breakdown of organic material, and mound building species such as Macrotermes natalensis find their southern distribution limits on the south-east coast confined to the older red dune sands covered in grassland where their hills of subsoil material are colonized by islands of thicket. Two specialized dune termites Microcerotermes psammophilus on the east coast and M algoasinensis on the east Cape coast occur in forested and scrub covered and even bare dunes and build a compact carton-like nest level with the sand surface (Callan 1964).

The most exciting discovery for me made during the dune survey was to find on the Tongaland forested dunes, a large black tenebrionid beetle Gonopus sp (Plate 57) which carries large fallen green and yellow leaves from the forest floor down burrows to beyond 100 cm depth. The burrows occur at a density of about one to the square metre, and the displaced subsoil is deposited near the burrow entrance where it becomes incorporated in the topsoil by rainwash and gravity creep. The animal measures up to 25 mm in length with an abdomen 16 mm broad, and is only active during the warm part of the day. This beetle appears to be the prime mover in soil and nutrient recycling in the east coast dune forests.

In summary these animals make major or minor contributions to soil turnover and nutrient exchange in dunes, increase soil aeration and enhance drainage especially where a hydrophobic capping occurs.

C. Soil moisture balance.

1. Climo-edaphic regime and nutrient expression. The striking regional ecosystem pattern on dunes, repeated on the local scale most conspicuously in steep dune topography (as at Groenvlei for example), is the replacement of thicket cover by fynbos heaths on calcareous sands. In broader terms calcicoles are replaced by acidicoles (or calcifuges) regionally where the summer rainfall of the eastern coasts gives way to the winter rainfall regime of the southern coasts. The acidicole group comprises heaths, forest (of most kinds), and grasses and trees of the moist savanna biome from leached ("sour") soils in contra-distinction to a calcicole group of thicket, savanna grasses and trees and semidesert shrubs of base saturated ("sweet") soils.

In the east Cape dune heath outliers occur in sandslip openings along and just below dune crests. These are devoid of humus and are the most overdrained sites in the dune topo-sequence. On the south Cape coast, thicket occupies the high moisture basal footslopes of dunes and trough sides in the Groenvlei area with fynbos heath on the driest steep upper slopes, temperate forest occurs on steep polefacing slopes as does dense shrub heath. West of Mossel Bay dwarf thicket, composed almost exclusively of calcicoles, occurs on lime sand overlying calcrete near the shore with a sharp change to fynbos immediately landwards on deep loose sands (Cape Vacca). This pattern is typical of the west coast south of Lamberts Bay. Fynbos heaths continue into the tropics on uplands and mountains on the one hand and in the extreme acid bogs and high water-table sands of the east coast on the other hand.

The main inferences derived from the above patterns is that the overriding determinant is soil moisture balance as determined by the interaction of the following features: (1) climo-edaphic influence on the expression of greater or lesser acidic (Fe, Mn, Mg, Al and hydrogen ions) or alkaline conditions under contrasting summer wet-winter dry or winter wet-summer dry conditions (ie interaction between water relations and pH under different regimes), (2) regional and local dune topocatena moisture clines, (3) acidification of sands by fynbos heaths (Grubb et al 1969), (4) greater droughtiness of sands due to increased water repellency from repeated burning of dunes under heath (DeBano 1969; Reeder and Jurgensen 1979), (5) species which may be strictly calcicole or acidicole at one end of their range, may occur on a wider variety of substrates at the other (Salisbury 1921) or on sands at the arid end and on clays at the wet end (Tinley 1982), (6) mosaics of alkaline and acid sands due to changes in shell content or contrasting age sequences and hence degree of decalcification of the topsoil (cf Soil Profile Samples 5a and 5b, Table 10). As noted above the leaching change that has occurred in the topsoil of cast dunes cannot be read from the pH value on its own as this is masked by sodium alkalinity derived from the salt-spray input.

2. Water repellent sands. Except in the lower parts of dunes and where a water-table may be fed by lateral drainage from the landward side, most of the water relations in dunes has to do with what happens to direct precipitation when it falls. From observation in the field during heavy rain two distinct sand characteristics occur in dunefields. Where bare "clean" dune sands, beige or yellow-brown in colour similar to dry beach sand occur, all the rain is soaked up with no surface runoff. Where grey sands (Chapman 1964) stained by humus occur which are covered in woody vegetation a surprisingly massive surface runoff occurs causing donga (gulley) erosion when heavy rains follow a dry period. Minimal runoff with deep percolation, however, occurs with heavy rains when the same grey sands are previously wetted by recurring light rains.

The cause of this remarkable phenomenon is the presence of a water repellent layer near the surface beneath the litter. This layer leaves the sand dry and dusty after heavy rain as it sheds water like a duck's feathers (DeBano 1969). Where water repellent sands drop into water they become rafted at the surface and are thus often referred to locally on the coast as "floating sands". Hydrophobic properties are commonly found on sandy soils in different parts of the world and are reported chiefly from North America and Australia (Gilmour 1968; DeBano 1969; Teramura 1980). The massive surface runoff caused by water repellent soils is a major conservation problem in the chaparral of south California (Osborn et al 1964). Although water repellent sands occur in South Africa little is reported on them in the literature (William Bond, Forestry Research Institute, Saasveld, and Malcolm Hensely, Head Soil Science Faculty, University of Fort Hare pers com 1982).

Water repellency is a property of organic skins coating individual sand particles, the hydrophobic substances originating from secondary plant products such as waxes, phenols and amines, from fungal mycelia and fungal metabolites, and substances produced as a normal consequence of litter decomposition (Reeder and Jurgensen 1979). The degree of water repellency of a soil depends on the type of plants, their biproducts and breakdown products (humus), both of which depend on the age of the stand. The occurrence of fire which transforms and volatilizes much of the organic matter at the soil surface also influences water repellence.

On thicket-covered hydrophobic grey dune sands at Nahoon seedling die-back is commonly seen, and the question is whether the repeatedly burned fynbos heath humus does not increase the soil droughtiness and inhibit succession? The accumulation of hydrophobic metabolic products is suggested as a potential factor affecting chaparral senility in California (Teramura 1980). As soil fungi are implicated in the development of hydrophobic conditions it may be significant that on west European dunes the acid heath humus increases the fungal population and depresses the bacterial population (Brown 1958; Nicholson 1960; Chapman 1964).

When heavy rains occur following a dry spell in forested dunes the only sites where rainwater was found to have penetrated through the repellent horizon to the subsoil was down tree trunks and in hollows where water lay sufficiently long to overcome the hydrophobic property. A parallel phenomenon occurs in savannas where overgrazing and sheet erosion results in the development of a firm rain-shedding surface patena. Here deepest rainwater penetration occurs beneath tree and bush-clump canopies at the base of trunks and stems, and in hollows (Glover et al 1962; Tinley 1977, 1982).

A similar effect is produced by any firm water-shedding surface protruding from highly porous bare sand, such as a rock, an isolated plant or a pole. Rainwater penetrates more deeply along the underground contact of the shedding surface and the sand, resulting in a higher moisture content out of reach of evaporation.

3. Water relations in dunes. A freshwater aquifer exists in dunefields which is usually close to sea level where the sands mantle, an impervious or slowly permeable base. Where the dune aquifer is close to sea level a freshwater lens overlies the saltwater phreatic layer in the frontal dune zone, a feature exploited since earliest time to the present by man. This water and deep percolated rainwater, which penetrates preferentially down along tree trunks and roots and from hollows, moistens the dune core and plinth fixing the position of the dune. Free water surfaces in slacks and along the backbeach. The sand of high wooded dunes may be moist at depth due to entrapment of rainwater in compact or partially cemented horizons.

Four types of water-table changes have been noted in dunes elsewhere (Chapman 1964): (1) seasonal wet season - dry season changes, (2) regular periodic changes in the frontal dune - backbeach zone related to tides, (3) daily rhythmic changes associated with evapotranspiration, and (4) irregular changes of the depth of the water-table due to sand movement from accretion and deflation processes related to strong winds. Irregular changes would also include unseasonal rain or drought occurrences.

Bare sand absorbs any moisture, particularly along the coast where the high salt content of the sands has a hygroscopic effect. Much of the moisture is conserved in the deeper parts, as evaporation is confined to drying the surface layer which then acts as a barrier to any further moisture loss (Tinley 1982).

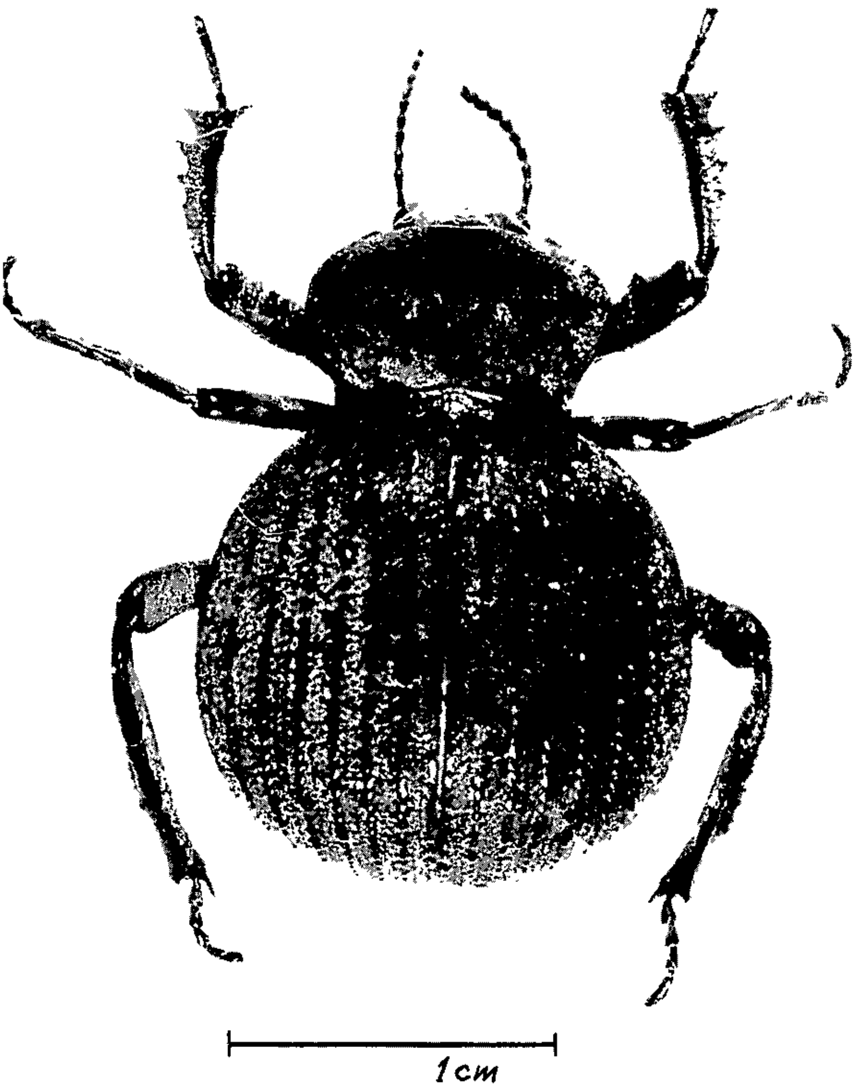


PLATE 57. Burrowing tenebrionid beetle (Gonopus sp) of the forested dunes in Tongaland, which store fresh leaf litter in the subsoil.

PLATE 58. Succession of old soil profiles exposed in the bare dunefield at Vleesbaai. 1. old surface humus horizon, strongly compacted, now covered by 20 m of mobile sand, 2. aeolianite and rubble calcrete horizon, 3. compact clayey red sand with saline polygon weathering.

PLATE 59. Fossil humus horizon of once forested dune surface, now buried by 30-50 m of remobilized sand. Vleesbaai dunefield near Cape Vacca.

Though the fine precipitation from advective sea fogs on the west coast desert is often copious, my experience of it north of Walvis Bay and south of Port Nolloth showed that bare dunes were not wetted beyond several centimetres from the surface and dried soon after exposure to the sun, ie it did not appear to be cumulative (see note below).

Wherever water-shedding surfaces protrude from desert surfaces, however, a greater runoff and penetration of fog moisture occurs similar to that noted above (Walter 1971, 1976; Louw and Seely 1980). This phenomenon is even exploited by specialized dune beetles which use their upended bodies as runoff surfaces directing the water droplets to their mouth parts, and plough a small trench in the dune surface which acts as a moisture trap (Seely and Hamilton III 1976; Seely 1979). In a three kilometre broad strip along the west coast it is estimated that up to 150 mm of this fog moisture is trapped by plants and runoff from rocks on the Namib Coast, and up to 300 mm in Namaqualand (Nagel 1962). The vital role of this moisture source to desert life can be appreciated from these figures (Koch 1961; Louw 1972; Seely 1974/75).

As important as the development of water repellency in dune sands is the phenomenon of internal dew formation in dunes (Chapman 1964). As loose sand is a poor conductor of heat during the day it is rapidly heated and at night rapidly cooled, the temperature drops sharply from the surface inwards and at night can fall below the dew point. This explains the survival of many plants growing in apparently completely dry sands. Dew can also form on the surface of bare sand and drain inwards. No record of this phenomenon is, as far as I know, reported from South Africa, either from coastal dunes, including those subjected to a high frequency of sea fogs, or those of the Kalahari in the interior. Nor is it known whether internal dew formation can occur in grey dunes capped with humus and a closed plant cover, or whether it is confined to bare sands where guttation is commonly observed in pioneer strand plants such as the dune cabbage Arctotheca populifolia (Plate 56).

3.4 DUNE VEGETATION

3.4.1 Zonation, succession and gradients

A. Zonation.

More than 80% of the South African coastline is composed of sandy beaches and dunes. Extending from the backbeach onto the dunes are several distinctive plant communities readily identified by their contrasting appearance, growth form and floristic composition. These form a discontinuous or patchy zonation parallel to the shoreline (Figure 1).

Closest to the sea is the youngest pioneer strand plant community (Zone I) composed of low creeping grasses and succulent leaved herbs with rhizomatous, stoloniferous and sympodial growth form. These colonize mobile sand and in growing ahead of accumulating sand are responsible for building up the first embryonic partially stable dunes (Plates 13-19, 22, 24, 60-63, 72, 73, 102, 104). Behind these is a shrub community (Zone II)

TABLE 10. Dune soil profiles (examples from around the South African coastline between Olifants River and Kosi Bay)

Depth cm	pH (H_2O)	Salinity Resistance (Ohms)	$CaCO_3$% (dil.HCL)	Colour, texture, consistence (structureless sands)

(1) Locality: 3 km south of Doringbaai, West Coast
Vegetation: *Eragrostis cyperoides* dune grassland
Site: Flat crest of foredune and mid-dune junction

Depth cm	pH (H_2O)	Salinity Resistance (Ohms)	$CaCO_3$% (dil.HCL)	Colour, texture, consistence (structureless sands)
20	8,2	405	5	Dune topsoil - grey loose sand with grass roots. Wet - 7,5 YR 5/3 dull brown.
100	8,5	1200	> 10	Dune subsoil - clean beige loose sand. Wet - 10 YR 7/3 dull yellow orange.

(2) Locality: Rocher Pan dunes north of St Helena Bay, West Coast
Vegetation: *Euclea-Ruschia* dwarf scrub-thicket
Site: Crest of gently rounded backdune

Depth cm	pH (H_2O)	Salinity Resistance (Ohms)	$CaCO_3$% (dil.HCL)	Colour, texture, consistence (structureless sands)
0-2				Compact friable humus layer.
3-7	8,7	525	< 0,5	Dry - whitish grey loose sand with filamentous roots. Wet - 2,5 YR 3/2 brownish black.
8-100	7,6	2120	0,5	Dry - grey sand with finely divided humus (and charcoal). Wet - 10 YR 3/2 brownish black.
101-180	8,6	1100	5	Dry - pale beige to brown clear sand. Wet - 10 YR 3/4 dark brown.

(3) Locality: Betty's Bay, Dawidskraal white milkwood grove, SW Coast
Vegetation: Grove of tall *Sideroxylon inerme* with woodland structure
Site: Backdune summit

Depth cm	pH (H_2O)	Salinity Resistance (Ohms)	$CaCO_3$% (dil.HCL)	Colour, texture, consistence (structureless sands)
0-15	7,8	810	2	Compact friable humus-rich layer. Wet - 5 YR 2/1 brownish black.
16-30	8,0	710	> 10	Dry - grey loose sand with abundant fibrous roots. Wet - 5 YR 4/2 greyish brown.
31-60				Gradual transition of grey topsoil to white sand subsoil.
61-220	8,9	2700	> 10	White sand with pale brown patches near roots. Some coarse shell fragments. Wet - 7,5 YR 7/2 light brownish grey.

(4)a Locality: Langekloof wind-rift dunes between Slangbaai and Tsitsikamma River. South Coast.

Vegetation: Grassland with bush-clumps (*Rhus*, *Euclea*, *Salvia*, *Cussonia*) and *Metalasia*
Site: Equator facing slope of high mid-dune ridge

Depth cm	pH (H_2O)	Salinity Resistance (Ohms)	$CaCO_3$% (dil.HCL)	Colour, texture, consistence (structureless sands)
10	8,3	1975	>10	Sliding topsoil of steep slopes. Wet - 7,5 YR 2/2 brownish-black.
100	8,7	3490	>10	Pale orange sand. Wet - 10 YR 5/6 yellowish brown.

Depth cm	pH (H_2O)	Salinity Resistance (Ohms)	$CaCO_3$% (dil.HCL)	Colour, texture, consistence (structureless sands)

b Locality: Same as 4a
Vegetation: Mixture of fynbos and grassland
Site: Summit plateau of mid-dune ridge

10	8,0	1380	1	Dry - dark greyish-orange-black loose sand grading to paler grey-black at 70 cm. Gradual transition to pale orange sand at 80 cm. Wet - 10 YR 1,7/1 reddish black.
100	8,6	2745	> 10	Pale orange sand. Wet - 10 YR 5/4 dull yellowish brown.

c Locality: Same as 4a
Vegetation: Dense fynbos heath 1 to 2 m tall with *Restio* understorey
Site: Polefacing slope of same ridge in 4a and 4b

12	8,0	1795	2	2 cm surface of fibrous greyish-black humus. Compact greyish black humus-rich sand to 80 cm. Wet - 5 YR 1,7/1 black.
100	8,5	2990	> 10	Gradual transition at 90 cm to pale orange loose sand. Wet - 10 YR 3/4 dark brown.

5(a) Locality: Langekloof wind-rift dunes, South Coast
Vegetation: Low dense cover 50 cm high of *Erica*, *Helichrysum*, bracken, sedges, herbs, moss
Site: Opening in dune thicket/forest, polefacing slope of high backridge

10	5,7	3305	< 0,5	Moist herb covered soil, dark grey compact sand to 60 cm with gradual transition to orange subsoil. Wet - 10 YR 1,7/1 black.
10	6,5	5330	< 0,5	Wet - 5 YR 3,6 dark reddish brown loose sand.

b Locality: Same as 5a
Vegetation: Dune thicket/forest, canopy 7 to 12 m in height (*Pterocelastrus tricuspidatus*)
Site: Polefacing slope of high backridge. Immediately adjacent to 5a

10	7,1	840	< 0,5	Dark grey sand to 60 cm with gradual transition to pale orange sand at 80 cm. Wet - 5 YR 2/2 brownish black.
100	8,5	2700	> 10	Pale orange sand. Wet - 10 YR 6/4 dull yellow orange loose sand.

(6) Locality: Dune cordon between Nahoon and Qwelera Rivers, East London, SE Coast
Vegetation: Dune thicket 7 to 12 m canopy (*Mimusops caffra*, *Diospyros natalensis*, *Cassine*)
Site: Plateau summit of main dune cordon

0-10	8,0	570	< 0,5	Compact fibrous humus root mat (can be cut into blocks). Wet - 7,5 YR 2/2 brownish black.
11-22	8,2	720	< 0,5	Loose grey sand strongly water repellent. Wet - 7,5 YR 3/2 brownish black.
23-40				Gradual transition of paler grey sand to clean beige sand.
100	8,6	3110	> 10	Clean beige loose sand. Wet - 10 YR 5/4 dull brown.

Depth cm	pH (H_2O)	Salinity Resistance (Ohms)	$CaCO_3$% (dil.HCL)	Colour, texture, consistence (structureless sands)

(7) Locality: Kosi Lake System, main dune cordon above Boteler Point, Tongaland, East Coast
Vegetatation: Dune thicket/forest similar to Nahoon example
Site: Plateau summit of first main forested cordon

0-10	7,7	485	< 0,5	Tough fibrous humus mat (can be cut into blocks). Wet - 7,5 YR 2/2 very dark reddish brown.
11-20	8,0	665	< 0,5	Loose dry sand, greyish-black, water repellent. Wet - 7,5 YR 2/1 reddish black.
21-30	7,3	405	< 0,5	Compact black humic sand. Wet 7,5 YR 2/1 reddish black.
31-105	7,4	1470	< 0,5	Fine grey sand, end of humus stained horizon. Wet - 7 YR 2/1 black. Greatest density roots within 80 cm.
106-130	8,2	3070	> 10	Pale orange sand, clean. Wet - 7,5 YR 4/3 brown.

Salinity R/Ohms		$CaCO_3$ (dil.HCL)	
250	highly saline	< 0,5 %	Non-calcareous
250-800	slightly saline	0,5-1 %	Very slightly calcareous
800-1800	normal	1-5 %	Slightly calcareous
1800-3000	leached	5-10 %	Calcareous
3000	highly leached	> 10 %	Highly calcareous

Colour Notation
from Revised Standard Soil Colour Charts
by H Takehara (1967)

(Soil samples analysed by Soil Section, Dohne Agricultural Research Station, East Cape).

composed of an open short cover of clumped bushes often with an understorey of herbs and climbers (Plates 70, 73, 77, 109), followed by the closed "clipped hedge" canopy of the scrub-thicket community (Zone III) (Plates 3, 17, 18, 64-68, 72-75, 79, 120). Furthest from the sea is the oldest mature community of tall thicket and/or forest (Zone IV) (Plates 25, 32, 33, 79-83, 108, 110, 112). Coastal sands are colonized and built up into wooded dunes by the interaction of wind and plant growth in a seral succession of the above communities.

All four zones are to be found on the moister coasts, but the zonation on the subdesert and desert coasts is in effect continuation and expansion of Zones I and II, and the contraction and tailing off of the woody zones so that Zone I, where it occurs, is eventually the "climax" cover on the Namib Desert coast.

As most of the sand coasts of the subcontinent are eroding, the zonation is rarely complete. More typically only two are represented and these occur discontinuously in a narrow telescoped, or interdigitating pattern, the intermediate zones having been eroded away by sea and wind. Most often Zones I and III abut sharply against each other, the strand plants subject to repeated phases of recolonization, growth and spread followed by erosion or elimination by storm seas. Great variation of zone patterns is thus typical, and masks their seral successional relationships.

The ideal zonation pattern is often broken up further by transgressive blowouts which carry bare mobile sand from the beach landwards and along which pioneer herb and shrub colonizers are able to invade in an interdigitating pattern (Plates 34, 35, 107-110). Interruptions are also caused by damaging factors such as the openings formed by slumping, clearing of bush and frequent fires which result in the establishment of a patchwork of secondary grassland, savanna or heath communities (Plates 86, 89, 91, 120).

The complete zonation is most clearly exhibited on homeostatic and growing shorelines, a classic example of which occurs at Mtunzini on the Zululand coast (Plate 100). Here a catena of parallel dune ridges and troughs form a progressive gradation in age, size and complexity of dunes and plant communities from the beach landwards (Weisser et al 1982).

B. Succession.

The plant communities which distinguish the four zones form part of a single plant succession. This succession is initiated by the strand plants and other pioneers which colonize bare mobile sand. Through the stabilizing effect and protection they afford, suitable habitat is provided for the establishment of precursors from the next zone in the seral sequence, and so on until the closed woody climax community is attained. The form the mature community will acquire is primarily dependent on the coactive influences of geographic position, moisture and edaphic conditions, level of contribution from abutting landward ecosystems, and a sufficient period of time free of disturbance.

Although the intrinsic trend of succession is towards a mature closed woody community, in dunes it is generally multidirectional as successional changes are taking place in response to erosion, accretion, secondary disturbances, and to the remobilization of dune sand which provides new and recurring arrays of habitats and niches. These set up new directions or sequences of succession, unless remobilization of bare sand results in the development of transverse dune conditions which effectively puts an end to plant succession for a long time. Under these conditions a prevailing bare sand habitat becomes established as the ever-shifting dry sand is inimicable to colonization even by sand pioneers, except as rare isolated clumps on plinths and in some hollows and slacks. Within such clumps succession does continue, but in many instances the growth response is chiefly in shoot production to keep ahead of burial by the sand (Figure 28; Plates 30, 31, 37, 41, 71, 100, 106, 107).

On the Namib Desert coast strand plant hummock dunes and isolated patches of a coarse grass Aristidia subulicola on dune plinths are the most mature plant communities that are able to develop in the extreme arid, bare, desert sand conditions. The plant clumps on hummock dunes are typically islanded from one another, Archipelago-like, with bare ground between, and attain their most extensive development on high water-table areas on the margins of lagoons, on spits and desert washes (Plates 38-40). Many of these plants are closely related to hummock-forming species that occur further south on the west coast in Namaqualand, and inland on the margins of salt flats such as those at Etosha, Makarikari and the Bushmanland panveld.

On the Namaqua Coast section increasing frequency and density of hummock and dwarf shrub clumps occur with the transition to less severe semidesert conditions. Further south on the west coast, as between Lamberts Bay and St Helena Bay for example, the mature plant community on dunes is a dense dwarf scrub-thicket one metre in height, increasing in size southwards and eastwards to tall thicket and eventually forest over 20 m in height on eastern coasts. Where the moisture regime allows the succession to proceed to Zone III and IV the following basic sequence of progressive seral and thus floristic and structural changes take place.

(a) Colonization of backshore sands by strand plants which have erect leaf-bearing parts growing from creeping stems or roots. These are distributed mainly by sea currents and wind (Good 1964), and those dispersed by sea are stranded by the highest reach of wave swash in the drift line and on berms where they germinate or are subsequently blown by wind to other sites. By growing ahead of the wind blown sand accumulating around them, strand plants begin the first stage of stable dune formation.

    Concomitantly the bare areas between the plant clumps are deepened by deflation and wind scour, increasing the contrasts in microrelief and those between windward and leeward sites.

(b) Once sufficient stabilization of sand occurs and protection from the direct impact of wind driven sand and salt-spray is provided by lee sites and the pioneer plants themselves, shrublets and creepers are able to become established.

(c) The second stage plants mature and eventually overtop the strand plants in sheltered sites. These plants are used as perch sites by birds which deposit more seeds of shrub species in and around the existing initials and in this way bush clump nuclei are formed which coalesce by lateral or outward growth (Plate 100, 107).

Wherever the shrubs grow above protection, the growth is continually pruned-off on the seawind side by salt spray producing a clipped-hedge appearance. This results in a compact, even canopy giving a dense shade. This and the nearly continuous rain of wind-borne sand accumulating on the floor, or continuous sand slides on steep slopes, appear to preclude the development of subordinate strata, hence the dense scrub-thicket community is typically single storeyed.

The shrubs on this zone have also undergone repeated sympodial shoot growth in response to pruning by salt spray, and to partial burial by advancing sand, thus even the taller, more stable, scrub-thicket areas are easily recognized by their single storey and multiple-stemmed structure (Plates 74-76).

(d) As the scrub-thicket matures it provides increasing protection and humus, with patches of uneven canopy in lee sites and hollows. Here sufficient light penetrates permitting the development of a dense groundlayer and an open fieldlayer of undershrubs and single-stemmed tree saplings. Both the multiple and single-stemmed trees grow taller and overtop the shrub components. In this way low scrub-thicket is gradually transformed to taller thicket, or to forest on the high rainfall coasts. Masses of creepers, climbers, scandents and some large-stemmed lianas entwine the canopy and invade openings.

(e) On land-facing slopes of the backdunes where salt spray effect is least, the tall thicket or forest canopy is very uneven and emergents are common. All steep slopes of dunes are under constant gravity adjustments of sand creep when dry sand slides or slumps when wet. This imposes a characteristic J-shape to tree profiles ie stems are bent in a downhill direction from the base and recurve to a vertical plane, a lateral branch often developing as the main stem. Multiple-stemmed trees and heliophytic savanna and thicket, or fynbos heath species are common components of openings. The mature climax community is thus under ongoing change on all steep and footslope facets; it is modified by fire at intervals on the landward margins; sections are buried by the advancing fronts of mobile dunes; and openings are also formed by windthrow or gravity. Disturbance by man and his stock add to the array of multidirectional successional sequences. Stock browse the understorey clear and in removing the replacement sapling stages, leave a forest shell of old canopy trees with a woodland, single-storeyed structure. Erosion and fire susceptibility too are increased under these conditions.

The secondary vegetation invading previously bush-covered dunes are grassland and savanna on subtropical and tropical eastern coasts, fynbos heath on southern temperate coasts and a grass and annuals mix on the subdesert west coast. These occur as a patchwork across the basic community zonation, but the heath shrubs are also a primary community on dunes (Taylor 1978; Kruger 1979b; Cowling 1982). The heaths occur both on cooler and moister pole-facing slopes as well as the over-drained upper slope and crest areas (Plate 94). In the latter sites they form part of an edaphic moisture gradient with tall milkwood thicket at the base, as best exemplified by the landward scarp profile at Groenvlei (Plate 32). The spread of extensive dune heath areas is, however, a secondary artifact from frequent fires. On the high heath covered windrift dunes at Langekloof west of Cape St Francis, grass pastures are maintained through the intermittent use of a scrub-cutting mower.

These secondary communities can be maintained indefinitely by the repeated use of fire, grazing and mowing. Where such areas are protected from disturbance bush clump initials spread and thicket invasion occurs (Plate 87). On the Tongaland Coast the savanna tree Acacia karroo invades dune grassland and old cultivation sites in pure even-aged stands (Plate 92). These increase in height and density and provide the perches for the development of tree-base thickets from bird dispersed seeds (Tinley 1977). The initial thicket patches spread and are invaded progressively by more shade-tolerant woody plants that eventually grow through to the canopy. However, prior to its maturation as tall thicket or forest, the acacias often attain a senile stage and die back en mass.

The low heath shrub communities too are invaded by forest precursors such as candlewood Pterocelastrus tricuspidatus and taaibos Rhus species which form bush clumps initiated and spread by birds, and that eventually coalesce by outward expansion reducing the area under heath. This trend is reversed, however, each time a fire burns through the heathland.

C. Gradients.

A moisture and geographic gradient of increasing size, density and structural complexity of dune vegetation along the coast is shown from the extreme arid Namib Desert and Namaqua subdesert on the west coast around the southern warm temperate Cape heath coasts to the moister subtropical and tropical forested eastern coasts. There is also a gradation of zone community dominance between the higher rainfall east coast dunes and the desert-subdesert dunes of the west coast. Those that are subordinate or seral communities on the moister sectors become the mature or climax dune vegetation in the arid sectors.

The floristic or species dominance on this moisture-geographic gradient parallels that of the zone or community dominance. Woody species that are subordinate on the moister tropical east coast dunes, and those in each succeeding geographic sector become increasingly important further south and westwards.

Arid thicket species (typically calcicoles) from the river valleys, clay soils, termitaria and rock outcrops are increasingly important on dunes wherever the rainfall on the littoral is less than about 800 mm. On the south and south-east coasts there is also an overlap and gradual filtering out of subdesert elements eastwards. Outlets of the dwarf scrub-thicket typical of the dunes on the west coast south of Lamberts Bay, occur south and eastwards wherever the sands overlie calcrete at shallow depth (eg Cape Agulhas, Cape Vacca).

Adjacent to these dwarf thickets, or lilliputian forests as Acocks (1975) called them, are tall thicket communities on deep sands dominated by white milkwood Sideroxylon inerme and candlewood Pterocelastrus tricuspidatus which form a mosaic with dune heath communities.

The coast fynbos heaths of the warm temperate southern coasts (south and south-west) exhibit a diminishing gradient of occurrence on dunes along the southern west coast and southern south-east coast. This contraction is coincident with a rapid drop-off in rainfall on the west coast and with increasing change to a summer rainfall regime eastwards onto the south-east coast. In the former area the decrease is more abrupt and terminates on dunes between Langebaan and St Helena Bay. From here the fynbos becomes confined to patches of leached sands immediately landward of the dunes (eg Rocher Pan), and further north, with intensifying aridity of semidesert conditions, it is increasingly confined to rocky outcrops and mountains. On the east Cape coast where thicket is almost the exclusive dune cover, fynbos becomes confined to the dry bare sand openings formed by sandslides along dune crests (Plate 94). Northwards, up the eastern coasts from East London, fynbos at the coast is confined increasingly to rocky outcrops and especially to acid high water-table sands and vlei sites, which are typically blackwater habitats (Tinley 1977; Heydorn and Tinley 1980).

The gradient pattern of dune heaths at each end is thus similar with diminishing occurrence on the dunes themselves, and increasingly confined to landward of the dunes, then either continuing on mountains and upland spurs (west coast, eastern coasts) and in acid high water-table lowland sites (east coasts). Certain species typical of the first two seral stages of dune succession on the temperate coasts (eg Metalasia muricata), occur northwards on the southern south-east coast increasingly further away from the shore and become confined to the openings on dune crests, or become subordinate components of the grassland which abuts the landward base of dunes (eg Restio eleocharis).

In addition to the growth-form gradient shown by trees both along the coast, as well as locally due to dwarfing by salt-spray, other species such as Rhus natalensis, which are generally scandent in the moister dune thicket/forest areas, occur as large discrete bushes in the drier shorter dune thickets where they are canopy components.

The canopy height decrease of the mature tall forest (eg Tongaland) - dwarf scrub-thicket (eg Lamberts Bay) gradient shows the following trend:

South Mocambique and Tongaland Dunes: 5 to 15 m (the lower canopy on the steeper slopes) with emergents to about 22 m.

South-east coast (Natal, Transkei, East Cape): 5 to 12 m with emergents to 14 m.

South Cape coast: 5 to 8 m with emergents to 14 m.

South-west coast: 2 to 5 m.

Southern west coast (St Helena Bay to Lamberts Bay): 1 to 2 m.

Northern west coast: clumped dwarf scrub-thicket patches 0,5 m to 1,5 m.

Superposed across the above gradients of geographical or regional dimensions are dune gradients at right angles to the shoreline. These involve relief sequences (variations in slope aspects and exposure) and distance from the shore which affect microclimate, habitat and edaphic gradients. Gradients are steeper and habitats more sharply defined where relief contrasts are greater, and vice versa. The largest areas of alternating mesocline and xerocline slopes are on those steep dunes of the south coast which have their axes close to an east-west alignment (Figure 16, Plates 31-33, 82).

Dunes with contrasting relief and conditions provide an arena of high ecological mosaicism where there is large habitat and gradient heterogeneity in space and time at all dimensions from instant catastrophic change to the geological scale. Due to these features and their linear along-coast distribution, traversing different regions and ecosystems, plant species on dunes occur kaleidoscopically in an imbricate pattern (refer to the woody plant distribution in Table 14). Yet despite this, or because of the recurring nature of these facets, characteristic plant communities or species mixes have been moulded and these identify particular coast sectors and the dune ecosystem as a whole.

3.4.2 The plant communities

The kaleidoscopically varying floristic composition of dune plant communities around the South African coastline, and within each sector and aspect of the dunes, are noted below for each zone. Figure 1 illustrates examples of the different kinds and combinations of dune vegetation zones along the coast.

Six main plant communities occur on coastal dunes, of which four form a seral suite of four zones parallel to the shore from pioneer sand colonizers nearest to the beach to a closed woody climax cover landwards. These are (1) the Strand Plant Community (Zone I), (2) the Shrub Community (Zone II), (3) the Scrub-thicket Community (Zone III), and (4) the Thicket/Forest Community (Zone IV).

The other two communities are mostly secondary, grassland and savanna which occur as small patches on some eastern coast dunes, and the extensive dune heathland of the southern coasts. As noted above, all these communities are seral to a closed woody climax community when undisturbed, except on the desert coasts where the earlier zonal communities are climax.

A. Zone I Strand plant community.

This littoral community is composed of low creeping plants which are colonizers of bare shifting sand on the backbeach and on berms at the highest reach of wave swash (Plates 13, 14). It is an ephemeral community, destroyed at intervals by sea erosion and reforming with phases of sand accretion. Even without interference several species die back after two years of growth (eg dune cabbage *Arctotheca populifolia*, (Plate 56)).

Open beaches are an extreme habitat for plants as the sands are subject to continual changes wrought by tides, waves and wind. There is a high salt content of the sand and air and the habitat is fully exposed to the sun and wind. The sand has a high infiltration rate, dries out rapidly after rain, and experiences high diurnal extremes of temperature. Ammeliorating factors include a year-round growing season and high moisture content of air and sand, temperatures are mild to hot and there is no frost.

There is often the presence of a lens of freshwater overlying a saline, tidally fluctuating water-table in the backbeach-foredune zone, and a high nitrogen input is obtained from the organic debris washed up in the drift line.

The features which enable the strand plants to contend with the above extreme conditions include the following: the ability to grow sufficiently rapidly to keep ahead of accumulating sand, which is enhanced by the withdrawal of nutrients and water from leaves that become buried for the continuous production of new shoots and roots; many species are succulents, and their buds are protected from salt spray by a thick cuticular covering; some of the grass components exude salt (Bayer 1952).

The frontline strand plant community tends to be dominated in each site by a single species. This appears to be related to seed availability coinciding with suitable conditions. Where the hummock dunes are able to persist for longer than a year additional species may become established to form a mixed herbaceous community. If this zone survives longer than about 10 years it is invaded from the landward edges by Zones II and later Zone III plants (Moll 1972; Weisser et al 1982).

Most of the pioneer strand plants have water and/or wind dispersed seeds. Many are pantropical or Indo-West Pacific in distribution as their seeds are dispersed by ocean currents and surf zone currents inshore (Muir 1937; Good 1964; Sauer 1965a).

In this survey a total of 34 plant species has been recorded in Zone I south of the tropic. More intensive study would probably not raise this number beyond about 50 species. Of these, 14 are considered to be the principal or core assemblage of beachfront pioneers (Table 11). The remainder are mainly intrusives from Zone II which invade where local site conditions permit.

Desert shore elements filter out southwards down the west coast overlapping with temperate species typical of the southern coasts. The latter in turn overlap here with tropical eastern coast species which reach their southern geographical limits on the south coast and near its junction with the south-south-east coast. These elements associate with species endemic to certain coast sectors (ie local regional elements). Due to the overlap of desert and tropical eastern coast elements with the temperate coast species, the overall pattern in Zone I shows the greatest number of strand species on the south Cape coast, with decreasing numbers in each direction up western and eastern coasts (Table 11). The decrease up the eastern coast sectors may, however, be an artifact of recording rather than a real one.

The tropical littoral species which reach their southern geographical limits southwards and westwards down the east and south coasts, reappear again on the tropical west coast north of about Mocâmedes in Angola (Muir 1937). This gap in distribution of species such as Canavalia, Ipomoea, Cyperus and Scaevola, coincides with the temperate and desert coasts (Figure 20).

1. West coast. On this coast by far the most important dune pioneer nearest the beach is the rhizomatous grass Eragrostis cyperoides. It generally grows in a pure cover and effectively stabilizes sand across Zones I, II and III (Plates 24, 62, 63, 101, 102). Its southern limit of distribution lies between False Bay and Cape Agulhas (Figure 20).

Less common and occurring generally as isolated plants or clumps on the edges of the dune grass are species such as Hebenstretia cordata and Pteronia onobromoides (Table 11).

2. South-west and south coasts. On the temperate coasts the succulent herbs Tetragonia decumbens and Arctotheca populifolia and the introduced rhizomatous grass Agropyron distichum (seawheat) are the most important components of Zone I (Plates 14-17). Seawheat is an extremely efficient upper beach sand binder, and attains its most vigorous growth on the temperate coasts (Plate 61). Locally the grasses Eragrostis sabulosa, Sporobolus virginicus and Stenotaphrum secundatum invade close to the beach usually in seep and high water-table sites.

3. South-east coast. The east Cape part of this coast sector has cool inshore waters and here Arctotheca populifolia (dune cabbage) remains one of the most important strand plants (Plates 13, 14, 56), with an increasing predominance northwards of Scaevola thunbergii, Ipomoea brasiliensis and Syperus maritimus. The dune cabbage grows for about a two year period and thereafter dies back usually en mass as it forms even-aged stands from the simultaneous germination of the seeds.

On the northern part of the south-east coast plants such as Launaea sarmentosa, Canavalia maritima and the grass Dactyloctenium australe become important with Scaevola the dominant hummock dune forming species (Plates 18, 19, 72, 73).

4. East coast. Scaevola, Ipomoea and Canavalia remain important on the Mocambique Coast but dune cabbage and Hydrophylax carnosa drop out north of Delagoa Bay. North of the Limpopo Mouth the tall rhizomatous grass Halopyrum mucronatum, typical of tropical Indian Ocean beaches, becomes increasingly important as a sand binder in Zone I (Plate 60).

Depending on the growth form of various strand plants quite different sand accumulations are developed. Rhizomatous plants such as Scaevola, Halopyrum, Tetragonia and Arctotheca build a pronounced crest and hollow relief, whereas stoloniferous plants with long trailing surface shoots tend to form low undulating sand accumulations, as exemplified by Ipomoea, Canavalia, Hydrophylax and Launaea. The opposite tendency is, however, shown by the two introduced dune grasses. Seawheat generally shapes low undulating dunes whereas a distinct hummock and hollow relief is formed by marram Ammophila arenaria in Zone II (Plates 15, 16).

TABLE 11. Distribution of plants recorded in the strand plant zone south of the tropic.
*denotes the 14 principal or core group of beach pioneers occurring closest to the sea

Plant Species	Life Form	Coast Sector M T N E S C W
Aizoon rigidum	h	+++++++++++
* Agropyron distichum	g	+++++++++++
* Arctotheca populifolia	h	++++++++++++++++
* Canavalia maritima	u	+++++++
Carpobrotus acinaciformis	h	+++++
C dimidiatus	h	++++++++++
C edulis	h	++++++
Chenopodium sp	h	+++++++++++++++++
* Cyperus maritima	c	++++++++++++++
Dactyloctenium australe	g	++++++++
* Eragrostis cyperoides	g	+++++
E sabulosa	g	++++++++
Gazania rigens	h	++++++++++++++
* Halopyrum mucronatum	g	++
* Hebenstretia cordata	u	++++++++
Heteroptilis suffruticosa	h	+++++++++++
* Hydrophylax carnosa	h	+++++++++++
* Ipomoea brasiliensis	h	++++++++++++
* I stolonifera	h	++
* Launaea sarmentosa	h	++++++++
Mesem creeper (Aizoaceae)	h	+++++
Osteospermum fruticosum	h	++++++++++++
Paspalum vaginatum	g	+++++++++++++++++
Polygonum maritimum	h	+++++++++++
Psoralea repens	h	+++++
Pteronia onobromoides	u	+++++
Salsola kali	h	+++++++++++++
* Scaevola thunbergii	u	++++++++++++++
Senecio elegans	h	++++++++
* Sporobolus virginicus	g	+++++++++++++++++++
Stenotaphrum secundatum	g	++++++++++++++++
Silene primuliflora	h	+++++++++
Tephrosia purpurea	h	+++++++
* Tetragonia decumbens	h	++++++++++++
34 spp		14 15 17 20 23 22 14

Life Form: c = sedge; g = grass; h = herb or forb; u = suffrutex or shrublet

Coast sector: M = south Mocambique; T = Tongaland; N = Natal; E = east Cape; S = south Cape; C = south-west Cape; W = west coast

B. Zone II Shrub community.

This community is a mixture of Zone I plants with the addition of a rich array of psammophytes from many other habitats, which are less tolerant of the highly saline and extremely unstable and severe conditions in Zone I (Table 12). Exceptional species richness in this zone is the hallmark of the southern coasts where the high floristic diversity of fynbos heath communities are superimposed on the basic zonation and expanded over large areas by fire.

The life-forms of these plants include annuals, forbs, creepers and climbers, geophytes, succulents, root-parasites and shrubs. Most of these plants are generally not restricted to Zone II but occur in nearly any site away from the beach where bare sand is exposed. In addition to its position and mixed character Zone II is typified by the occurrence of certain shrub components along particular coast sectors.

The indicator shrub on the east coast, particularly north of Delagoa Bay, is the silver-leaved legume *Sophora inhambanensis* (*tomentosa*), which has a pantropical Indo-West Pacific range (Good 1964). On the south-east coast this shrub community is referred to as the Passerina Zone due to the pre-eminence of the fine-leaved thymeleaceous shrub *Passerina rigida* which can attain three metres in height (Bews 1920; Bayer 1938; Hillary 1947; Ward 1980). This shrub remains important in this zone on southern coasts where it is associated with additional species of the same genus (Boucher 1974, 1978), and a larger fine-leaved composite shrub *Metalasia muricata* which is the predominant component in this region.

On the west coast the second zone remains a mixed life-form community, but the shrub colonizers are the precursors and subsequent canopy components of the climax closed dwarf scrub-thicket community that develops (Plates 24, 63). In many sites little to no mixed community develops and the shrubs invade directly into dunes stabilized solely by the dune grass *Eragrostis cyperoides*. The bietou or tickberry *Chrysanthemoides monilifera* is one of the most important shrub colonizers of Zone II on all backshores as far as the Groen River on the west coast (Bickerton 1981b).

On dune ridges of the growing shoreline sequence at Mtunzini the shrub *Helichrysum kraussii* and two grasses, *Imperata cylindrica*, a pantropical rhizomatous species, and a tufted species *Stipagrostis zeyheri* are key colonizers of the second zone (Moll 1972). Two rhizomatous grasses *Ehrharta villosa* and the introduced marram *Ammophila arenaria* are important sand binders on exposed sand landwards of the backshore on southern coasts. The *Ehrharta* occurs typically along dune slipfaces where it is often associated with the shrub *Myrica cordifolia* which has a sympodial growth form (Plate 34). On southern coasts two low-growing, evergreen, rhizomatous, restios *Restio eleocharis* and *R leptocladus* are very important sand binding components which extend from Zone II landwards wherever the woody canopy is not too dense.

The shrubs in Zone II are chiefly wind (eg *Metalasia*, *Helichrysum*) or bird (eg tickberry, *Passerina*, *Myrica*) dispersed species. The other plants are dispersed by the full array of methods. Over time this zone is increasingly invaded mainly by bird dispersed shrubs and trees typical of the scrub-thicket community (Zone III) (Plates 22, 70, 73).

TABLE 12. Partial lists of plants recorded from the shrub zone south of the tropic
Broad distribution indicated by coast sector symbol and life form in parentheses

---

Ammophila arenaria S-C (g)
Anthospermum littoreum T-S (h)
Aster sp W (h)
Asparagus capensis var: littoralis E-W (s)
Asystasia gangetica M-N (h)
Borreria sp M (h)
Chironia baccifera T-C (u)
Chrysanthemoides monilifera M-W (s)
Cleome stricta M (h)
Cynanchum spp M-C (p)
Cynodon dactylon M-W (g)
Didelta carnosa W (s)
Ehrharta villosa E-C (g)
Felicia aphylla S-C (h)
F echinata S-C (h)
Ficinia lateralis S-C (c)
Gloriosa superba M-S (p)
Guettarda speciosa M (s)
Helichrysum crispum S-C (u)
H ericifolium T-C (u)
H kraussii M-N (s)
Heterocarpa schiemanniana M-T (g)
Imperata cylindrica M-C (g)
Indigofera kirkii M (h)
I neglecta M-T (h)
Lebeckia cinerea W (s)
Limeum africanum S-C (h)
Lycium spp M, E-W (s)
Mesems (Aizoaceae) 3-4 spp C-W (h,u)
Metalasia muricata E-C (s)
Myrica cordifolia E-C (s)
M quercifolia S-C (s)
Nylandtia spinosa E-W (s)
Othonna floribunda W (u)
Passerina falcufolia S-C (s)
P glomerata S-C (s)
P paleacea S-C (s)
P rigida T-C (s)
P vulgaris S-C (s)
Pentzia suffruticosa W (u)
Phyla nodiflora T-C (u)
Phylica ericoides S-C (s)
Polygala nyrtifolia N-C (s)
Psoralea fruticans S-C (p)
Restio eleochris S-C (r)
R leptocladus S-C (r)
Rhoicissus spp M-S (p)
Salsola spp W (s)
Scaevola taccada M (s)
Secamone alpinii M-S (p)
Senecio elegans E-W (h)
S halimifolius C (s)
S litorosus N-C (h)
S maritimus S-C (h)
Sesuvium portulacastrum M-W (h)
Silene primulaeflora E-C (h)
Stipagrostis zeyheri T-C (g)
Stoebe plumosa E-C (s)
Tetragonia fruticosa S-W (s)
Thesium spp S-C (u)
Trachyandra divaricatum S-W (b)
Zygophyllum morgsana S-W (p)

Life Form: b = geophyte; c = sedge; g = grass
h = herb or forb; p = creepers/climbers;
r = restios; s = shrub; u = suffrutex or shrublet

Coast Sector: M = south Mocambique; T = Tongaland; N = Natal (+ N Transkei); E = east Cape (+ south Transkei);
S = south coast; C = south-west coast; W = west coast

C. Zone III Scrub-thicket community.

This is a dense, unistratal community of multiple-stemmed dwarf trees and shrubs with a compact canopy. Apart from a litter layer of fallen leaves and twigs the understorey is mostly devoid of plants. On eastern and southern coasts where steep foredunes rise immediately above the backshore the canopy is hedged by salt-spray pruning (Plates 77, 79).

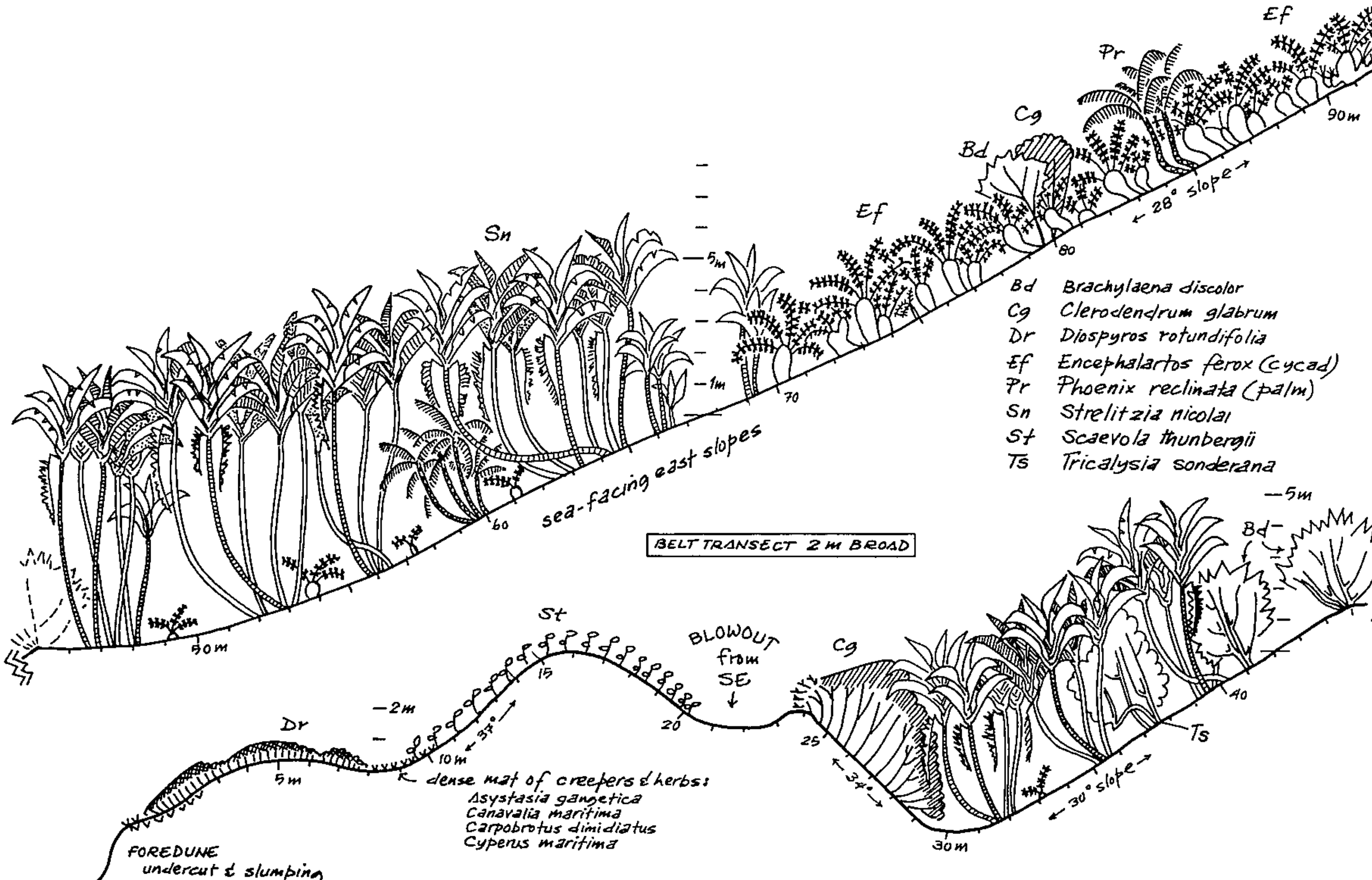


FIG 14 PROFILE STRUCTURE OF CYCAD & STRELITZIA DOMINATED DUNE THICKET ON EAST COAST DUNES 6 km SOUTH OF BANGA NECK, TONGALAND.

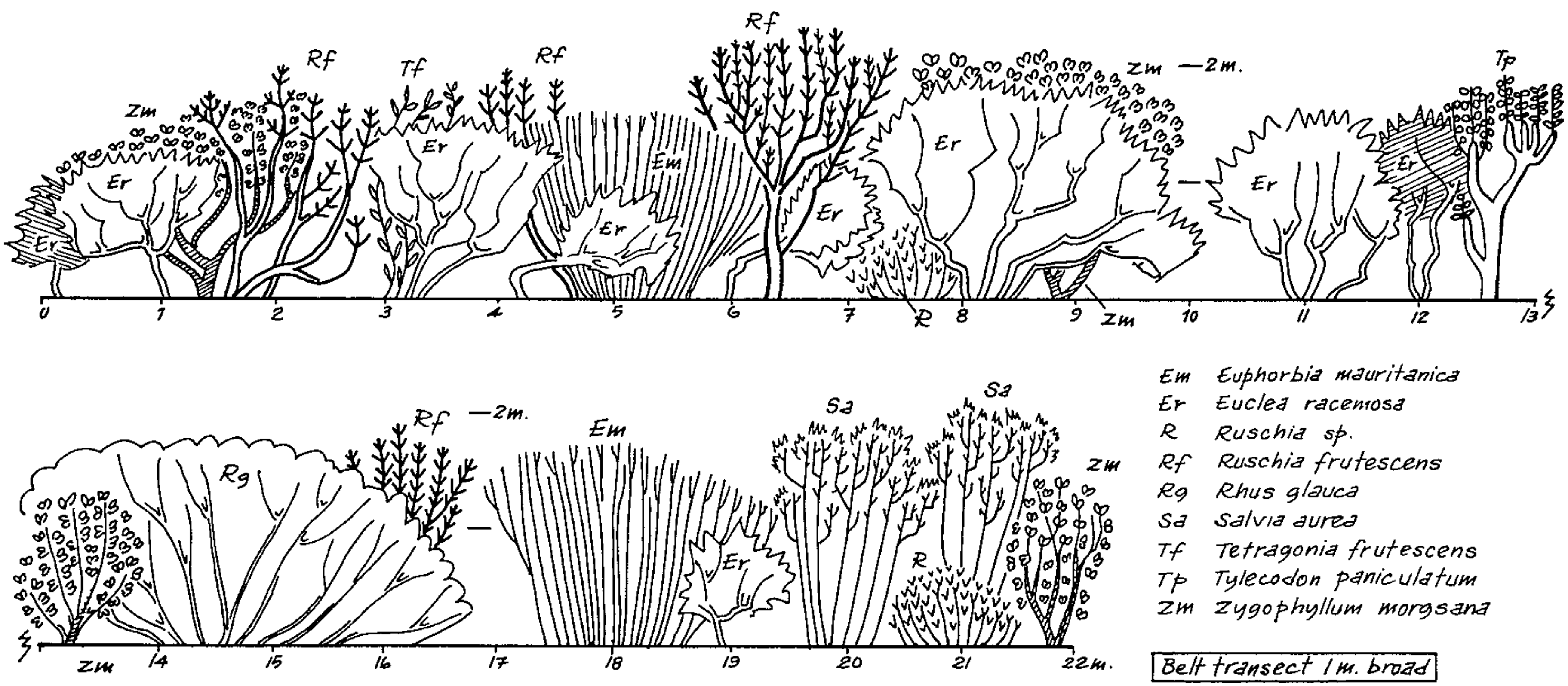


FIG 15. STRUCTURAL PROFILE OF DWARF SCRUB-THICKET ON WEST COAST DUNES (example from Rocher Pan Nature Reserve north of St Helena Bay).

The canopy is hedged on the seafacing slopes of the dunes and is taller in the lee of dunes or other obstacles. The mature community thus varies from about 10 cm above ground level to over five metres (on moist coasts) where the same woody species assume a tree growth-form in hollows. Height is thus dependent on the rise and fall of dune relief beneath an even canopy. Where dunes have a low undulating relief the canopy is more uneven and the cover tends to be clumped.

The scrub-thicket community is the regional climax cover on dunes on the southern part of the subdesert west coast, and locally on certain parts of the temperate southern coasts (Plates 64, 65, 67, 68).

On eastern and southern coasts typical scrub components of Zone III include jackal-berry (Diospyros) and guarri (Euclea) of the ebony family, milkwoods (Mimusops and Sideroxylon), taaibos (Rhus), myrtle (Eugenia), saffronwood (Cassine), cats-claw (Scutia), Kei-apple family (Dovyalis), honeythorn (Lycium), sandlewood (Colpoon), olive (Olea), and spike thorns (Maytenus, Putterlickia).

Of these Maytenus procumbens is an indicator species for this zone from the east to the south-west coast. Diospyros rotundifolia is the main dominant from the Tugela River northwards to central Mocambique where it overlaps with the gum copal Trachylobium verrucosum which becomes increasingly important on dunes northwards. From the Tugela River southwards to Woody Cape Mimusops caffra is a dominant, with many Rhus species, Olea exasperata, Euclea racemosa and Pterocelastrus tricuspidatus increasingly important westwards from the east Cape. Euclea becomes the leading dominant on west coast dunes with succulent arborescent mesems.

Creepers and climbers are common in Zone III particularly where openings occur and include the following genera: Asparagus, Cassytha, Cissampelos, Commelina, Cynanchum, Rhoicissus, Secamone, Senecio and Smilax. A more complete list of species is noted in Zone IV.

1. East coast. A point quarter analysis of this zone on the Tongaland Coast one kilometre north of Banga Neck (Kosi Lake System) showed the following percentage importance* of species in a single site: Diospyros rotundifolia (54%), Sideroxylon inerme (15%), Apodytes dimidiata (12%), Mimusops caffra (6%), Euclea schimperi (4%), Euclea undulata (4%) and Eugenia gueinzii (4%). Refer to Plates 70, 74, 75.

In some sectors patches of the tree-strelitzia Strelitzia nicolai and dune cycad Encephalartos ferox form a dense cover on steep sea-facing foredune slopes (Figure 14, Plate 78). This community is maintained by recurrent fires which inhibit the invasion of thicket/forest species.

Trees and shrubs typical of the tropical Indian Ocean islands (Vesey-Fitzgerald 1942; Good 1964; Sauer 1967) begin to appear on the Tongaland Coast (eg Guettarda speciosa, Thespesa acutiloba) and become increasingly important north of Delagoa Bay, though they seldom assume more than a local patchy dominance. Others of this group include Tournefourtia argentea,

---

*Importance Value (IV) of Curtis and Cottam (1962) = summed percentages of relative frequency, density and basal area (from dbh), divided by three.

Suriana maritima, Colubrina asiatica, Caesalpinia bonduc (from Natal northwards), Pemphis acidula and Calophyllum inophyllum. Madagascan (eg Brexia madagascariensis) and east African (eg Terminalia boivinnii) trees also become important northwards.

2. South-east coast. Other species which occur in Zone III on the Tongaland dunes and which become increasingly common southwards on the south-east coast include Brachylaena discolor, Clerodendrum glabrum, Dovyalis longispina, Eugenia capensis, Ficus burtt-davyi, Maytenus nemorosa, Scolopia zeyheri, Scutia myrtina and Zanthoxylum capense (Bews 1920; Bayer 1938; Hillary 1947; Moll 1968; Ward 1980). The arborescent aloe A thraskii is typical of this zone on the Natal South Coast.

On the southern part of the south-east coast at Kwelega Point north of East London a point quarter analysis of Zone III showed the following importance values for woody species: Mimusops caffra (43%), Euclea racemosa (13%), Linociera foveolata (8%), Cassine aethiopica (6%), Maytenus procumbens (5%), Euclea natalensis (5%), Brachylaena discolor (4%), Acokanthera oppositifolia (3%), Allophylus natalensis (2%) and five species with one per cent - Canthium obovatum, Cassine papillosa, Olea capensis, Pterocelastrus tricuspidatus and Sideroxylon inerme.

3. South coast. Dwarf scrub-thicket on the foreshore occurs in St Francis Bay, at Cape Vacca and Cape Agulhas (Plates 67-69). That at Cape Vacca immediately east of the Gouritz River mouth is formed by the following species: Aloe africana, A arborescens, Azima tetracantha, Carissa bispinosa, Cassine tetragona, Clutia daphnoides, Cotyledon orbiculata, Cussonia thyrsiflora, Euclea racemosa, E undulata, Euphorbia mauritanica, (resembling E Caput-medusa or E tuberculata), Maytenus heterophylla, M procumbens, Olea exasperata, Polygala virgata, Pterocelastrus tricuspidatus, Putterlickia pyracantha, Rhus crenata, R glauca, R laevigata, R longispina, Salvia aurea, Sideroxylon inerme, and Zygophyllum morgsana. Two shrubs Cassine maritimum and Rhus schlechterani endemic to the south Cape coast are common components of Zone III.

4. South-west coast. In the south-west Cape the following woody species are typical components of Zone III: Cassine eucleiformis, C peragua, Chrysanthemoides monilifera, Colpoon compressum, Cussonia thyrsiflora, Helichrysum ericaefolium, Metalasia muricata, Myrica cordifolia, Olea exasperata, Passerina spp, Phylica spp, Pterocelastrus tricuspidatus, Rhus crenata, R glauca, R laevigata and R lucida. Refer also to Heydorn (1975), Boucher (1978) and the "Estuaries of the Cape" series of CSIR/NRIO (Coastal Unit) reports (1980-1984).

5. West coast. On the subdesert coast both the prevailing and strong winds are quasiparallel to the coastline hence the compact hedged physiognomy is uncommon and confined to shoreline curves which catch the wind directly onshore.

On the west coast into Namaqualand, but particularly south of Lamberts Bay a dense closed canopy dwarf thicket is the climax dune community. Here dwarfing appears to be due to low rainfall rather than pruning by salt spray. The canopy which attains an average height of between 0,8 and 2 m is closed in patches or clumped form with openings of varying widths between patches. The openings are colonized by isolated clumps of succulents such as Euphorbia caput-medusae and especially by creepers which include mesems, pelargoniums and the annual dune-grapple Grielum tenuifolium whose abundant hard-spined fruit make it impossible to walk barefoot in the dunes.

At Rocher Pan the average height of the dwarf scrub-thicket on the back-dunes is 1,4 m. Here Euclea racemosa had the highest importance value* of 32% followed by the succulent arborescent mesem Ruschia frutescens (18%), Euphorbia mauritanica (13%), Rhus glauca (9%), Zygophyllum morgsana (8%), Salvia aurita (4%), Pterocelastrus tricuspidatus (3%), Tetragonia fruticosa (3%), Chrysanthemoides monilifera (2%), Limonium perigrinum (2%), Putterlickia pyracantha (1%), Rhus laevigata (1%), Tylecodon paniculatus (1%), Cotyledon orbiculata (1%) and Lycium sp (1%) (Figure 15, Plates 64, 65). Most of these species are active invaders of the frontal dunes covered by almost pure swards of Eragrostis cyperoides grass (Plate 63).

The initial woody colonizers form nuclei for the development of bush-clumps which are smaller and more widely spaced seawards and denser and taller landwards where they form the mature (oldest) community (Plate 65).

6. Dune stabilizing alien trees. Rooikrans: A major part of the woody cover on southern coastal dunes today is that formed by dense thickets of the Australian wattle Acacia cyclops (rooikrans). Due to its proficiency in colonizing drift sand areas, when planted or seeded in conjunction with brushwood mats, it has been the chief means until recently of stabilizing coastal dunes (Walsh 1968). This shrub generally forms a pure cover and is a major threat to the native flora which it successfully invades and replaces, particularly where this is disturbed or burnt by fire. This success may be due to the nitrogen supply obtained from rhizobial nodule development on its roots (Roux and Warren 1963; Roux and Marais 1964), and the dispersal of its seeds by birds (Stirton 1978).

Casuarina: Until recently the casuarina tree Casuarina equisetifolia has been used as the main dune stabilizing plant on eastern coasts particularly in southern Mocambique, Tongaland and St Lucia (eg at Ponta do Ouro, Kosi Estuary, Gobeys Point, and Cape St Lucia).

The casuarina is a pine-like angiosperm with wind and water dispersed seeds, having a wide distribution on Indo-West Pacific Islands (Good 1964) where it forms pure woodlands or groves on sandspits, backbeach and low dunes. Its southernmost natural distribution along the east coast is the line of small islands off the coast between Pebane and Antonio Enes north of the Zambezi (Gomes e Sousa 1966, 1968; Tinley 1971b).

Unlike rooikrans, however, it is not an aggressive invader, though its dense growth and shade, and heavy leaf litter inhibits succession towards thicket/forest. This casuarina species may develop rhizobia like others in the genus and the rooikrans above.

---

*Using crown area in place of basal area for the third factor

D. Zone IV Thicket/forest community.

The mature closed arborescent vegetation on coastal dunes is composed of between 50 and 60% thicket (including savanna) species from base-saturated clayey soils, and some 30 to 40% of species from forests of several kinds eg Afrotemperate, equatorial, tropical sand forest and hygrophilous types (riverine, swamp) (Table 13). It is thus most accurately designated thicket/forest.

Field experience across southern Africa has shown that it is not possible to separate or identify thicket from forest purely on physiognomic and structural grounds alone due to the wide variability, overlap and parallel of features expressed by these quite different, though often serally related, closed woody formations in different situations.

The canopy trees of thicket are typically heliophytes and those of forest are sciophytes in all stages of growth prior to reaching the upper canopy, hence the two formations are most easily recognized on floristic grounds, as species are habitat or ecosystem indicators (Tinley 1975a, 1977).

Thicket is composed of species which form bush-clumps in most open formations such as grassland, semidesert, savanna (Bews 1917) and heathland. It also includes forest precursors which are typical of edges, openings or secondary habitats. As most bush-clump species are bird dispersed the thicket initials typically develop around any perch sites such as isolated trees and shrubs, termitaria, rock outcrops or fence posts etc (Tinley 1977).

Depending mainly on moisture regime, thicket can either be seral to forest, the forest shade-tolerant canopy species growing up through the thicket canopy and replacing it, or climax where shade tolerant plants may form subordinate strata or are sparse to absent resulting in a unistratal cover. Coastal dunes are perhaps unique in that the full spectrum of seral stages, woody formations and structural types are represented either in the local dune sequence or linearly in adjacent coast regions.

True forest on dunes occurs patchily where the mean annual rainfall approaches or exceeds 1 000 mm, on particular landform facets or backdunes such as landfacing and polefacing slopes, hollows and troughs or footslopes. Forest seems to be particularly associated with the older oxidized (laterized or podzolized) dune sands which are more compact and with their higher clay content have a better soil moisture balance than the younger, loose and rapidly permeable (droughty) sands, ie red to orange Hutton Form (fersiallitic) sands as opposed to pallid Fernwood Form regic sands.

Such sites are confined to parts of the Gazaland and Tongaland Coasts, in Natal (Ward 1980) particularly on the older red Berea-type dune sands as at Tugela Mouth where Chrysophyllum viridifolium is a major canopy tree (Cooper and Moll 1966), at Hawaan (Moll 1968), and Umdoni Park (Guy and Jarman 1969) for example where forest trees dominate in the canopy (Plate 81). On the Transkei Coast, at Dwessa for example, forest is replacing dune thicket on regic sands where dunes are low and shallowly overlie the oldland surface which acts as a perched water-table.

Here straight-boled ("shade/high density growth form") Podocarpus latifolius are replacing milkwood thicket canopy with its multiple contorted stems and many degrees of branching ("sun/exposed growth form"). The fieldlayer is dominated by an abundance of the shrub Psychotria capensis and yellowwood saplings with a dense groundlayer of shade grasses and the bulbous Haemanthus puniceus, interspersed with dense groves of the wild date palm Phoenix reclinata where the water-table is close.

Elsewhere on eastern and southern coasts the canopy of the mature woody community is dominated by heliophytic thicket and savanna elements as exemplified by species of Acacia, Aloe, Cassine, Euclea, Euphorbia, Mimusops, Maytenus, Rhus, Sideroxylon, and Ziziphus, as well as forest precursor species such as Apodytes dimidiata, Celtis africana, Pittosporum viridiflorum, Pterocelastrus tricuspidatus and Trema orientalis.

Not only the variety of dune relief, but the degree of steepness also determines the species content and height of the thicket/forest cover, as the crest and a band below it have the driest soils in the topographic profile, and the sands on oversteep slopes are constantly being shifted by gravity slides and rainwash.

In these natural openings on Tongaland dunes the savanna tree Acacia karroo is the main colonizer as a single tree or in scattered patches fitting the shape of the openings. Where tribal subsistance cultivators made clearings in dune forest, when left fallow these were invaded by the acacia in pure even-aged stands forming a closed canopied woodland (Plates 91, 92). This provides sufficient shade to initiate the seral succession back to forest (Tinley 1958b; Weisser 1978a,b). This acacia is quite absent from coast dunes south of the Tugela River, despite its abundance immediately adjacent to the landward base of backdunes. It does, however, occur on older coast sands and rarely in grass covered dune troughs in the east Cape where moisture conditions are better.

On the east and south Cape dunes the dry sandslip crest sites are colonized mainly by low fynbos heath communities composed of species such as Agathosma apiculata, Helichrysum spp, Metalasia muricata, Myrica cordifolia, Restio eleocharis, a widespread karroid shrub Nylandtia spinosa, the grasses Ehrharta villosa, Imperata cylindrica and Stipagrostis zeyheri and a sedge Ficinia lateralis (Plate 94).

The salient physiognomic feature of eastern coast dune cordons is the generally unbroken thicket/forest canopy which covers them from their seaward to landward bases (Plates 79, 80, 112). Although on the east Cape coast most of the shrub and scrub-thicket communities (Zones II and III) have been eliminated by erosion and replaced by bare buttress-barchanoid dunes. At the southern end of the south-east coast the prevailing thicket/forest cover gives way to an increasing patchiness where low heath communities colonize the bare openings formed on steep dune facets. From Cape St Francis westwards the mosaic dominance is reversed with thicket/forest occurring as lesser patches within a more extensive cover of dune heath or of the introduced rooikrans. This cover dominance reversal of two quite different formations is coincident with the change to a winter rainfall regime along the coast (Figure 13).

Generally stratification in dune thicket/forest always consists of a closed upper canopy with emergents, with extremely variable subordinate strata consisting of (a) smaller trees and shrubs, (b) fieldlayer, and (c) groundlayer which may be distinct or sparse to absent.

Where soft leaved understorey plants exhibit periodic growth and dieback, cover values can change from extremely dense to nearly bare. Epiphytic orchids, ferns and lichens are generally uncommon compared to most forest, branch parasites (Loranthaceae) are relatively common, but it is the abundance of creepers, climbers and lianas which are a characteristic feature of this zone.

Dune thicket/forest is mostly evergreen with small oval leaves which are smooth and shiny with a brittle and hard texture (crustaceous) characteristically of the nano-microphyll leaf size class as exemplified by species of Cassine, Canthium, Diospyros, Dovyalis, Euclea, Mimusops and Rhus. Most of these have obovate leaves (or leaflets) with rounded to emarginate apices, and the drip-tip feature of rain forest (Richards 1957; Longman and Jenik 1974) is absent or rare. These leaf form characteristics are similar to those of tropical sand forest and miombo savanna woodland.

The full range of leaf size types as classified by Raunkiaer (1934) are, however, represented from virtually leafless (eg Euphorbia) and leptophyll (eg Acacia) to the banana-form megaphyll leaves of Strelitzia nicolai. A change in species dominance of canopy trees thus results in a textural physiognomic change in cover. On the south Cape coast a predominant canopy tree of dune thicket is Sideroxylon inerme whose larger micro-mesophyll leaves with their obovate-elliptic-oblong shape lends a more lush appearance to the usual appearance of dune thicket.

This leaf type is xerophytic of a sclerophyll form (Bews 1925), a feature even shared by equatorial rain forest leaves which Richards (1957) has termed megasclerophyll to distinguish them from the microsclerophyll leaves typical of mediterranean climates.

As noted earlier, the distribution of woody species on dunes show a linear imbricate pattern with a kaleidoscopically changing composition and important values along the coast, from area to area within the same sector and locally on different relief facets. Examples of this in each stratum are noted below for the various coast sectors.

1. Canopy. Decrease in canopy height from the east coast to the west coast is noted above under Gradients.

(a) East coast

On the Gazaland Coast of Mocambique at Pomene, halfway between Bazaruto Island and Inhambane, the canopy of the landfacing slope of the backdune thicket/forest was composed of the following species: Acacia robusta, Balanitis maughamii, Brexia madagascariensis, Casearia gladiiformis, Commiphora schimperi, C schlecteri, Cordyla africana, Croton gratissimus (zambesicus), Diospyros inhacaensis, D rotundifolia, Dovyalis rotundifolia, Drypetes natalensis, Flacourtia indica, Ficus natalensis, Inhambanella henriquesii, Macphersonia hildebrandtii, Mimusops caffra, Sideroxylon inerme, Trachylobium verrucosum, Terminalia bovinii, Trichilia emetica, Vepris undulata, Zanthoxylum capense and Z schlechteri.

In the Kosi Lake System one kilometre north of Banga Neck a midslope contour sample of the inland-facing backdune slope above Lake Nhlange was made using the Point Quarter Method (PQM of Curtis and Cottam 1962). From 14 points 56 trees and 26 species were recorded with the highest numerical dominance led by Diospyros inhacaensis.

When basal area (derived from dbh) however are added to complete the Importance Value the following results are obtained: (IV 19%) Mimusops caffra; (13%) Sideroxylon inerme; (12%) Diospyros inhacaensis; (5%) Vitellariopsis marginata, Vepris undulata, Cassine papillosa, Drypetes natalensis, Teclea gerrardii, Acacia karroo, Acokanthera oblongifolia; (2%) Commiphora neglecta, Ptaeroxylon obliquum, Olea woodiana, Ziziphus mucronata, Canthium inerme, Diospyros natalensis, Dovyalis longispina, D zeyheri, Euclea schimperi, Linociera foveolata, Trichilia dregeana, Euclea undulata, Ficus tremula; (1%) Clausena anisata, Linociera peglerae, Scolopia zeyheri. The low IV percentages are typical of communities with a large species diversity and lack of dominance by a few species which is the reverse in Zone III and certain savannas for example.

This sample was on steep slopes where the average canopy height was eight metres with emergents to 13 m, and a density of about 1 736 trees to the hectare. The presence of subordinate small tree elements in the canopy such as the Acokanthera, Commiphora and Clausena illustrates the important influence steep dune relief has in telescoping stratification by reducing the average canopy height. For the ecology of the Kosi Lake System and its vegetation, mapped from 1942 aerial photographs at a scale of 1:36 000, refer to Tinley (1958b).

On the high forested backdune cordon above Lake Sibayi the change in importance value of canopy dominants on each relief facet is well illustrated by PQM results obtained by Venter (1974).

DUNE CREST: Ptaeroxylon obliquum (11,4), Croton gratissimus (11,0), Cassipourea gerrardii (9,3), Drypetes natalensis (9,1), Ziziphus mucronata (8,5), Acacia karroo (3,9), Mimusops caffra (2,1). INLANDFACING SLOPE: Mimusops caffra (22,0), Apodytes dimidiata (14,8), Acacia karroo (14,7), Canthium obovatum (12,3). FOOT OF LANDWARD SLOPE: Ziziphus mucronata (20,2), Diospyros inhacaensis (18,3), Teclea gerrardii (16,1), Croton gratissimus (14,7), and Drypetes natalensis (6,0). The vegetation of the Lake Sibayi area as a whole was decribed and drawn from the 1942 aerial photograph coverage by Tinley (1958a) and later detailed studies on dune forest in the area by Breen (1971) is summarized by Weisser (1980). Oblique aerial photographs of the dune forests between Kosi Bay and Lake Sibayi appear in Tinley and van Riet (1981). In 1965 I completed five separate transects of the coast dune forest area between Sodwana and Cape St Lucia at (1) Ntabende south of Sodwana, (2) Sekholwe south of Ochre Hill, (3) Mafutha north of Cape Vidal, (4) Perrier Rocks between Vidal and St Lucia Estuary, and (5) between Mapelane and St Lucia Lighthouse later studied in detail by Venter (1976). All canopy trees encountered in a two metre wide strip between the backdunes and the frontal dunes (Zone III) were recorded, and later expressed by Weisser (1980) as a per cent of the total trees counted in each traverse.

As both Zones III and IV were lumped together these data are more useful in illustrating the kaleidoscopic change in species importance in which the following trees had the highest recurrence: Celtis africana, Diospyros inhacaensis, D natalensis, Euclea schimperi, Euclea undulata, Linociera peglerae, Mimusops caffra, Sideroxylon inerme, Strychnos decussata, S madagascariensis (var gerrardii), and Teclea gerrardii.

The coast dunes south of St Lucia-Umfolozi Estuary (Plate 80) have more recently been studied in detail by Weisser (1978a,b, 1982). Weisser and Marques (1979), Weisser and Muller (1983) and in the Richards Bay area by Venter (1972). The classic growing beach ridge dune sequence at Mtunzini is described by Moll (1972) and Weisser et al (1982) (Plate 100 B).

(b) South-east coast

On the northern Natal part of this sector studies of dune thicket/forest have been made by Bews (1920), Bayer (1938), Hillary (1947), Edwards (1967) and Ward (1980), and a preliminary quantitative analysis at Umdoni Park by Guy and Jarman (1969).

Forest canopy and emergent trees in the Isipingo area near Durban for example included the following species (Ward 1980): Canthium obovatum, Celtis africana, Commiphora harveyi, C woodii, Cordia caffra, Diospyros natalensis, Euclea natalensis, Ficus vogelii, Linociera peglerae, Mimusops caffra, M obovata, Olea woodiana, Podocarpus latifolius, Sideroxylon inerme, Strychnos decussata, S madagascariensis (var gerrardii), Zanthoxylum capensis and Ziziphus mucronata.

In comparison to the above areas little is known about Zone IV in south Natal, Transkei and the east Cape apart from brief descriptions and species lists from a few sites, eg Dwessa (Moll 1974 and my notes above), East London District (Board 1962; Comins 1962), Gt Fish to Bushmans River (Dyer 1937). Recently quantitative studies of dune thicket have been made near the latter area and in the Algoa Sand Sea (McLachlan et al 1982).

In the east Cape Mimusops caffra is generally the dominant tree, if not numerically then in size, very often occurring as emergents from the backdune thicket/forest. Most display the "sun" or "open" growth form with several large boled contorted stems and branching close to the ground.

Canopy trees recorded from the east Cape include the following: Allophylus natalensis, Apodytes dimidiata, Brachylaena discolor, Canthium obovatum, Cassine aethiopica, C crocea, C papillosa, Cordia caffra, Diospyros natalensis, Dovyalis rotundifolia, Ekebergia capensis (rare), Erythrina caffra, Euclea natalensis, E racemosa, Euphorbia tetragona, E triangularis, Harpephyllum caffrum, Linociera foveolata, Maytenus heterophylla, Mimusops caffra, M obovata, Olea capensis, Podocarpus falcatus (rare), Pterocelastrus tricuspidatus, Schotia afra, S latifolia, Scolopia zeyheri, Sideroxylon inerme, Strelitzia nicolai, Tarchonanthus camphoratus, Vepris undulata and Zanthoxylum capense. Refer to Plates 25, 94, 108.

Pterocelastrus tricuspidatus, Schotia afra, S latifolia, Scolopia zeyheri, Sideroxylon inerme, Strelitzia nicolai, Tarchonanthus camphoratus, Vepris undulata and Zanthoxylum capense. Refer to Plates 25, 94, 108.

Wherever the canopy is short, small trees and large shrubs of the understorey or openings become an effective part of the upper canopy as exemplified by species such as: Aloe africana, Azima tetracantha, Clerodendrum glabrum, Colpoon compressum, Eugenia capensis, Metalasia muricata, Olea exasperata, Putterlickia pyracantha, Rhus crenata, R glauca, R laevigata, R longispina, R natalensis and Scutia myrtina.

A feature on many crest and lee slope sites are the pure species groves of trees developed from maturation of the multiple stems produced by sympodial growth from one or several root clones as a result of past burial by mobile sand. This results in a single storeyed woodland structure, and is especially common in genera such as Brachylaena, Euclea, Mimusops, Olea and Sideroxylon.

(c) South coast

Like the south east coast little detailed work on the Zone IV Community has been done apart from the contribution by Cowling (1982) from the Cape St Francis area.

On the south Cape coast the predominant canopy trees of tall dune thicket on backdunes are the candlewood Pterocelastrus tricuspidatus and white milkwood Sideroxylon inerme, both of which tend to form pure species aggregations (Plates 31, 83).

The canopy trees of Zone IV on this coast include the following species as recorded from the Langekloof wind-rift dunes, Natures Valley, Keurbooms, Buffalo Bay, Groenvlei and Visbaai (between Vleespunt and Cape Vacca): Allophylus decipiens, Buddleja salviifolia, Canthium obovatum, C spinosum, Cassine aethiopica, C peragua, Dovyalis rhamnoides, Euclea racemosa, Linociera foveolata, Maytenus heterophylla, Olea capensis, Pterocelastrus tricuspidatus, Scolopia zeyheri, Sideroxylon inerme, Tarchonanthus camphoratus and Zanthoxylum capense.

Despite the close proximity of moist Knysna-type forest at Natures Valley and Keurbooms, no Afrotemperate trees were found in my traverses of the backdunes. In the candlewood forest on the mesocline slope of the Langekloof backdune ridge the following Afrotemperate trees were noted by Richard Cowling during a combined fieldtrip: Pittosporum viridiflorum, Podocarpus latifolius, Rapanea melanophloeos, and Widdringtonia sp probably W nodiflora (Plate 33).

On high steep dunes of the Cape south coast, best seen at Groenvlei, tall thicket/forest is confined to the basal slope of the landward dune scar where a higher moisture balance pertains. The thicket canopy decreases in height and density upslope where it peters out and is replaced by dune heath vegetation on overdrained aspects (Figure 16, Plates 31, 32, 82, 83).

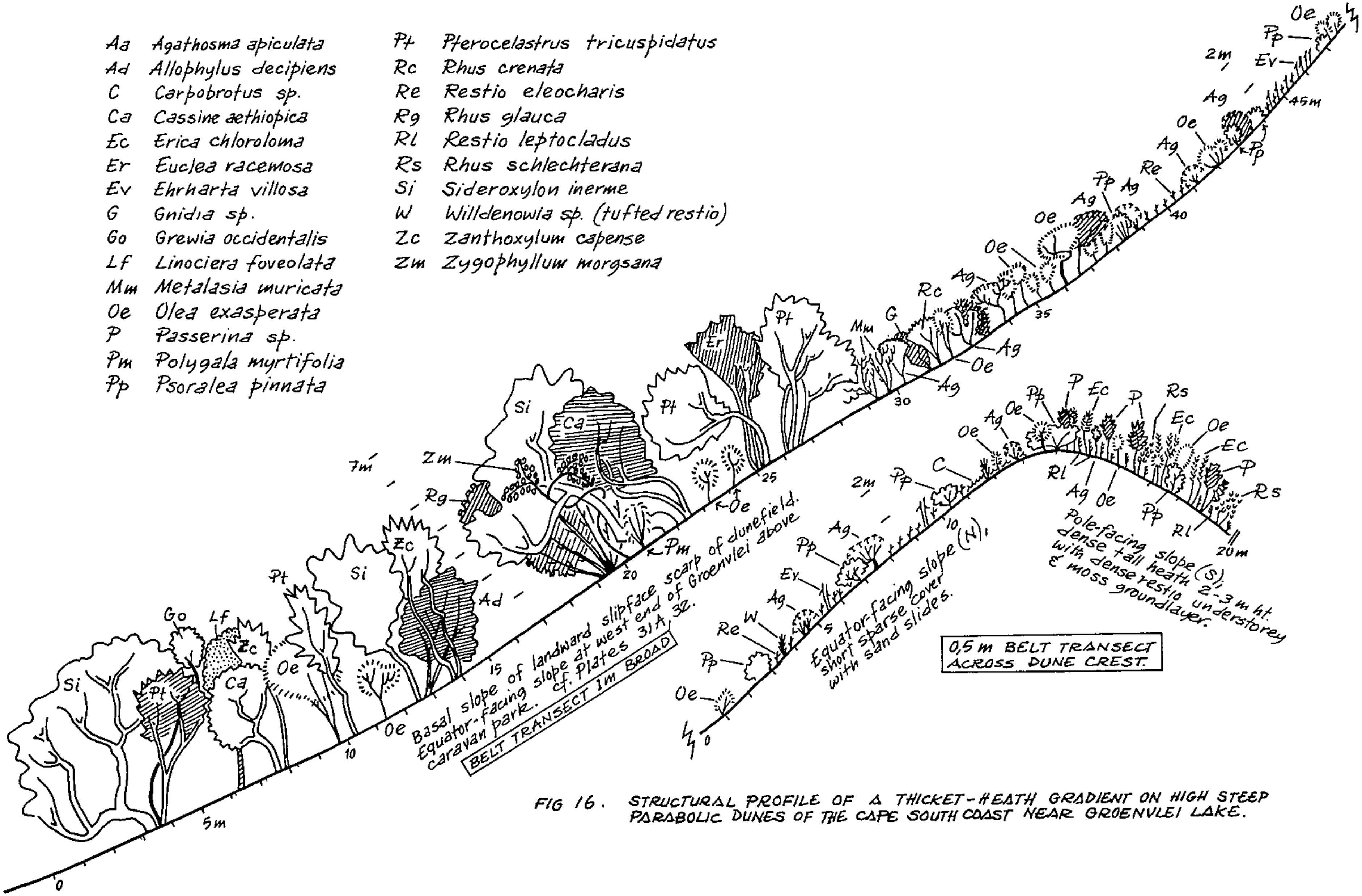


FIG 16. STRUCTURAL PROFILE OF A THICKET-HEATH GRADIENT ON HIGH STEEP PARABOLIC DUNES OF THE CAPE SOUTH COAST NEAR GROENVLEI LAKE.

(d) South-west coast

West of the Gouritz River mouth most of the mature climax thicket on dunes is the Zone III Community, though small patches of the Zone IV Community in the form of white milkwood groves occur to the Cape Peninsula. The occurrences at Palmiet River mouth, Betty's Bay and False Bay included the following canopy trees: Cassine maritimum, C peragua, Euclea racemosa, Linociera foveolata, Olea capensis, O exasperata and Sideroxylon inerme.

Details on the dune succession and influence of groundwater on dune thicket constituents is given by Heydorn (1975), and Boucher (1978) describes the vegetation of the Cape Hangklip area, including the dunes, using the Braun-Blanquet method of analysis.

2. Understorey trees and shrubs. Typical subordinate small trees and shrubs common to Zone IV on eastern coast dunes are: Acokanthera oblongifolia, Carissa bispinosa, Clausena anisata, Deinbollia oblongifolia, Diospyros whyteana, Dracaena hookerana, Erythroxylum emarginatum, Ficus burtt-davyi, Maerua cafra, Ochna arborea, Pavetta revoluta and Turraea obtusifolia. Psychotria capensis is common, and locally abundant in higher rainfall areas from the Transkei northwards.

Like the canopy trees the striking feature of the subordinate trees and shrubs is the increase in species and their relative density towards the tropics, especially of the Rubiaceae (Canthium, Pavetta, Tricalysia) as well as Annonaceae, Burseraceae, Erythroxylaceae and Ochnaceae. Beginning either in Natal or Tongaland the following tropical species form part of the dune forest understorey: Canthium setiflorum, Cussonia zuluensis, Drypetes natalensis, Ephippiocarpa orientalis, Kraussia floribunda, Pavetta gerstneri, Peddiea africana, Plectroneiella armata, Suregada africana, Tricalysia sonderana, Coddia obovata and Baphia racemosa appears to be confined to Natal dunes.

From the southern end of the south east coast subordinate shade tolerant trees and shrubs become increasingly rare in species and number, so that most of the Zone IV Community tend to have a single-layered woodland structure with an herbaceous groundcover (Plate 83). Of the first list for example only Carissa bispinosa reaches the south west coast and Clausena anisata probably does not extend beyond the Gouritz Mouth on dunes.

3. Fieldlayer. The fieldlayer is composed of woody and herbaceous plants, few of which are confined to it, as the majority are the young stages of trees, shrubs and lianas. The characteristic undergrowth plant on eastern coast dunes is Isoglossa woodii, a soft-leaved acanthaceous suffrutex which forms a pure fieldlayer society. It has a growth periodicity of about 10 years culminating in a single flowering and fruiting followed by death and new growth from seed (Ward 1980).

Wherever this species occurs the typical fieldlayer pattern is a mosaic of patches each at a different even-aged height. The fieldlayer can thus vary from completely bare to dense massed growth of isoglossa attaining up to three metres in height in some areas (eg St Lucia).

During their period of dominance the deep shade formed by isoglossa has a strong suppressive and selective influence on seedlings (Bayer 1938, 1952; Ward 1980), especially the light demanding thicket and climber elements.

This phenomenon is a feature of forest ecology in many regions (Richards 1957; Longman and Jenik 1974), as exemplified by the dense pure species undercanopy thickets formed by Trichocladus crinitus in Afrotemperate forest at Knysna (Phillips 1931), and Sloetiopsis usambarensis in the moist tropical groundwater forests of the Cheringoma Coast north of Beira. Clearing of these undercanopy thickets which impose over-dark conditions on the forest floor, immediately augments light values, results in a rise in soil moisture content and even the water-table, and a marked increase of woody plant seedlings (Phillips 1931; Tinley 1977).

Compared to the long-term effects of the above small tree understorey species, that of isoglossa is more transitory, however, it has a definite impact on the groundlayer and may play a role in age group layering or replacement of upperstorey species.

4. Groundlayer. From the southern east coast to Natal the young stages of isoglossa which form a pure goundlayer cover beneath thicket/forest on backdunes is typically replaced seawards on mid to frontal dunes by a ground fern Phymatoides scolopendria which also occurs in nearly pure swards (Tinley 1958b; Moll 1972; Weisser and Cooper in press). Other groundlayer plants have extremely patchy distribution on eastern coasts and include: Barleria repens, Bonatea speciosa, Clivia nobilis, Commelina spp, Cyperus albostriatus, Dietes vegeta, Gonatopus boivinii, Haemanthus spp, Justicia capensis, Sansevieria hyacinthoides, Zamioculcas zamiifolia, the grasses Oplismenus hirtellus, Panicum chusqueoides, P laticomum and the seedling and sapling stages of trees and of lianas such as Monanthotaxis caffra and Uvaria caffra (MacNae and Kalk 1958; Tinley 1958a,b; Ward 1980; Weiser 1980, 1982; Weisser and Cooper in press).

In the tall white milkwood thickets on the south coast dunes near Groenvlei a dense groundlayer is formed by a soft-leaved acanthaceous herb (40 cm in height) and a tufted shade grass with inflorescences reaching 110 cm in height (Plate 83). In parallel with other Synusiae there is a marked decrease in species richness in this layer from the tropical east coast southwards and especially west of the south-east coast on the temperate coasts. Where the understorey is open, a dense groundlayer of fallen leaves and dead branches is a feature of dune thicket/forest.

5. Climbers. A striking feature common to Zone II, III, and IV communities, but excluding the dune heaths, is the dense tangle of creepers, climbers, scandents and woody lianas which entwine the canopy. These are most abundant on the margins of thicket/forest, in openings where the canopy is light and especially in secondary habitats. They are least common, apart from large stemmed lianas, in mature closed forest. A specialized group of machanically dependent plants, the strangler figs, are uncommon and occur mainly from Natal northwards.

Again like the other Synusiae of dune thicket/forest there is a marked decrease in climbers westwards from the south-east coast. For example 42 species are recorded on dunes south of Durban at Isipingo (Ward 1980), 35 species are noted from a one hectare area near the Nahoon River mouth at East London, and less than 10 species from the south-west Cape (Acocks 1975; Boucher 1978).

Climbers confined to the north-eastern coasts include: Acacia kraussiana, Cissampelos spp, Cissus quadrangularis, Dalbergia armata, D obovata, Flaggelaria guineensis, Grewia caffra and Smilax kraussiana. Two latex lianas Landolphia kirkii and L petersiana are rare or uncommon in the dune forests of Tongaland but are abundant in immediately adjacent thicket and forest landward of the dunes. Parallel to many tree and shrub species, climbers such as the two dalbergias and Monanthotaxis caffra are absent from the drier east Cape dunes but occur in moister adjacent thicket habitats of valleys, riverbanks and cliffs.

Climbers, creepers and scandents generally common to eastern coast dunes and some extending to the southern coasts include: Asparagus africanus, A asparagoides, A falcatus, Behnia reticulata, Capparis sepiaria, Cassine tetragona, Clematis brachiata, Cynanchum ellipticum, C natalitium, C obtusifolium, Gloriosa superba, Rhoicissus digitata, R tomentosa, Sarcostemma viminale, Secamone alpinii, Senecio deltoideus, S mikanioides, S quinquelobus and Solanum geniculatum (Ward 1980; Weisser and Cooper in press).

A large liana Combretum bracteosum occurs on the Natal, Transkei and northern east Cape dunes, and three endemic scandents Aloe ciliaris, Cussonia thyrsiflora and Rhoiacarpos capensis occur from the east Cape to the south Cape, the cussonia continuing to the south-west coast with Asparagus falcatus and Cynanchum ellipticum. Two scandents which have their beginning on the south end of the south-east coast, Tetragonia fruticosa and Zygophyllum morgsana, becoming increasingly important around to the west coast. Climbers and scandents recorded in dune bush from the south-west coast thus include: Asparagus falcatus, Cussonia thyrsiflora, Cynanchum ellipticum, Dipogon lignosus, Solanum geniculatum, Pelargonium gibbosum, Tetragonia fruticosa and Zygophyllum morgsana.

6. Epiphytes and branch-parasites. Two other Synusiae, epiphytes and the semiparasitic Loranthaceae dispersed by birds, are patchily common on trees and shrubs of eastern and southern coasts.

Epiphytes include the orchids Angraecum pusillum, Cyrtorchis arcuata, Mystacidium capense, the fern Microgramma lycopodioides, "Old Man's Beard" (Usnea barbata) and crustose lichens. In the eastern Cape epiphytes are most abundant on the seafacing aspects of branches and tree trunks related to the copious aerosol of moisture carried by onshore winds and advective sea fog, despite these aspects receiving the most salt-spray.

Amongst the bird-limes, Loranthus dregei, L kraussianus and L quinquenervis are widespread on eastern and southern coasts. Viscum nervosum is the mistletoe more common northwards on eastern coasts (Ward 1980), V obscurum is abundant in the drier dune thickets of the east Cape and Viscum capensis occurs from about the south-west coast northwards into the dwarf scrub-thicket of west coast dunes.

In summary, the floristic composition of thicket/forest is influenced by (1) geographical position, (2) selective dispersal of species by avian frugivores, (3) moisture conditions (climo-edaphic), (4) adjacent landward ecosystems, (5) steepness of dune relief and contrasting slope aspects (eg protection or exposure to salt-spray: xerocline-mesocline slopes), (6) acidity or alkalinity of the sands, (7) shade intensity of overstorey and/or understorey.

E. Dune heath.

Large areas of dense fynbos shrubland 0,5 to 2 m in height occur on dunes of the south and south-west coasts. Due to their floristic complexity detailed analysis of this dune habitat was not attempted due to time constraints (Cowling 1982). The most striking heath communities are those which display a strong relief aspect dominance as on the high and steep wind-rift dunes at Langekloof near Slangbaai west of Cape St Francis, at Buffalo Bay west of the Knysna Heads and on the high compound nested parabolic dunes at Groenvlei in the Wilderness area (Figure 16, Plates 31, 32, 87). The dense cover of thin-stemmed shrubs has a two-tiered structure with a groundlayer or micro-fieldlayer mainly of Restio leptocladus (Plate 88).

Main shrubs identified for me in the field by Richard Cowling on the Langekloof dunefields were: Agathosma apiculata, A stenopetala, Cullumia decurrens, Cliffortia ilicifolia, Erica chloroloma (a South Cape dune endemic), E glumiflora, Helichrysum sp, Leucadendron salignum, Metalasia muricata, Myrica quercifolia and Passerina vulgaris. In this cover were large-leaved thickets and forest initials forming isolated bush clumps or patches.

Extensive areas of short pyrophytic dune heath occur immediately west of Cape Agulhas in the Renosterkop area (Plates 84-86). As well as many of the components noted above were tall tufted Willdenowia restios which attain 2,5 m in height (Plate 69). The most instructive feature about these dune heaths on low undulating dune topography is the clear post-fire succession displayed in adjacent patches, where annual burning in a mosiac pattern has been applied in an attempt to maintain pasture quality for small stock. Patches are burnt in the late summer-autumn prior to the first winter rains. Four seral regrowth stages were clearly identifiable, each successive stage forming the understorey to the earlier stages: (1) A pure Metalasia muricata stage up to 20 cm in height, (2) a Metalasia (100 cm) - Passerina (50 cm) stage (both species recolonizing in situ from seed), (3) an Agathosma stage where the cover is 120 cm in height, and (4) shrub-thicket stage (Chrysanthemoides, Euclea, Olea, Pterocelastrus, Rhus, etc). Each mix of species at each stage results in a two-tiered structure as the first stage colonizers form the upper larger shrub layer and the following species a lower small shrub layer.

In some areas the two-layered structure is formed by two unpalatable species, a Passerina shrub stratum with a Restio leptocladus groundlayer. Many shrub species show the typical fire-forms characteristic in many savannas of the tropics where mopane and roundleaf kiaat, for example, form continually expanding basal root plates with multiple coppicing and a dwarfed growth form. In this area Euclea racemosa and Olea exasperata show sympodial lateral growth from repeated fire, but the shrub Myrica quercifolia forms the largest patches of sympodial coppice clones.

The dune heath formation is concentrated along the southern coasts (south and south-west sectors) and the longest breaks in shoreline dunes are those formed by the cliff coasts of Tsitsikamma, the coast west of Plettenberg Bay, between Gouritz Mouth and De Hoop, and on the Cape Peninsula (Heydorn and Tinley 1980).

Fynbos heath communities on dunes terminate relatively abruptly in the west at Saldanha and narrow into discontinuous patches east of Cape St Francis to past Woody Cape from where they tail off in sandslip openings amongst dune thicket to about the Igoda River south of East London.

F. Dune grassland and savanna.

Grassland areas with a greater or lesser sprinkling of shrubs, small trees and bushclumps occur on parts of dunes along the east (Plate 89), southern south-east and south coasts. Most of these sites appear to be a secondary expansion of grassland and savanna from the landward margins onto the dunes, where annual veld fires have burnt back the dune thicket cover. Such areas appear, however, to be topographically related, that is, where dune relief is low this seems to facilitate the expansion of open communities, and where abrupt or steep the dunes remain thicket or forest covered though their lower landward edges are all sharply defined by singeing from veld fires.

In other sites they are secondary communities on fallow lands in clearings made in the dune bush by subsistence shifting cultivators (eg see 1:36 000 vegetation maps of Sibayi and Kosi dune cordons traced from aerial photographs of 1942 in Tinley 1958a,b; see also De Carvalho 1969; Weisser 1978a, 1979; Weisser and Marques 1979).

In Mocambique the following grassland plants were collected by the writer from low angle landward slopes of the coast dunes at 23° S near Pomene (Barra Falsa) in December 1971: Andropogon schirensis, Aristida congesta, A stipitata, Cymbopogon excavatus, Digitaria milanjiana, Heteropogon contortus, Hyparrhenia dissoluta, Perotis patens, Schizachyrium sanguineum, Trichoneura ciliata and Triraphis schinzii. A legume forb Indigofera podophylla and two sedges Cyperus obtusiflorus and particularly Bulbostylis burchellii were abundant. This grassland is essentially an extension of the adjacent miombo savanna without the trees. In some areas scattered patches of short trees and shrubs occurred in the grassland, these were composed mainly of: Garcinia livingstonei, Syzygium cordatum, Trichilia emetica and the two palms Hyphaene natalensis and Phoenix reclinata. The dwarf geoxylic (White 1977) shrubs Parinari capensis and Salacia kraussii form large colonies in the grassland.

Immediately landward of the dune cordon, on old fallow lands, low dense thicket patches are formed by Brachystegia spiciformis and Julbernardia globiflora with a closed upper canopy and an abundance of the two dune tree dominants Diospyros rotundifolia and mimusops caffra in the understorey.

The miombo dominants and most of their associated tree and shrub species do not occur on the coastal dunes. This disjunction is sharp except for the example cited above where dune species extend a short way landwards in miombo thickets. The composition of coast grasslands which occur on dunes in Mocambique southwards to the South African border is described by Barradas (1962) and Myre (1971), and adjacent in Tongaland by Tinley (1958a,b), and on the dune cordon south of the St Lucia-Umfolozi Mouth by Weisser (1978a) and Weisser and Marques (1979).

In secondary dune grasslands on the Langekloof ridges west of Cape St Francis the following grasses were recorded in the field by Richard Cowling and myself in September 1981: Cynodon dactylon, Ehrharta calycina, Imperata cylindrica, Setaria flabellata, Stenotaphrum secundatum, Stipagrostis zeyheri, Themeda triandra and Tristachya hispida with an abundance of forbs. Scattered patches of bush clumps composed of the trees and shrubs noted under Dune Heath above, testify that where undisturbed by man, stock or fire all this dune area would eventually be covered by a mosaic pattern of closed woody communities.

Despite their high calcareous content in the subsoil, dunes support an acid grassland type characteristic of the miombo savannas, northern Kalahari Sands, the South African Highveld, and eastern seaboard. In these grasslands the abundance of associated forbs, suffrutices and herbs is a distinguishing characteristic (Tinley 1977).

3.4.3 Seed dispersal

The dispersal of seeds naturally plays a fundamental role in the survival, migration, colonization and succession of plants at all levels from a niche to the biome. The climax vegetation of thicket/forest on the coast dunes is composed predominantly of tree and shrub species with coloured drupaceous, baccate or arilloid diaspores typical of bird-dispersed plants (Ridley 1930; van der Pijl 1972). Frugivorous birds are thus the prime mover components in the natural afforestation of dunes.

This afforestation is a successional process, originating around perch sites such as dune crests and isolated dune pioneer plants visited by omnivorous birds such as the black-eyed and Cape bulbuls. Around these perch sites or feeding stations bird-borne seeds are evacuated and result in the development of isolated bush clumps. As these bush clumps are formed by preferred fruit species, such as the tickberry or bietou Chrysanthemoides monilifera, they attract a greater concentration of frugivorous activity to their immediate surrounds, multiplying further the deposition of bird-dispersed seeds. In this way the bush clumps become nodes of centripetal seed accumulation resulting in the enlargement of the bush clumps which coalesce by lateral growth to form larger thickets or forest composed predominantly of trees and shrubs favoured by avian frugivores.

Although the habitat composition is exponentially enhanced by the selective action of the frugivores, maturation of the cover physically alters the structure precluding many of the bird species responsible for the habitat's original creation, but these are replaced by a fruit-eating guild of closed habitat species (Tinley 1977).

A parallel coevolutionary successional process, involving many of the same species on dunes, occurs in grasslands and savannas where thicket invasion is initiated as bush clumps from bird-dispersed seeds on termitaria, in dongas (water-based sites), and around the base of trees and shrubs originally disseminated by other means, as in the ungulate-formed savannas (eg Acacia nilotica, A tortilis), or those dispersed mainly by wind and sheetwash (eg mopane, combretum), or those spread by explosively dehiscing pods as in the miombo (Tinley 1977), or of wind and ant dispersed fynbos heath species (Slingsby and Bond 1981). In its predominance of mainly bird-dispersed trees and shrubs, dune thicket/forest is similar to thicket formations elsewhere in Africa between the Cape and Sahel with which it shares many species (see Section 3.5).

Whilst birds are overall the most important seed dispersers of broadleaf trees and shrubs on dunes, mammalian frugivores become an increasingly important component from the east Cape northwards into the tropics. These include fruit bats (Megachiroptera), primates (thick-tailed galago, chacma baboon, samango, vervet monkey (Pooley 1968), omnivorous fruit-eating carnivores (civet in Mocambique, the large-spotted genet in the Cape and Transkei, and rusty-spotted genet in Natal and Zululand) which habitually use dung middens on bare sites from which seeds germinate, if conditions are favourable, to form bush clumps (Tinley 1977). Seeds are also dispersed by ungulates such as bushbuck, forest duiker and bushpig which eat fallen fruit, and though rare in dune forest on the east coast the red squirrel is the only rodent known to be important in seed distribution.

The most important fruit eating and seed dispersing birds in the dune ecosystem include: ground-feeding game birds and doves (red-necked francolin, crested guinea-fowl, cinnamon dove, tambourine dove), the rameron and green pigeons, the turacos or loeries (Knysna, Reichnow's in Tongaland and Mocambique), mousebirds (speckled, white-backed, red-faced), hornbills (trumpeter, crowned), barbets (pied, red-fronted, black-crowned, black-collared), orioles (black-headed), bulbuls (sombre, terrestrial, black-eyed, red-eyed, Cape), thrushes (olive), robins (Cape, Natal, Karoo), starlings (black-bellied, and redwing which visit from adjacent cliff areas), white-eyes (Cape, yellow) and collared sunbird.

Waxbills, such as the swee, grey, green twinspot, pink-throated twinspot and firefinch feed on the large 'drop seeds' of Panicum and other shade grasses which occur in openings and along the edges of the dune bush. Birds typical of open ground and scrubby areas visit the foreshore where rock pigeons, Cape and yellow-eye canaries are often feeding on the seeds of the seashore pioneer Arctotheca populifolia. Although some seeds may be damaged or destroyed (dystrophic influences) by seed-eaters, the animals are nevertheless probably instrumental in the dissemination of part of their seed intake (Davidse and Morton 1973), linking the grassy glades of forest openings or landward areas with the foreshore.

A notable feature of the bird-dispersed dune tree and shrub cover southwards, down the eastern coasts from the tropic, is the increase in number and density of Rhus species with small dry, thinly fleshed berries less than six millimetres in diameter.

Conversely there appears to be a reverse trend in that the larger fleshy fruit species increase in density and/or number northwards up the eastern coast into the tropics, as exemplified by Mimusops caffra with ovoid fleshy fruits 2 x 1,3 cm in size.

The distribution patterns, flight paths and range of movement by the different animal species must have far reaching influences on the degree of similarity and kaleidoscopic mix of zoochorous plants between adjacent ecosystems and within the same habitat along the linear coastline gradient. Far ranging birds include the turacos, pigeons, red-faced mousebird, hornbills, orioles and the two starlings whereas other species have an intermediate or more local range (eg speckled mousebird, sombre bulbul).

The year-round occurrence of bird fruits in the dune thicket/forest, at least above the 700 mm isohyet, is in direct contrast to the adjacent arid valleys where many of the same thicket plant species follow strongly seasonal phenophases. Movement between adjacent thicket systems and linearly within the coast dunes would enable birds to encounter fruit all year. This implies that the nomadic or wider ranging species are able to be obligate frugivores whereas those with a narrow range of movement would have to be facultative frugivores with an omnivorous fare to survive local fruitless periods. Liversidge (1972) points out a significant feature of fruit utilization by birds in the dune bush where the abundance of preferred fruits, such as those of Chrysanthemoides monilifera and Maytenus procumbens, results in other species being ignored or underutilized, most of their crops ripening and falling to the ground where, however, some may be dispersed by other agencies.

A prima facie analysis of the dispersal type composition of the dune bush ecosystem is illustrated by Figure 17. The canopy and subordinate layer components are shown separately. Only the woody plants are used with the exception of the west and south-west coasts where all subordinate plants were included.

Thus the histograms of the first two subordinate layers are not strictly comparable with the rest. The ant-dispersed species (Slingsby and Bond 1981) are lumped with the other zoochorous species (Z). The striking feature in both strata along all coasts is the overall importance of zoochorous, mainly bird-dispersed species, and the increasing importance of wind-dispersed species westwards to the subdesert Namaqua Coast.

In contrast the other dune communities are composed of plants with seeds which are dispersed either by the elements or by microzoochorous means. The strandflora is comprised chiefly of species with sea and wind-dispersed seeds (Ridley 1930; Muir 1937; Good 1964; Sauer 1965a,b). A polychorous species mix forms the second zone, with sea, wind, gravity (barochory) and zoochorous dispersal methods. On the south and south-west Cape coasts where the heaths are a major community on many of the dune fields, the main means of dispersal are wind and ants, though lesser bird dispersed components such as Passerina and Myrsine remain key elements in succession towards invasion by thicket or forest precursors.

The myrmecochorous species have seeds with small fleshy protuberances termed elaiosomes which are the edible attraction to ants. Up to the time of publication Slingsby and Bond (1981) discovered that at least 24 plant families composing the fynbos heathland contain more than 1 000 species with elaiosome-bearing seeds which are typically dispersed over very short distances up to eight metres.

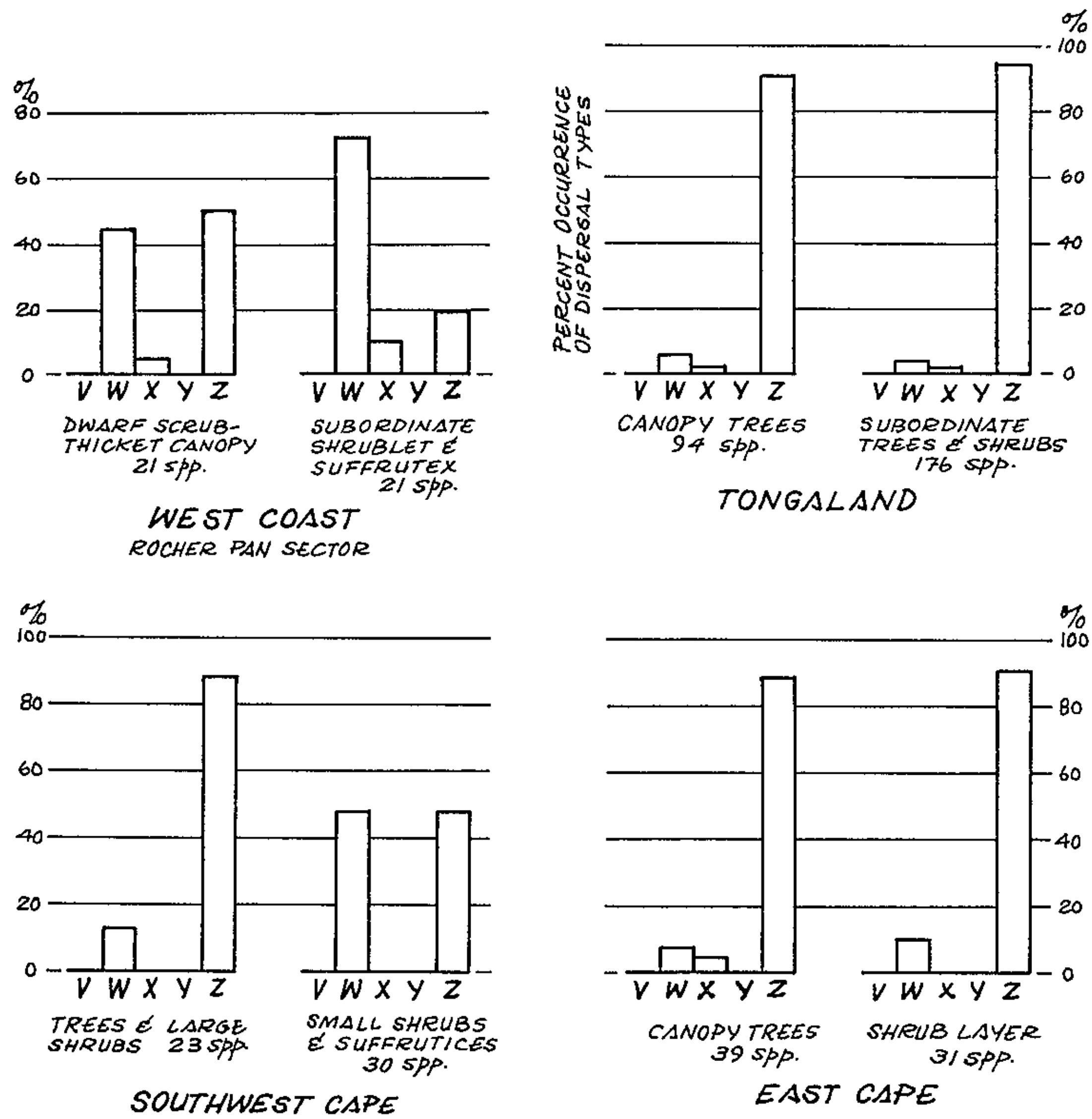
This reinforced localization of species or variants by ant dispersal, compared to the wider dispersal from wind, sea and birds, must have far reaching evolutionary implications compounding microgeographic isolation of species and of intra-populations variants especially if substrate and aspect diversity (niche array) is high, and/or where recurrent fires burn in varying mosaics.

In the heathlands of the North Temperate region it has been found that exposed conditions or cold and wet weather causing a scarcity of insect pollinators favours autogamy and anemogamy (Proctor and Yeo 1973 see references to O Hagerup). Autogamy is apparently also a common condition in hot arid areas (Proctor and Yeo 1973).

Is it possible therefore, that high speciation in the fynbos may have been influenced by a winter rainfall regime with cold wet winter conditions and hot dry summers affecting the insect pollinators such that autogamy or limited outcrossing would compound varietal differences of microgeographically separated populations in space and time (eg staggered flowering of different age patches recovering from fire). A montane to mangrove transect across the Rift Valley in the central Mocambique tropics (Tinley 1977) showed that high plant species diversity in small unit areas of grassland and their associated forbs was characteristic of acid leached, hydrogen-ion saturated soils in all climate and relief situations. High plant endemism in the Chimanimani Mountains, for example, is confined to quartzites (Wild 1964). The converse of few species over large unit areas was typical of base-saturated soils.

The fynbos heath appears to be characterized by the abundance and diversity of myrmecochorous plants and none were found in adjacent semidesert dwarf shrubland of the Karoo (Slingsby and Bond 1981). Seed dispersal by ants has, however, also been observed in grassland and savanna by myself, in secondary forest in west Africa (Gibbs and Leston 1970), and recently a classic example of elaiosome-bearing seeds in a croton under-shrub (cf Croton rivularis) from the Amatola Mountain forests was shown me by Anthony Duckworth of the Forestry Department.

The collection and planting of the seeds from indigenous dune plants has in recent times been increasingly employed in the reclamation or stabilization of dunes and driftsands as best exemplified by the work of Paul Camp on the open-cast dune mining at Richards Bay and by the Forestry Department in the eastern Cape and at Elands Bay on the west coast. As demonstrated by the successional process of perch-based thicket development, successful reclamation of dunes and other eroded areas can by greatly enhanced and speeded-up by the simple expedient of providing perch sites of scattered poles in the area being stabilized. Most efficient of all would be to use plants of a preferred fruit species such as bietou which serves as both an attractive focus and a perch.



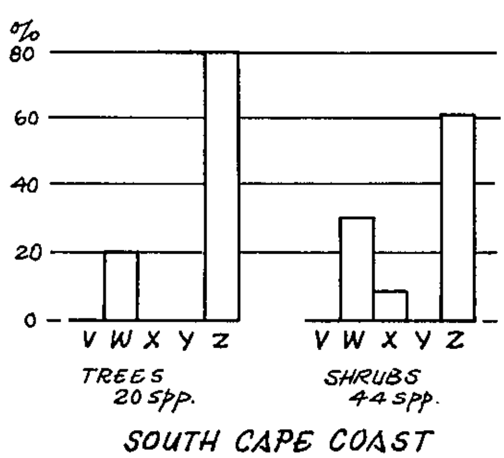


FIG 17

COMPARATIVE IMPORTANCE OF SEED DISPERSAL TYPES IN THE BROADLEAF DUNE THICKET-FOREST GRADIENT AROUND THE SOUTH AFRICAN COASTLINE.

ZOOCHOROUS SPECIES ARE PREDOMINANTLY BIRD-DISPERSED.

V = barochory, W = anemochory,
X = active autochory, Y = hydrochory,
Z = zoochory

FOR LIST OF SPECIES USED IN THIS ANALYSIS REFER TO TABLE 14.

3.4.4 Phenology

A knowledge of the plant phenology is particularly valuable in habitats which require management reclamation as in the drift sand areas of dunefields. This enables the identification of fruiting periods for seed collection, and the production of new leaves and shoots coupled with the mean annual rainfall indicates the best planting times. As most of the dune bush species are dispersed by birds the availability of different preferred fruits influences the movement of birds. The main flowering and fruiting periods in turn influence the phenology of pollinators and animal dispersants.

A detailed monthly phenological record of flowering and fruiting over a two and three-quarter year period of the dune bush between Port Elizabeth and Cape Recife made by Liversidge (1972) showed the following results: (a) Two peaks of flowering; one from January to March and the other from July-October followed by (b) bimodal equinoctial peaks in fruiting (March-April, and September-October). Mature fruit occurred generally some five months after flowering. (c) A third, lesser peak, is also discernible in the tabled data (Liversidge 1972) of flowering in January and of fruiting in July.

Liversidge (1972) found that certain species exhibited a regular annual cycle whilst others were irregular with biennial, half-yearly, annual or three to four year intervals in flowering and fruiting with phase shifts earlier or later about the average equinoctial peaks.

A rough monthly record of vegetative and reproductive phenology of woody species on eastern Cape dunes was made. In summary the records show the following patterns (Figure 18).

(1) Mature leaves are carried throughout the year with individuals of only a few species showing complete leaf fall and bare conditions during droughts (eg *Cordia caffra*, *Erythrina caffra*). A larger number show leaf discolouration with partial leaf fall in times of drought. On the Natal dunes the most deciduous tree is *Celtis africana* (Ward 1980), and this species with *Cordia caffra* and *Ziziphus mucronata* on the east coast.

(2) New leaves and shoot production occurs in every month, most profusely in spring and autumn which coincides with the bimodal rainfall peaks. Highest percentage of leaf fall and bare conditions coincide with moisture stress from midsummer dry spells and especially with prolonged drought conditions as recently experienced in 1982 and 1983 (Figure 18).

(3) Although inadequate data is available for three months (October-December 1981) due to field work elsewhere, flowering also appears to occur throughout the year with peaks in midwinter of 1981, autumn of 1982, in October 1982 and February 1983.

(4) Fruit also occurs throughout the year with peaks in autumn and midwinter. The best fruiting peak during the period of record occurred three months after the highest rains of the 1981-83 period and was derived from the flowering peak in the month(s) prior to the rains (Figure 18).

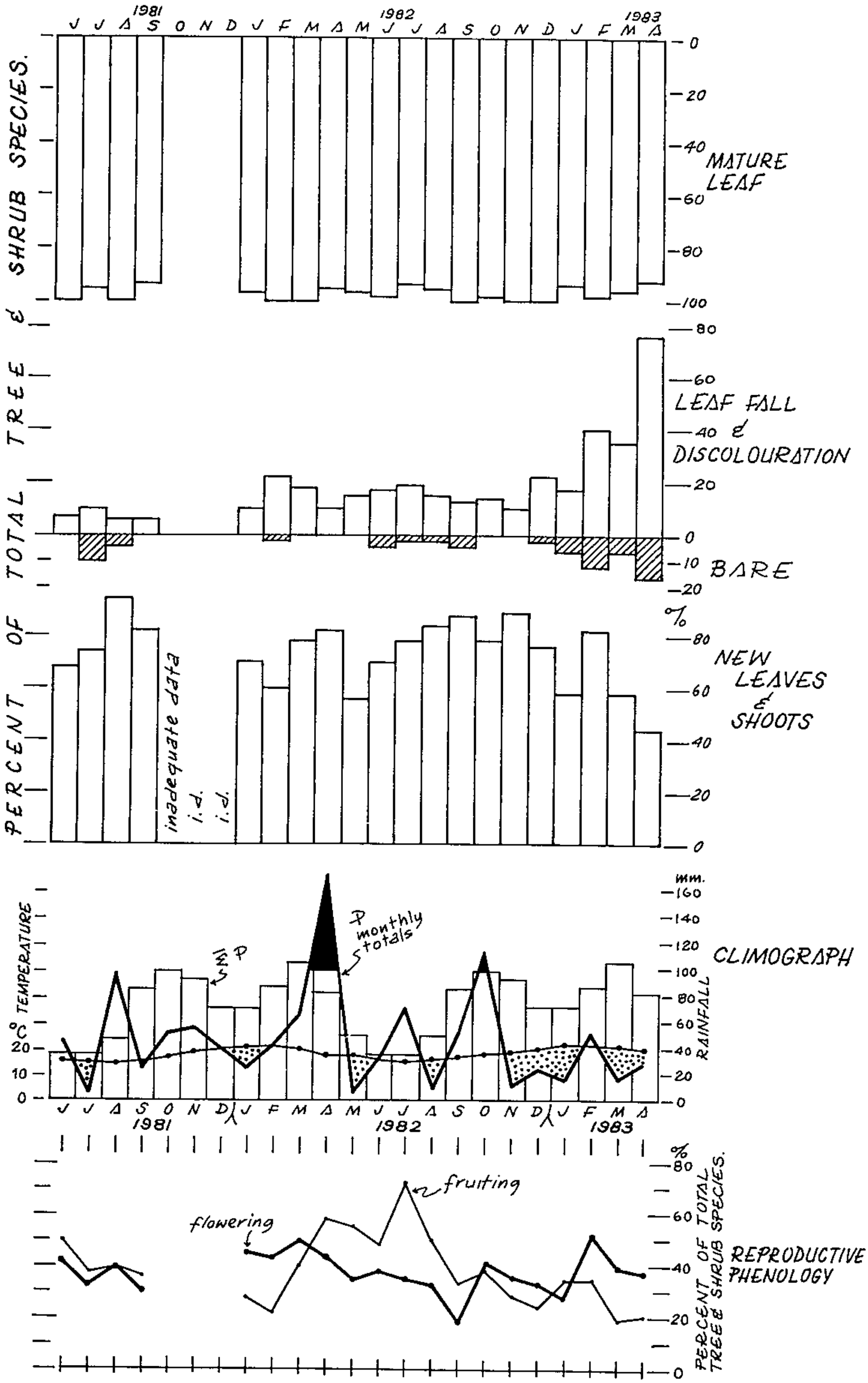


FIG 18. PHENOGRAMS OF COAST DUNE THICKET IN THE EAST CAPE. (Nahoon-Kwelera coast sector).

(5) Unfortunately the monthly phenological record was terminated in April 1983 thus it is not possible to show quantitatively the extraordinary high percentage of flowering and new leaf and shoot production which occurred in spring 1983 after exceptional rains broke the drought. A drought period followed by good rains initiates a new sharply demarcated seasonality on the phenophases which eventually fades when year round occurrences of rain return.

Throughout its distribution dune thicket/forest is typically evergreen, except for a few species. Although flowering and fruiting occurs amongst dune trees and shrubs in every month of the year there is a large variation amongst species and individuals in timing, quantity and quality of fruits (Phillips 1931; Liversidge 1972; Bond 1980).

Liversidge (1972) has noted various influences on fruit production including unseasonal weather, the absence of pollinating agents and the loss of fruits falling to the ground due to selective attraction of frugivorous birds to preferred fruits such as Chrysanthemoides monilifera and Maytenus procumbens when they are in abundance.

Herbivorous insects are another important element causing unseasonal phenological events in dune plants. Amongst the pioneer strand plants tortoise-beetle larvae (Cassidinae) feed on the leaves of Ipomoea brasiliensis defoliating large patches until only the shoots remain. This occurs in autumn through winter; only particular patches are affected, which recover in spring. The milkwoods Mimusops caffra and M obovata are infested in late summer and autumn by caterpillars of the pyralid moth Zith carnicolor which spin communal web nests on the distal branches of the trees (identified by Dr Brian Stuckenberg, Natal Museum) (Plate 93). Between February and May 1980 a heavy infestation defoliated Mimusops trees of all their leaves, resulting in a synchronous new leaf flush in June and July. A year later a light infestation occurred in April and trees were patchily defoliated. The resultant new leaf flush likewise was patchy.

In the central Mocambique Rift Valley under a quite different climate, termitaria thicket trees and shrubs, many of which occur on the coast dunes of the eastern coasts, also show bimodal equinoctial peaks in flowering and fruiting, with a third at the solstices (Tinley 1977), although the number of species flowering or fruiting was quite different to those near Cape Recife as recorded by Liversidge (1972). The parallel reproductive phenophases between termitaria thicket species of base-saturated clayey soils in the tropics and of dune thicket on calcareous sands on the subtropical south-east coast is suggestive of a basic phenological pattern related mainly to the equinoxes and to a lesser extent the solstices. Whether the summers are wet or dry an equinoctial reproductive strategy enables plants to take advantage of any shift in the rainfall regime from summer peak to winter peak, or through the bimodal rain zone of South Africa which is linked intermittently up the west side of the subcontinent to the equatorial bimodal rainfall zone (Tinley 1975a).

Of the three common branch-parasites in the east Cape dune thicket Loranthus dregei flowers from January to March and again in June, L quinquenervis from January to September, and Viscum obscurum from May until October. The first species is deciduous in November and December. In the same order their fruiting patterns are February to September, April to January and July to April respectively.

In the strand plant zone of the east Cape, tropical species are reproductively active over summer between spring and autumn, eg *Cyperus maritimus* (December-March), *Ipomoea brasiliensis* (flowering from December with fruit dispersing by March), *Scaevola thunbergii* (flowering September-October, in fruit November-January). Southern coast species such as *Arctotheca populifolia*, *Heteroptilis suffruticosa* and *Silene primuliflora* produce flowers and fruits all year. The temperate dune grasses *Agropyron distichum*, *Ammophila arenaria* and *Ehrharta villosa* flower in October and November, and seedlings of the annual *Salsola kali* first appear on beaches in October.

In the southern and south-west Cape a similar diversity of phenological patterns is recorded in the heathlands (Kruger 1979b; Bond 1980). In summary, although thicket/forest is an evergreen community in a year round highly humid climate, with particular species and/or individual trees and shrubs in flower or fruit in every month of the year, an overall bimodal reproductive pheno-rhythm is indicated by fruiting peaks at the equinoxes.

A third, lesser, peak occurs near one of the solstices. Thus for the frugivore avian disperser group, or for the dune reclamation manager the most likely time to obtain fruits and seeds is over autumn from late summer to midwinter. The most successful methods and times of planting of various indigenous dune plants is noted by Walsh (1968) and Stehle (1980a,b).

It is clear that a more holistic approach is required to unravel the dynamics and implications of ecosystem and community phenology in evolutionary terms and in practical application for predictive purposes and as an aid to effective land husbandry. This should be along the lines of the classic study made by Davies (1945) of Brazilian forests, in which plants, insects, birds and the environmental factors were correlated.

PLATE 60. Strand plant hummock dunes (Zone I) formed by the tropical Indian Ocean beach grass Halopyrum mucronatum on the Mocambique Coast between Limpopo Mouth and Lake Quissico.

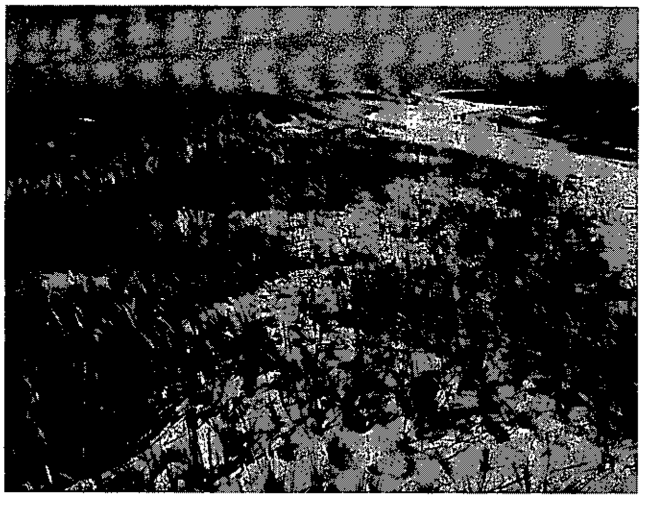


PLATE 61. Seawheat Agropyron distichum, a temperate beach grass, actively colonizing the backbeach seawards to the edge of the high spring tide reach at Struisbaai, Cape south coast.

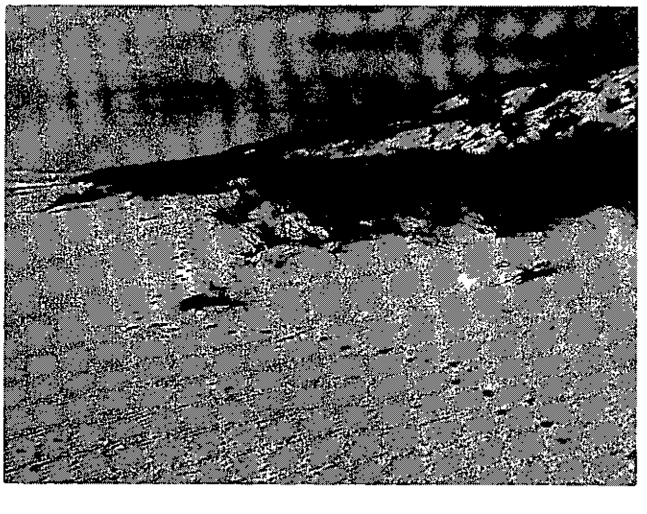


PLATE 62. The dominant strand plant on the west coast to near the Orange River mouth is the rhizomatous grass Eragrostis cyperiodes. Here it has grown down from the foredune to colonize a new berm deposit.

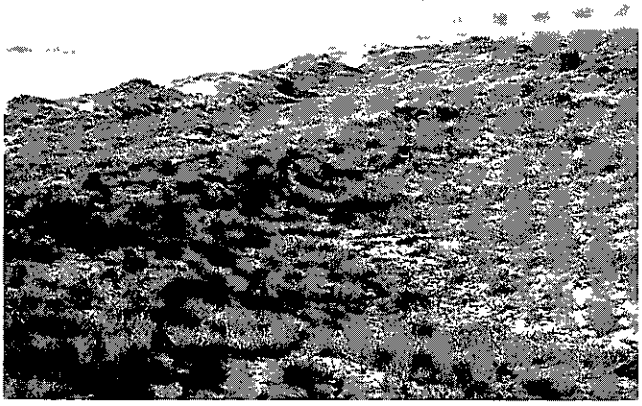


PLATE 63. Predominance of the west coast dune grass across a broad zone, with shrub invasion (Zone II) occurring in clumps (right background). South of Doringbaai.

PLATE 64. Dense dwarf scrub-thicket climax on west coast Dunes. Near Lamberts Bay.

PLATE 65. Taller patches of the temperate forest tree Pterocelastrus tricuspidatus in dwarf scrub-thicket cover of the landward dunes at Rocher Pan.

PLATE 66. Typical patchy occurrence of dwarf scrub-thicket on landward compact red sand over calcrete south of Donkins Bay, west coast.

PLATE 67. Dwarf scrub-thicket of white milkwood Sideroxylon inerme on calcrete at Cape Agulhas, with Euclea racemosa, Olea exasperata and Zygophyllum morgsana.

PLATE 68. Dwarf scrub-thicket on calcrete immediately above the back-beach at Vleesbaai, Cape south coast. Eastmost occurrence of the west coast type of dune woody cover.

PLATE 69. Dune fynbos of tall restios Willdenowia sp. on deep sand immediately landward of previous PLATE. Note mole-rat mounds in foreground.

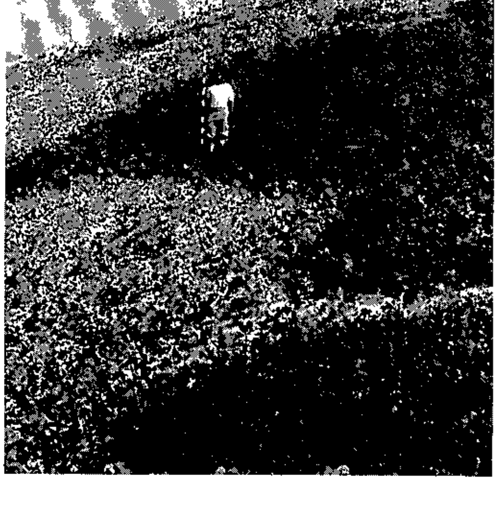


PLATE 70. Extremely high hillock built by the tropical succulent strand plant Scaevola thunbergii on the backbeach north of Banga Neck on the Tongaland coast. The strand plant cover of Zone I is in the process of replacement by the low sympodial expansion of the Zone II and III tree Diospyros rotundifolia.

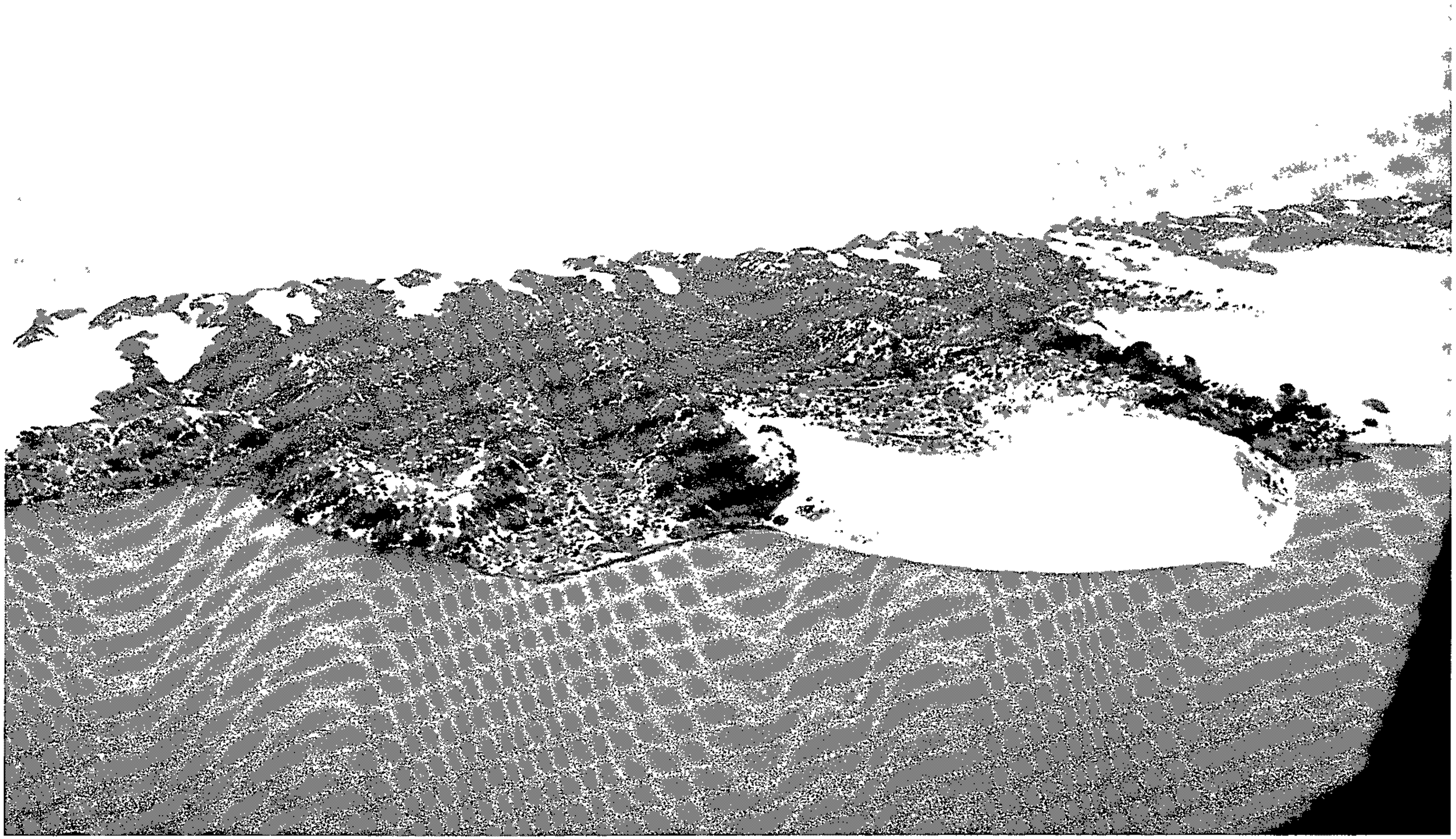


PLATE 71. Opposite zonation sequence of vegetation on transgressive parabolic dunes encroaching on barrier lakes of the Mocambique South Coast. Pioneer and seral communities on the landward slipfaces and troughs grading seawards to mature dune forest in the process of being overridden or breached by a new set of parabolic blowouts rising off the beach. An illustration of multi-directional succession on dunes. Lake Uembje in the foreground, downcoast south-west of the Limpopo Mouth. (See Figure 5).

PLATE 72. Sharp junction between Zone III scrub-thicket cover and a new line of strand plant hummocks in the half-heart bay at Banga Neck. Note eroding dune sector in background on the long curve of the bay.

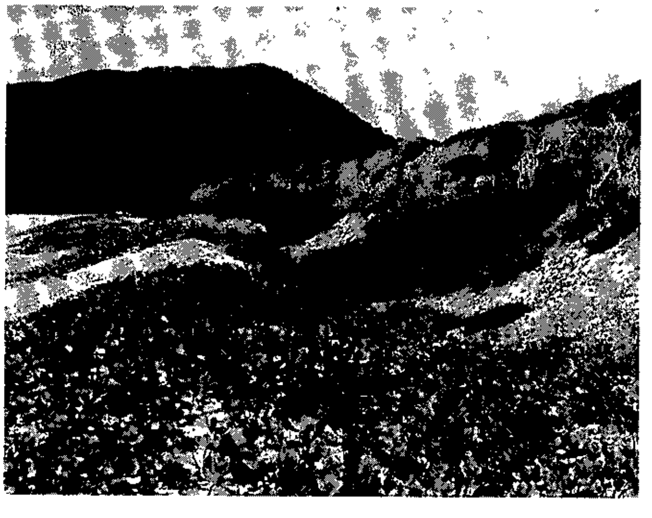


PLATE 73. Forested dune headland at Banga Neck. Dead Zone III canopy trees exposed by removal of protective foredunes by storm seas. Here subsequent development of new foredune line.

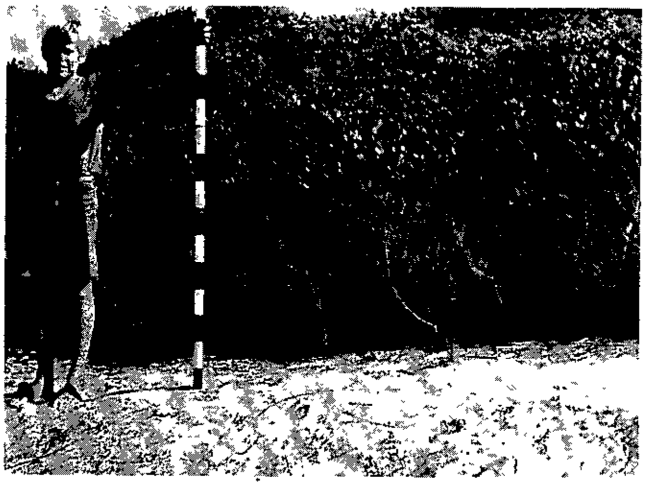


PLATE 74. Profile structure of dense, low, Diospyros rotundifolia scrub-thicket exposed on the foreshore by undercutting and slumping of foredune slope.

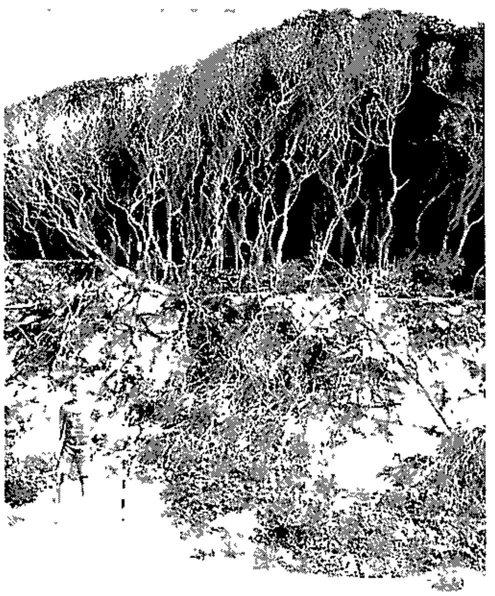


PLATE 75. Wave cliffed dune exposing tall pure cover of dune diospyros forming a single stratus with dense hedged canopy and dark interior.

PLATE 76. Dune milkwood Mimusops caffra trees killed by exposure on the foreshore with removal of foredunes by storm seas, recover by coppice regrowth.

PLATE 77. Coppice regrowth shaped by salt-spray laden wind to the profile of the dune slope and that of the mature forest canopy.

PLATE 78. Dense scrub-thicket of the endemic cycad Encephalartos ferox on the upper seafacing slopes of the main dune cordon 6 km south of Banga Neck, Tongaland Coast. The tree Strelitzia nicolai is dominant downslope.

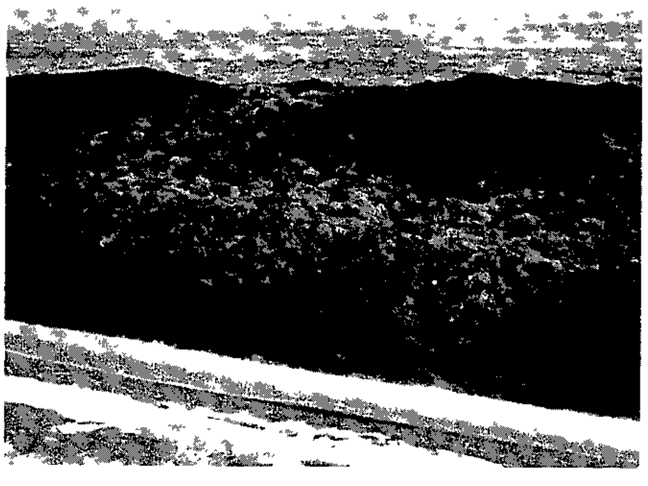


PLATE 79. The complete closed woody cover sequence on forested east coast dunes. From dwarf, salt-spray pruned, frontal scrub-thicket to high forest landwards. Zone I and II absent, south of Mapelane.

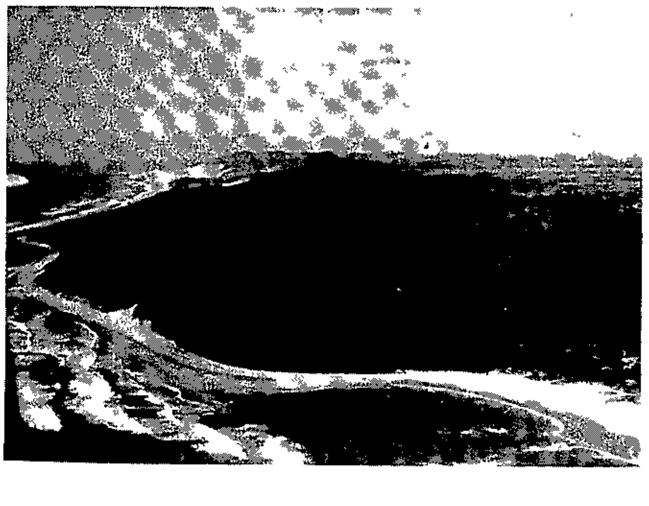


PLATE 80. The highest forested dunes between Mapelane and Cape St Lucia in the distance. Note reappearance of primary zones in the bay at right of plate.

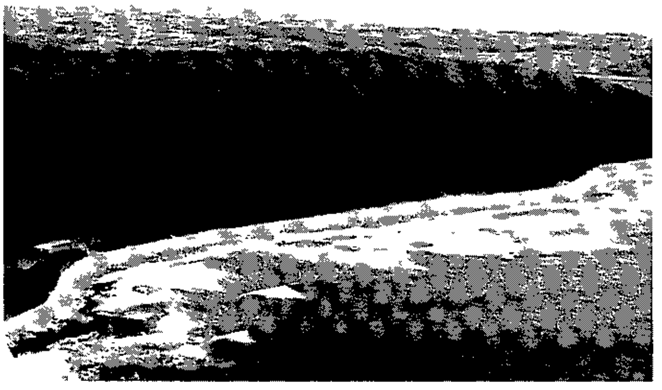


PLATE 81. Tall moist coast forest on old clayey red dune. Hlogwane Forest near the Tugela River mouth. Northern south-east coast.

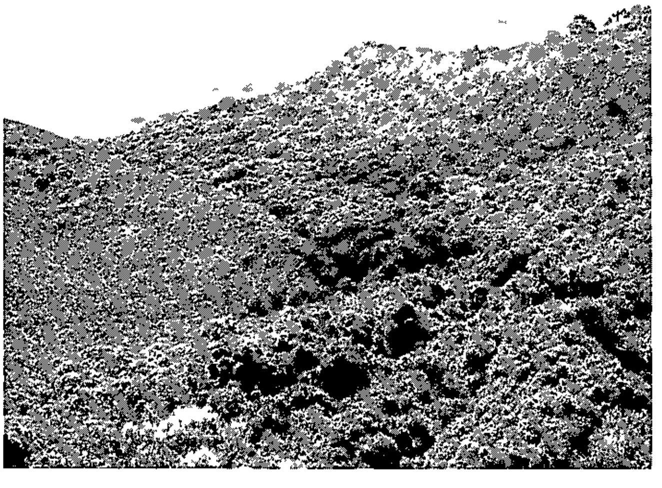


PLATE 82. Thicket/forest in dune valley of white milkwood Sideroxylon inerme surrounded by dune heaths. High imbricate parabolic dunes at west end of Groenvlei, Cape south coast.

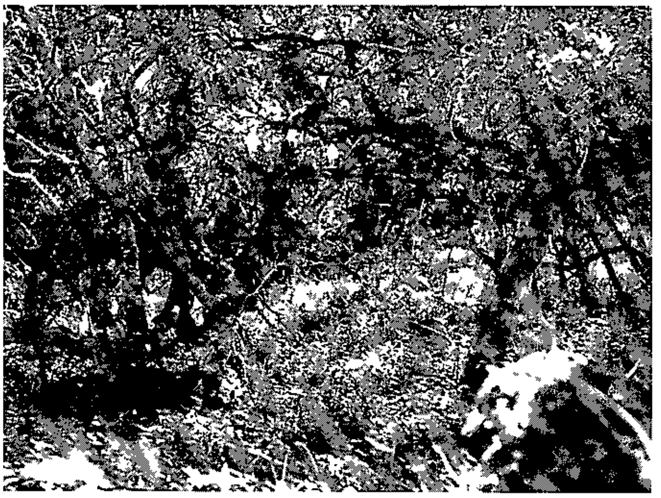


PLATE 83. Closed woodland structure of white milkwood groves with soft leaved herbs and sedges forming a dense groundlayer. Same site as previous PLATE.

PLATE 84. Dune fynbos heath vegetation on the hummock-blowout dunefields west of Cape Agulhas at Renosterkop. In foreground partially colonized blowout.

PLATE 85. Blowout completely stabilized by heaths and thicket bush clumps. Summit left between adjacent blowouts (upper right) will be a new site of blowout breaching.

PLATE 86. Post-fire regrowth with the woody Myrica quercifolia forming dense sympodial patches (geoxylic shrub clones).

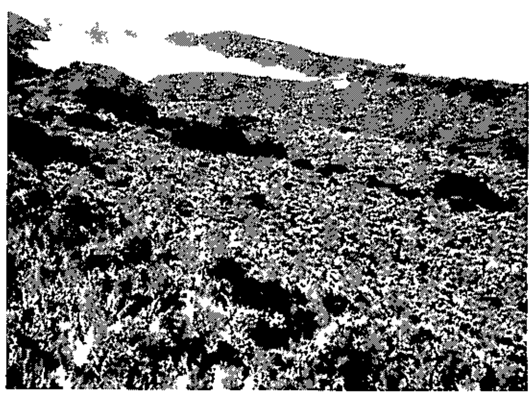


PLATE 87. Mature dune heath community on the polefacing seaward slopes of the Langekloof wind-rift dunes. Mainly Erica and Passerina spp. Bush clumps of invading forest initials formed by Pterocelastrus tricuspidatus.

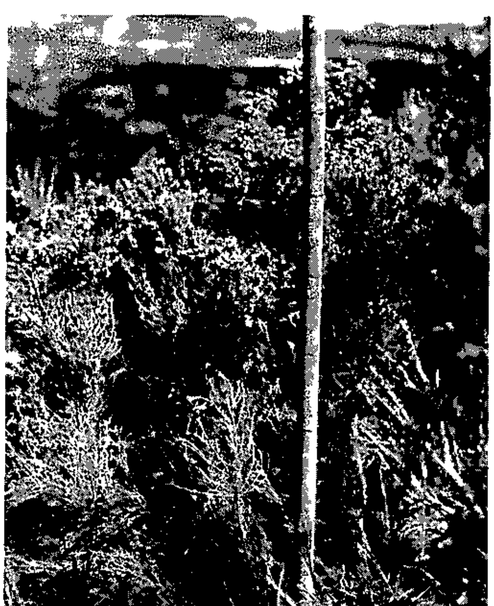


PLATE 88. Two-layered structure of dune heaths with ericoids forming closed canopy and Restio leptocladus the main understorey. Langekloof wind-rift dunes, Cape south coast.

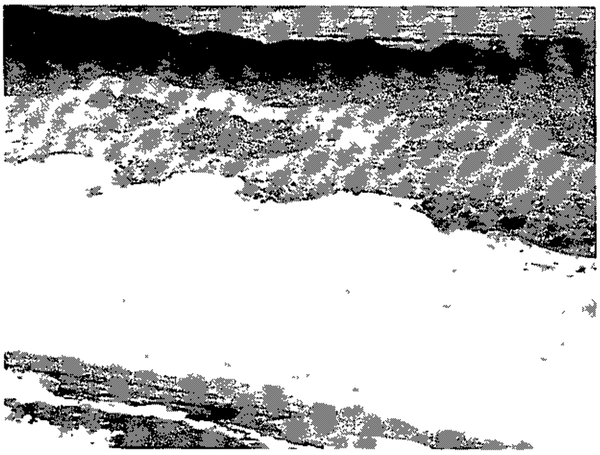


PLATE 89. Secondary dune grassland with savanna patches and thickets south of Mapelane on the east coast. Bare reversing buttress dunes in the foreground.

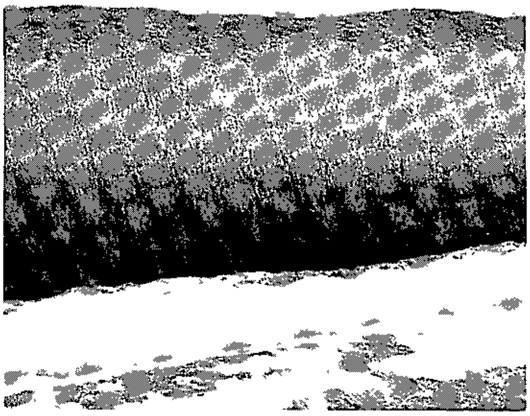


PLATE 90. Once bare reversing buttress dunes, now completely stablized by establishment of casuarina plantations. Cape St Lucia area, east coast.

PLATE 91. Old cultivation clearings in a dune valley near Lake Bangazi South colonized by even-aged woodlands of Acacia karroo (fine textured canopy).

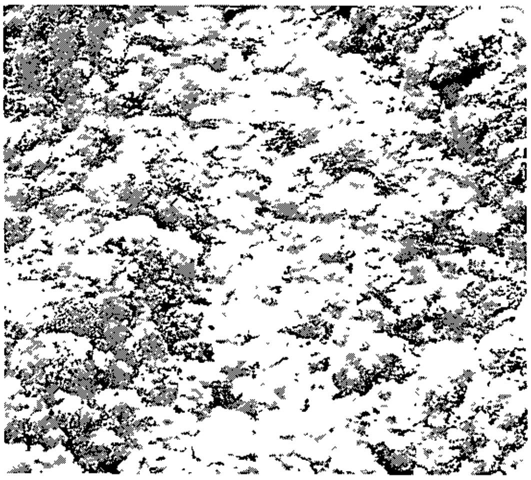


PLATE 92. Contrasting canopy architecture of dune forest and Acacia karroo tree crowns (centre of dune trough). Cape Vidal area of east coast.

PLATE 93. Communal web nests spun by the Mimusops defoliating caterpillars of the pyralid moth Zith carnicolor. South-east coast.

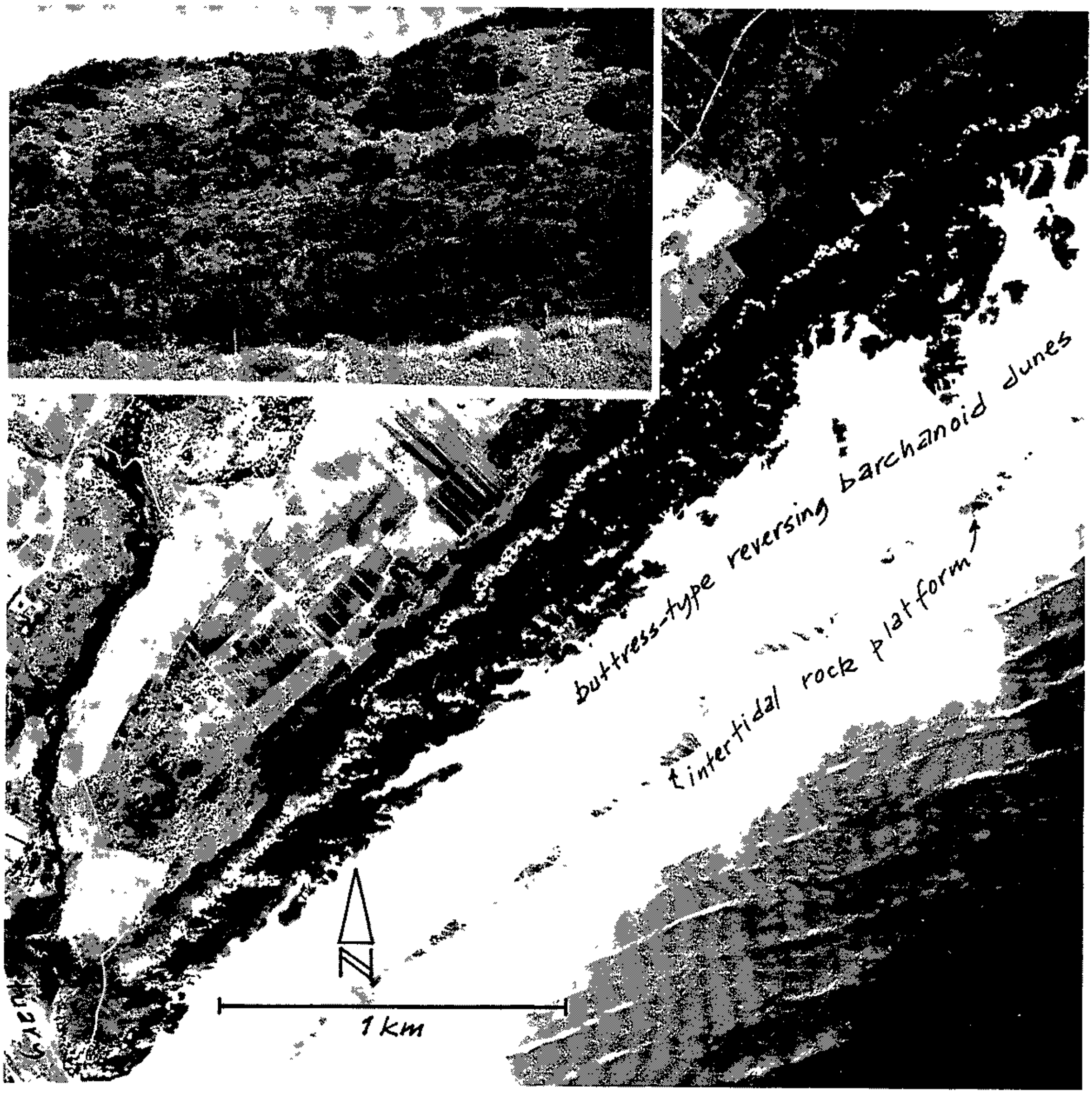


PLATE 94. Forested dune cordon on the east Cape coast immediately north of the Mgwalana River mouth with 'staring' upper landfacing slopes (north-west aspects) below crests. These sandslip openings are colonized by dune heath elements, which enables the Cape flora to persist on dunes as far north as the Kei Mouth area (inset). North of this, fynbos heaths are confined to acid soils landward of the dunes. Note radial pattern of blowouts related to the faint inward curve of the coastline. (Airphotography of 1965 reproduced under South African Government Printer Copyright Authority 7811 of 25.5.1982).

3.5 PLANT GEOGRAPHY AND CONSERVATION

3.5.1 The arena

Coastal dunes form a linear, discontinuous, ecosystem along the coastline. Their continuity is broken by the occurrence of rocky shores, cliffs and river mouths.

Protruding some 12° of latitude south of the tropic of Capricorn, the southern end of the African continent traverses several major geographical and climatic regions as the coastline curves around the warm temperate region in a U-shape between the hyperarid tropical west coast and the moist tropical east coast.

On south-west, south and south-east coasts where uplands abutt closely on the coast, or are linked to it by riverine and cliff forests, the Afrotemperate forest flora has its greatest influence on the species content of the dune vegetation. Heath vegetation likewise makes its greatest contribution to dunes on the southern coasts, and desert and subdesert elements on the west coast. Species from tropical and subtropical forests, thickets and savannas are some of the most important components of dune vegetation on eastern coasts and overlap with the temperate formations on southern coasts and with desert formations on the southern west coast (Figure 19).

As the coastline passes through each of these regions the dune floras gain and lose species from the variety of ecosystems juxtaposed against the coast. The narrow linear ecosystem pattern, traversing a diversity of biomes and ecosystems and being influenced by each in turn, is paralleled by riverine plant communities. In analogy with a man-made linear system such as a railway, there is a continuum of stations acquiring and losing passengers (species) which mix with the locals (endemics) at each.

Coastal dunes have been shifted during the long term geological time scale and by contemporary and instant happenings. From a high position some 300 m above the present level, 10 million years ago the sea receded to -100 m below datum-level and has fluctuated with greater drops below, and lesser recoveries above, datum-level to the present. The coast dune ecosystem has thus undergone up and downslope deposition, erosion, elimination, reformation and modification by rising and falling sea levels with a concomitant sequence of contrasting climates (Section 2.2).

In addition to this constant state of flux at different tempos providing a spectrum of substrates in which moisture and calcium-rich sands are pre-eminent, changes in the content of abutting ecosystems, and prime mover components, have strongly influenced the species mix and thus the plant geography of dune vegetation and its communities.

The species mix encountered in the field is the predominance of calcicolous species, with an abundance of acidicolous heath and moist forest elements in suitable climo-edaphic sites, as well as halophytes and generalized psammophytes.

In summary, dunes have provided a successional continuum of multidirectional change towards a mature climax condition or away from it

FIG 19

THE PRINCIPLE OF JUXTAPOSITION IN PLANT GEOGRAPHY AS DEPICTED BY THE LINEAR COAST DUNE ECOSYSTEM (kaleidoscopic change in plant species along coast by addition from &/or loss to changing abutting landward communities).

to a prisere of bare mobile sand resulting in a mosaic of linking, congregating, isolating and recombining conditions.

This has led to the development of localized and wider ranging dune endemics, and the proliferation of new species or varieties as in the coast dune heaths of the Cape (Taylor 1978). The species content of coast dune communities thus changes kaleidoscopically along the coast in an overlapping, imbricate, pattern in response to the coactive influences of the above features which orchestrate the biogeography of coastal dunes in southern Africa.

3.5.2 Biomes and formations

The easiest means of classifying terrestrial biomes (major life zones) and ecosystems is by identifying the units of vegetation on the basis that these are an integrated expression of particular environmental complexes (Tinley 1975). The biome is a total community unit of associated plants, animals and their environment, in effect a macro-ecosystem, whereas a plant formation is solely a major vegetation unit in which physiognomy, structure and floristics are similar or related.

Eight major systems are represented on the coastal dunes of southern Africa: (1) Strandflora, (2) Desert and Subdesert, (3) Heath, (4) Afrotemperate Forest, (5) Tropical Forest, (6) Tropical and Subtropical Thicket, (7) Tropical and Subtropical Savanna, and (8) Grassland.

(1) STRANDFLORA: This shoreline system is composed of cosmopolitan, pantropical, Indo-West Pacific, North Temperate and endemic species. Together the temperate and desert coast regions form a major biogeographic interval or gap in the distribution of pantropical strand plants such as Canavalia maritima, Ipomoea brasiliensis and Scaevola thunbergii which drop out down the east and southern coasts - Canavalia in Transkei, Ipomoea near Algoa Bay and Scaevola at Arniston, east of Cape Agulhas. These three species reappear again in Angola north of Benguela (Muir 1937). Most of the eastern coast species have either a pantropical or Indo-West Pacific wide distribution (eg Muir 1937; Good 1964; Sauer 1965a,b, 1967), one species for example, a grass, Halopyrum mucronatum is however confined to tropical Indian ocean shores. Some of these species combine with those characteristic of the temperate South African coasts such as Arctotheca populifolia, Tetragonia decumbens, Hebenstretia cordata and Eragrostis subulosa, plus the two introduced temperate dune grasses the seawheat Agropyron distichum and marram Ammophila arenaria (Plate 61, Figure 15). These grasses, whose seeds are also sea dispersed, have their northern limits at about the same latitude 33° S on the west coast and at about 32° S on the south-east coast. Regional coast endemics include Psoralea repens on the south Cape coast, Eragrostis cyperoides confined to the western coasts between False Bay and the Orange River, Namib-Namaqua dune hummock-forming species such as Salsola nollothensis, and the endemics of the tropical coast sector of the Namib between Walvis Bay and South Angola (eg Ectadium virgatum, Indigofera cunenensis, Merremia multisecta).

Finer grained analysis will probably show up lesser patterns of distribution within the broader ones sketched above. On the western coasts for example, between the Orange River and Table Bay, a detailed study by Boucher and le Roux (in press) has revealed five plant species groups which characterize particular coast sectors, each overlapping with the ones on either side of it.

(i) A Namib element southwards to Port Nolloth (eg Zygophyllum clavatum).

(ii) A northern Namaqua element between the Holgat and Bitter Rivers, overlapping with the Namib elements in the north and with a south Namaqua element to the south.

(iii) A southern Namaqua element (eg Crassula tomentosa) between the Spoeg and Olifants Rivers.

(iv) A northern Capensis element (eg Prenia pallens) between the Olifants River and Saldanha Bay.

(v) A southern Capensis element (eg Carpobrotus acinaciformis) south of Saldanha.

(2) DESERT AND SUBDESERT: Mainly west coast, this system attenuates in two directions, northwards to near Benguela where subdesert is transitional to arid savanna, and southwards on the Namaqua Coast where subdesert dwarf shrubland is replaced by dwarf thicket on dunes and the heaths of the temperate coast.

(3) HEATH: Predominant on the south-west and south coasts, this system peters out on dunes in two directions. Northwards on the western coast dunes it pinches off abruptly near Saldanha and more gradually on eastern coast dunes to near East London.

(4) AFROTEMPERATE FOREST: Elements from this formation also decrease and terminate in two directions on dunes. Westwards to near Elands Bay (eg Pterocelastrus tricuspidatus) and northwards up the east coast as far as Inhaca Island (south side of Delgoa Bay eg Pittosporum viridifolium, Strelitzia nicolai).

(5) TROPICAL FOREST: From its major area along the east coast, elements from this system diminish in one direction only, southwards down the south-east coast (eg Strychnos decussata to the Knysna Forest on sand). The greatest fall off in tropical forest species occurs at the southern end of the Mocambique Coastal plain where it is pinched off against the oldland shoreline at Mtunzini (Table 13).

(6) TROPICAL AND SUBTROPICAL THICKET: Unlike tropical forest the thicket formation at first narrows southwards from the tropics along the eastern seaboard in Natal and Transkei, where it is confined to river valleys, and re-expands into a major formation with high species diversity in the eastern Cape. Many species occur through the subdesert karoid formation, in suitable habitats, to the west coast dunes (eg Putterlickia pyracantha), whilst others decrease and terminate northwards from the south-west coast up the west coast (eg Maytenus heterophylla). Other species such as the buffalo thorn Ziziphus mucronata exhibit a temperate interval in their distribution. They occur on east coast dunes, and approach close to the coast in a horseshoe pattern from the east Cape across the northern Cape to the riverine and rock outcrops of northern Namaqualand and again in the central to northern Namib Desert.

(7) TROPICAL AND SUBTROPICAL SAVANNA: The savanna system shows a similar pattern to tropical forest, and becomes rapidly impoverished in species southwards. South and west of the east Cape a single species, the sweet thorn Acacia karroo, forms pure species savannas and woodland or thicket along riverbanks in the subdesert regions of the Karoo. In the tropics many other savanna trees become confined to riverine sites into desert areas. Although sweet thorn is distributed over the greater part of South Africa (Palgrave 1977) it is only on the Tongaland sector of the east coast that it is a true member of the dune vegetation.

(8) GRASSLAND: The grassland patches which occur on dunes are in general merely an extension of the immediately adjacent grassland or savanna groundlayer. In South Africa on eastern and southern coasts these are mostly acidicolous species of dystrophic soils with the addition of a few calcicolous or eutrophic species such as kweek Cynodon dactylon.

3.5.3 Ecosystem and floristic affinities

The plants which make up the dune communities are derived from, or have their closest affinities with some 21 ecological and floristic units of various kinds and dimensions such as biomes, plant formations, ecosystems, communities, endemic centres, and more widespread or cosmopolitan groups. The combination of elements from these units are responsible for the particular plant geographic mix of the dune vegetation in each area (example in Figures 20, 21, 22). Examples of these elements include the following:

(1) Hummock-dune forming plants of desert washes, fans and saltpans: Arthraerua leubnitziae, Merremia multisecta, Salsola nollothensis, Zygophyllum clavatum.

(2) Subdesert dwarf shrub (karoid) elements: Lycium cinereum (aggr sp), Nylandtia spinosa, Pteronia divaricata, Salsola tuberculata, Zygophyllum morgsana.

(3) Cape Heath (fynbos): Agothosma apiculata, A stenopetala, Cullumia decurrens, Cliffortia ilicifolia, Erica glumiflora, Felicia echinata, Helichrysum vellerium, Leucodendron coniferum, L salignum, Leucospermum cuneiforme, Metalasia muricata, Phylica ericoides, P litoralis, Protea cynaroides, P obtusifolia, Restio eleocharis, R leptocladus.

(4) Montane Grassland: These include associated heaths and forbs which occur north of the Cape in upland or montane habitats, eg Metalasia muricata, Stoebe plumosa and forbs such as Geranium incanum, Lobelia and Satyrium species.

(5) Afrotemperate Forest: Apodytes dimidiata, Calodendrum capense, Maytenus acuminata, Myrsine africana, Olinia radiata, Pittosporum viridiflorum, Podacarpus falcatus, P latifolius, Pterocelastrus tricuspidatus, Rapanea melanophloeos, Rhamnus prinoides, Widdringtonia nodiflora.

(6) Tropical Dry Forest (sand forest): These elements enter dune forest almost exclusively along the south Mocambique-Tongaland sector of the east coast. Trees include: Balanites maughamii, Cladostemon kirkii, Cleistanthus schlechteri, Craibia zimmermannii, Croton gratissimus, Drypetes arguta, Hymenocardia ulmoides.

(7) Equatorial Rain Forest and its east African Domain: Bridelia micrantha, Celtis africana, Blighia unijugata, Morus mesozygia, Xylopia parviflora. Examples from the east coast moist forests include: Chrysophyllum viridifolium, Cola greenwayi, Diospyros natalensis, Drypetes natalensis, Ficus polita, F vogelii, Inhambanella henriquesii (Mocambique endemic), Pancovia golungensis, Strychnos henningsii, Suregada zanzibariensis, and Warburgia salutaris.

(8) Widespread forest understorey species: Erythroxylum 4 spp, Ochna 5 spp, Pavetta 5 spp, Psychotria capensis, Rawsonia lucida, Rinorea ilicifolia, Strychnos mitis, Tarenna 4 spp, Tricalysia 3 spp.

(9) Thicket elements: Trees and shrubs which form extensive thickets mainly associated with calcic-sodic clays or duplex sands in the mesic and arid savanna regions. They also form characteristic bush-clump communities in savanna on termite hills, around rock outcrops, the base of trees and on old alluvia. Many of these elements range from the Cape to the Sahel Zone and westwards to the edge of the Namib (Tinley 1975a, 1977; Heydorn and Tinley 1980). Typical thicket elements include: Azima tetracantha, Bauhinia tomentosa, Cassine aethiopica, Commiphora neglecta, Ehretia rigida, Euclea schimperi, E undulata, Euphorbia triangularis, Manilkara concolor, Maytenus heterophylla, M senegalensis, M undata, Olax dissitiflora, Pappea capensis, Phyllanthus reticulatus, Ptaeroxylon obliquum, Putterlickia pyracantha, Rhus gueinzii, R longispina, R undulata, Scutia myrtina, Sideroxylon inerme, Spirostachys africana, Ximenia americana, Zanthoxylum capense and Ziziphus mucronata.

(10) Savanna: These elements belong to either the Arid Savanna Biome with base-saturated soils, also typical of old flood-plain alluvia, or to the leached sandy soils of the Moist Savanna Biome: Acacia karroo, A robusta, Annona senegalensis, Commiphora serrata, Dalbergia nitidula, Dichrostachys cinerea, Hyphaene natalensis, Ozoroa obovata, O paniculosa, Parinari curatellifolia, Sclerocarya caffra, Strychnos madagascariensis, S spinosa, Tabernaemontana elegans, Trichilia emetica, Vangueria infausta, Ximenia caffra.

(11) Grassland: Andropogon schirensis, Aristida congesta, Cymbopogon excavatus, Cynodon dactylon, Digitaria milanjiana, Heteropogon contortus, Hyparrhenia dissoluta, Perotis patens, Setaria flabellata, Stenotaphrum secundatum, Stipagrostis zeyheri, Themeda triandra and Tristachya hispida.

(12) East African coast: Hyphaene thebaica (on dunes as far south as Pebane and the Ilhas Primeiras e Segundos offshore, Terminalia boivinnii, Trachylobium verrucosum.

(13) Madagascan elements: Brexia madagascariensis, Macphersonia hildebrandtii.

(14) Old World Tropics and Pacific Islands: Imperata cylindrica (Good 1964).

(15) Pantropical Weeds: Caesalpinia bonduc, Cassytha filiformis, Dodonaea angustifolia, Sesuvium portulacastrum (Good 1964).

(16) Indo-West Pacific Islands: Casuarina equisetifolia, Guettarda speciosa, Pemphis acidula, Suriana maritima, Tournefortia argentea.

(17) Western Great Escarpment: Tylecodon paniculatus the succulent dwarf tree from the brokenveld of the Richtersveld, Namaqualand, Roggeveld, Nuweveld and Little Karoo.

(18) Riverine and High Water-table elements: Antidesma venosum, Bridelia micrantha, Garcinia livingstonei, Phoenix reclinata, Syzygium cordatum.

(19) Halophytes: Most Zone I components can be looked upon as psamma-halophytes. The genus Salsola is a typical group of halophytes which are confined mostly to the west coast. The cosmopolitan temperate annual Salsola kali is common seasonally along the southern and west coasts.

(20) North Temperate European coasts: Seawheat Agropyron distichum and marram Ammophila arenaria.

(21) Dune Endemics: Examples of trees and shrubs confined mostly to the coast dunes (Figures 21 and 22).

(a) Kenya to south Mocambique - Terminalia boivinii.

(b) North Mocambique to Tugela Mouth - Diospyros rotundifolia.

(c) Central Mocambique to Woody Cape - Mimusops caffra.

(d) Peninsula south of Bazaruto Islands to Sodwana - Encephalartos ferox.

(e) Cabo dos Correntes (south of Inhambane) to Pondoland - Aloe thraskii.

(f) Southern coasts (east Cape to south-west Cape): Cassine maritima, Erica chloroloma, Myrica cordifolia, M quercifolia, Phylica litoralis, Rapanea gilliana, Rhus crenata, R schlechteri (Cowling pers com 1982). Few of the above elements occur the full length of this coast sector. By far the largest number of endemic plants of all kinds occur amongst the fynbos heaths on dunes and limestones along the southern coasts (Taylor 1978; Kruger 1979b).

A prima facie analysis of the woody tree and shrub components on dunes, excluding the Cape fynbos, shows that between 50 and 60% are thicket species including savanna elements which are thicket-forming (eg Ziziphus mucronata). These are chiefly from duplex sands and base-saturated clayey soils in tropical and subtropical arid to mesic savanna regions. As most of these species are bird dispersed they are characteristic of perch and water-based sites.

In South Africa the largest areas of these thickets occupy the hot dry river valleys which drain to the Indian Ocean comprising Acocks's Valley Bushveld types 10, 11, 23, 24 and 25 (Acocks 1975). The same kinds of thicket are scattered across the whole of southern Africa (Heydorn and Tinley 1980) and across the equator to the Karamoja-Turkana region of Uganda and Kenya on the Sudan border, clearly depicted in the plates and species lists furnished by Langdale-Brown et al (1964) in their book on the vegetation of Uganda; thence scattered across the breadth of the Sahelian zone between the Atlantic coast and the Red Sea (as at Erkowit).

True forest elements make up about 45% of thicket/forest, of which the Afrotemperate and general moist forest species (mostly subordinate shade strata) contribute about 16% each. Tropical Sand Forest contributes only about 7% despite its close juxtaposition with dune forest in south Mocambique and Tongaland and Equatorial Rain Forests and its east coast outliers only contribute 6%. North of the Limpopo River in Mocambique the *Brachystegia* Savanna Woodland (miombo) grow to the landward base of the forested dunes on leached sands. Despite this close junction there is only about a 2% contribution to the dune thicket/forest on calcareous sands. As noted previously, the reverse contribution is far greater locally of dune species into adjacent areas of miombo thicket.

3.5.4 Imbricate distribution and attenuation of species overlapping from opposite directions

The distribution of the broader leaf woody tree and shrub constituents of the dune vegetation is listed alphabetically in Table 14. The number of tree and shrub species in common between each coast sector was analysed using Sorenson's Coefficient of Similarity (Figure 23).

This shows an overlapping "roof-tile" (imbricate) sequence of species distribution with the sharpest drop-off of tropical elements on dunes occurring at Delagoa Bay. The west coast has its highest shares species content with the south-west Cape, with the termination point of its elements eastwards on the east Cape coast near the Kei River mouth. All coast sectors share most species in common with the sectors on either side of them and decrease in affinity markedly in both directions beyond the immediately adjacent sectors (compare Natal, east Cape, south Cape and south-west Cape sectors).

There is a progressive reduction in number of tree and shrub species southwards from the tropical south Mocambique coast dunes around to the west coast. The Tongaland sector has some 20 species more than that recorded for the Mocambique Coast to the north. Although this is possibly due to an artifact of collecting intensity, it is significant that the contribution of southern Afrotemperate forest species terminates sharply north of Delagoa Bay as exemplified by *Pittosporum viridifolium* which has its northernmost record from dunes on Inhaca Island (MacNae and Kalk 1958).

The attenuation of tree and shrub species on the continental margin as a whole shows quite a different pattern to the progressive reduction noted on the coast dunes. The greatest number of tropical species (131) drop out at the southern end of the Mocambique Coastal Plain between the Tongaland dunes and Mtunzini, and the second highest have their southern limits along the east Cape (109 spp). These two coast areas are thus major bottleneck

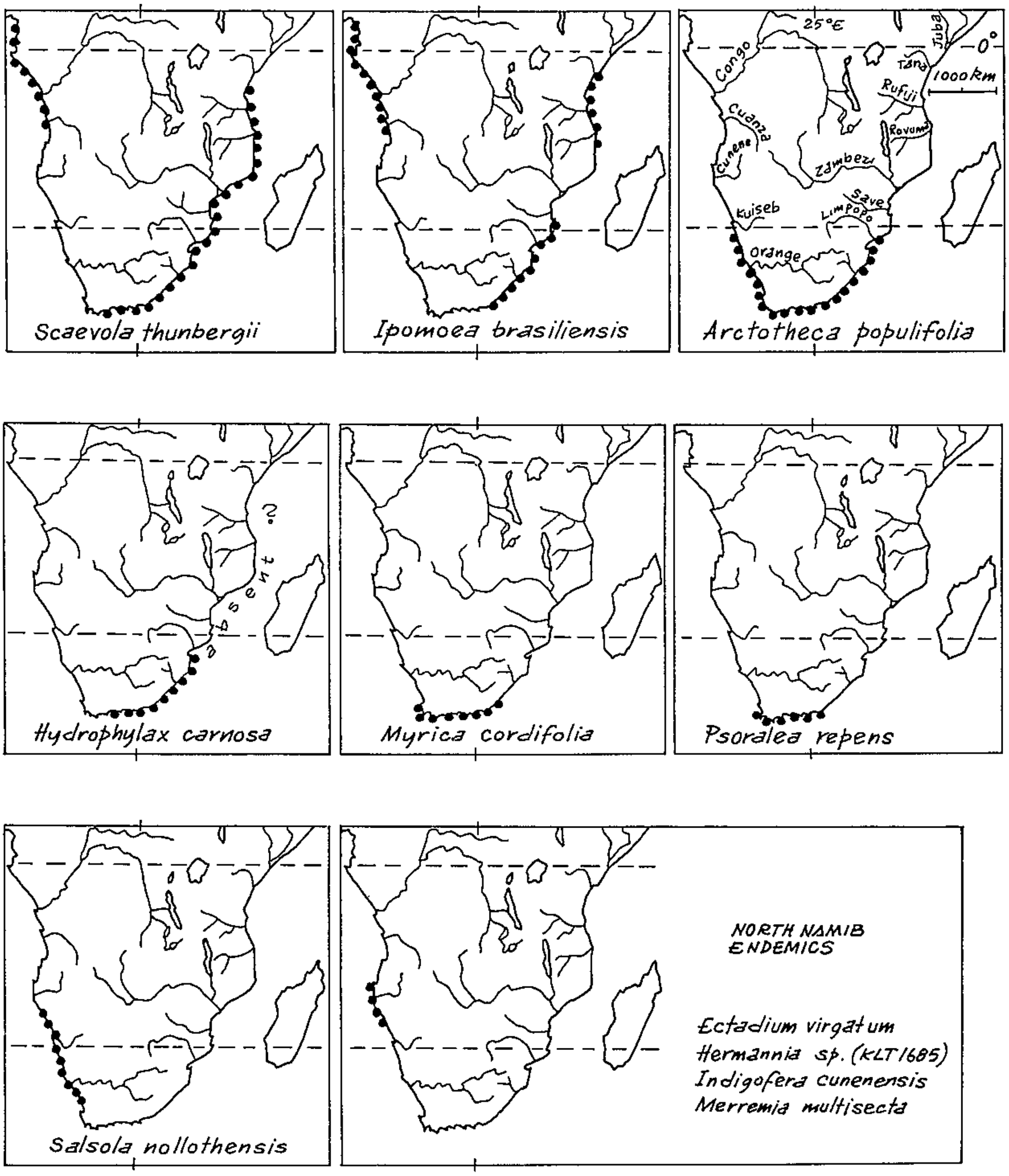


FIG 20. DISTRIBUTION PATTERNS OF MOUND-FORMING PRIMARY DUNE PLANTS.

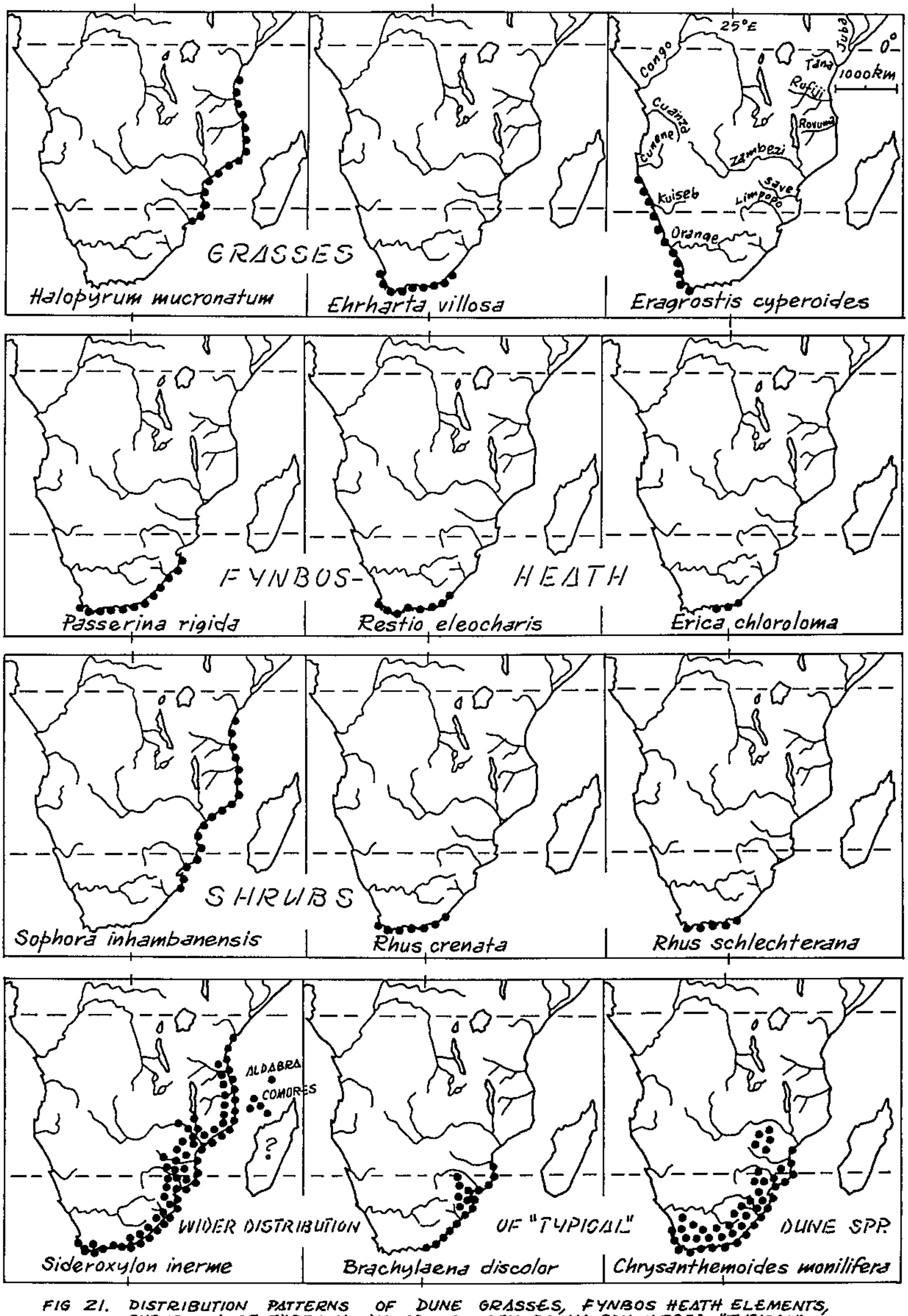


FIG 21. DISTRIBUTION PATTERNS OF DUNE GRASSES, FYNBOS HEATH ELEMENTS, SHRUBS, & OF THREE WOODY SPECIES GENERALLY CONSIDERED "TYPICAL" OF DUNE THICKET.

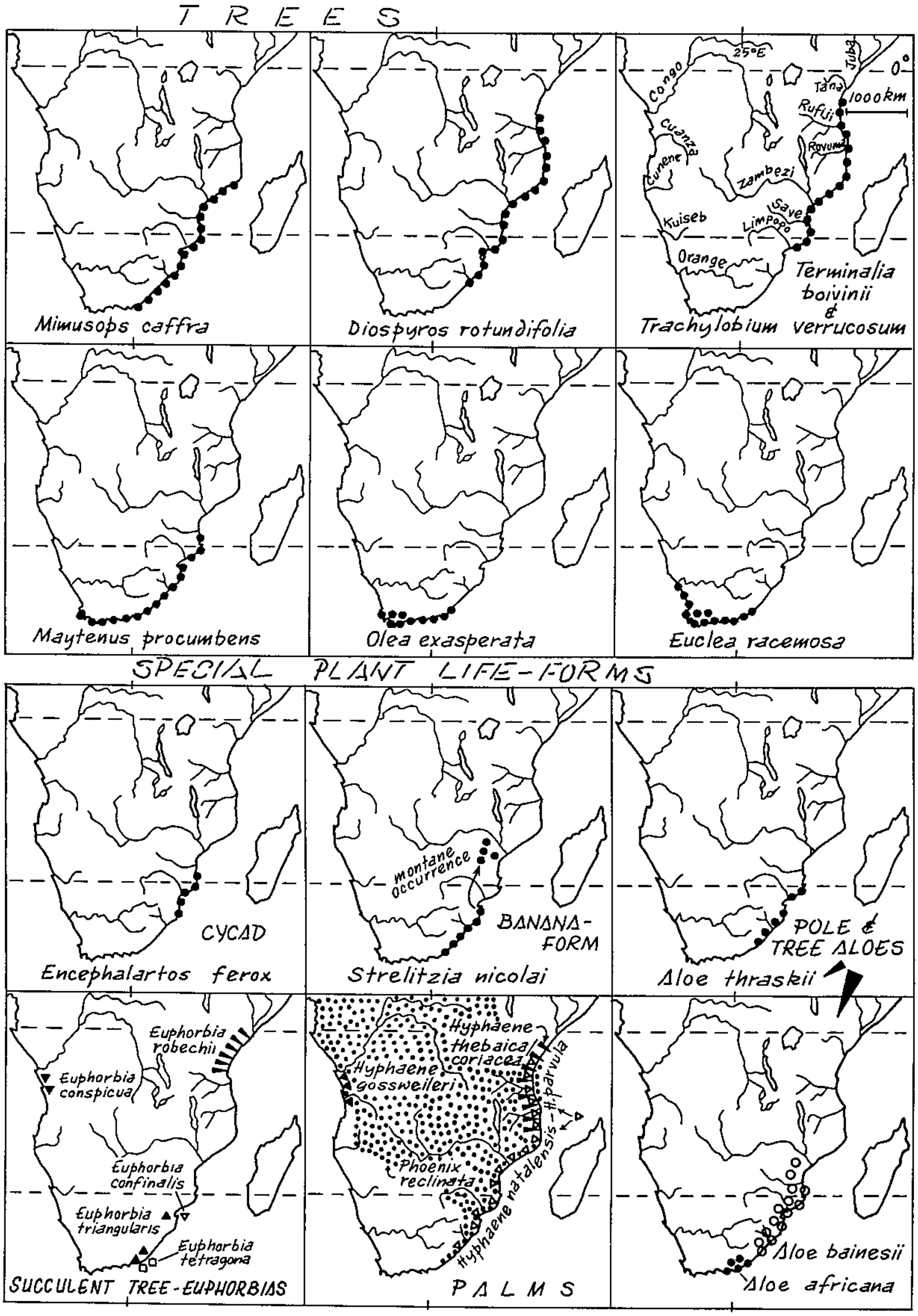


FIG 22. DISTRIBUTION PATTERNS OF COAST DUNE TREES & OF SPECIAL PLANT LIFE-FORMS.

filter sites for tropical species (Table 13). In the opposite direction is the attenuation of southern Afrotemperate forest elements on the coast, the species dropping out progressively northwards from Natal into Tongaland, some reaching as far as Delagoa Bay.

TABLE 13. Southward attenuation and terminal areas of tropical thicket/forest trees and shrubs on the continental margins

Tongaland to Mtunzini	131	species
KwaZulu	31	
Natal	79	
Transkei	68	
East Cape	109	
South Cape	39	
South-west Cape	33	(end point)

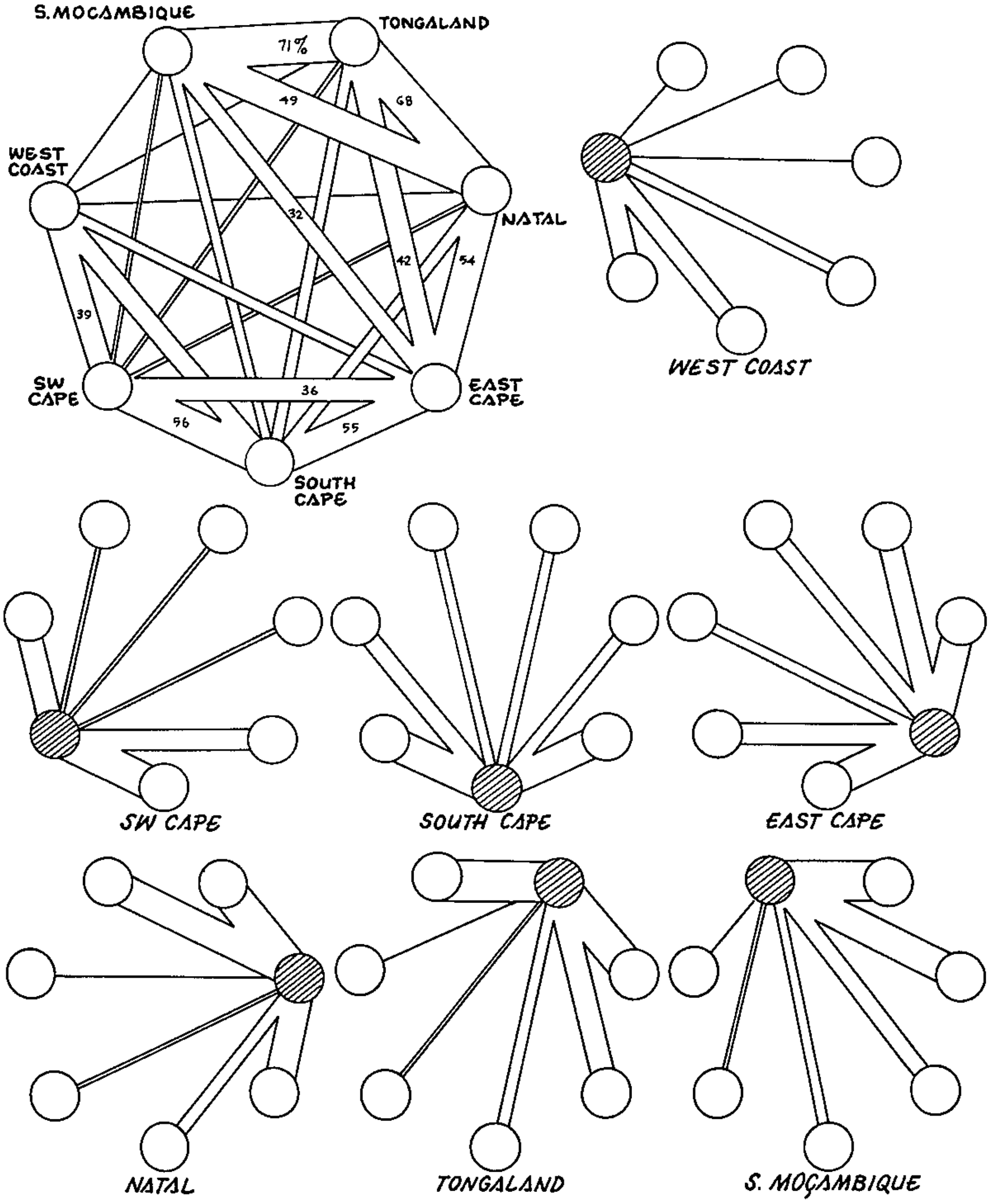
South African forest endemic Brachylaena glabra, Cunonia capensis, Noltia africana and Olinia ventosa reach their northern limits in Natal. Afrotemperate trees which become confined northwards to montane high rainfall sites and which reach their northernmost limits on the coast in the dune and swamp forests of Tongaland and the adjoining part of Mocambique to Delagoa Bay include Caladendrum capense, Combretum krausii, Cussonia sphaerocephala, Bersama lucens, Cassine peragua, Olinia radiata, Linociera foveolata, L peglerae, Maytenus acuminata and Pittosporum viridiflorum (Weisser and Drews 1980). In adjacent swamp forests Afrotemperate trees include Halleria lucida, Ilex mitis, Podocarpus falcatus and Rapanea melanophloeos (Tinley 1967).

One species Olea capensis however, remains in both the higher rainfall dune and coast forests as well as the upland forests of Mocambique to beyond the Zambezi River.

On the coast the most important biogeographic arena of attenuation, overlap, and distribution end-points of tropical thicket/forest elements from the north and temperate forest elements from the south (and inland) lies between Lake St Lucia and Mtunzini. An area some 130 km long by 50 km deep in the north reaching to the Hluhluwe forests, and 30 km inland in the south reaching to the Eshowe forests and Nkwaleni Valley thickets. Other forests of high phytogeographic importance in this area occur at Ngoye (Huntley 1965), Richards Bay (Venter 1972), and at Dukuduku (Henkel et al 1936).

3.5.5 Conservation strategies as determined by nodes of endemism amongst coastal trees

The distribution of endemic biotic elements in any region should form the basis to a first level delimitation of conservation areas. Due in part to their disjunct occurrence, thickets and forest of all kinds exhibit a kaleidoscopic change in species content and relative abundance from site to site, though each formation is unified by common linking species. A mosaic of representative coastal communities of optimal size (Diamond 1975) should thus be included in any protective strategy in order to ensure coverage of as many permutations as possible.



TOTAL Nº SPP.		M	T	N	E	S	C	W
174	M		130	71	41	16	8	3
195	T	130		106	59	19	10	3
117	N	71	106		55	19	8	2
86	E	41	59	55		39	23	10
55	S	16	19	19	39		27	11
41	C	8	10	8	23	27		12
19	W	3	3	2	10	11	12	

TREES & SHRUBS
No. SPECIES IN COMMON

	M	T	N	E	S	C	W
M		71	49	32	14	7	3
T	71		68	42	15	8	3
N	49	68		54	22	10	3
E	32	42	54		55	36	19
S	14	15	22	55		56	29
C	7	8	10	36	56		39
W	3	3	3	19	29	39	

SORENSONS COEFFICIENT OF SIMILARITY %
2w/a+b

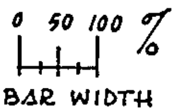


FIG 23
SPECIES SIMILARITY OF DUNE TREES & SHRUBS ON VARIOUS SECTORS OF THE SOUTHERN AFRICAN COASTLINE.

This option, in contrast to having a few large reserves, is also administratively practical if landowners or users are involved in the protection of such resources and unique elements on a basis of local cooperation (Tinley 1979 and Chapter 6 here).

A mosaic of reserves is only ecologically effective in island biogeography terms (Diamond 1975; Simberloff and Abele 1976) where such areas can be linked by natural self-protecting habitats such as escarpments, cliffs and river gorges or by the proclamation of conservation corridors.

It is some of the self-protecting habitats on the eastern seaboard, on outcrops of Table Mountain Quartzites in Pondoland and south Natal (van Wyk 1981), which harbour the largest array of tree endemics within the smallest unit area.

Vital in the context of coastal conservation therefore is the identification of adjacent sites of highest floristic and ecological diversity or value which can be linked in a protection strategy to the coast dune ecosystem. In Figure 24 the patterns of occurrence shown by endemic trees on the continental margins is drawn from known distributional data to provide a first stage templet for further refinement and application.

The endemic tree group was chosen for several reasons: (a) trees are the dominant life forms in wooded habitats, (b) the present state of knowledge regarding their distribution is more readily available in the literature, and (c) the ecosystem and floristic affinities of the tree and shrub components are those best known to the writer from personal records made in the field across southern Africa.

As further collecting will naturally refine the dimensions of the areas of distribution, Figure 24 represents a first approximation in the identification of the nodes of tree endemism and overlap areas along the coast and coast hinterland of southern Africa.

The bargraphs were constructed by using the number of tree endemics on the vertical scale multiplied by distance of occurrence (length parallel to the coast in kilometres) on the horizontal scale. Ideally the horizontal scale should be the area of occurrence (Senanayake et al 1977). However, gross inaccuracy of area results from using extremely small scale maps (Palgrave 1977) and broad descriptions given in other publications as these exaggerate the area error exponentially when multiplied.

All bargraphs with a square to vertical shape are high priority conservation areas for the endemic tree group, as these have higher numbers of endemics over shorter distances than the others. A most-least priority or importance scale is thus indicated by the relative dimensions of the vertical rectangles, the narrower the more important they are (eg areas 9, 10, 17, 18). By contrast those bargraphs with greater horizontal dimension contain few endemics dispersed over a greater distance.

The histogram inset in Figure 24 indicates the areas in which the greatest overlap of tree endemics occur. By adding the attenuation and terminal distribution areas noted above (Table 13) to those illustrated in Figure 24 a composite importance value can be given to particular areas or sites where the greatest number of species concentrations coincide. These

TABLE 14

DISTRIBUTION & SEED DISPERSAL AGENTS OF TREES & SHRUBS OCCURRING ON COASTAL DUNES IN SOUTHERN AFRICA (Lamberts Bay to Bazaruto).

COAST SECTORS: M,T,N,E,S,C,W (REFER TO TABLE).

DISPERSAL AGENTS: V = BY WEIGHT (BAROCHORY), W = BY WIND (ANEMOCHORY), X = BY EXPLOSIVE DEHISCENCE WITH SEEDS THROWN (ACTIVE AUTOCHORY OR ACTIVE BALLISTS), Y = BY WATER (HYDROCHORY), Z = ANIMAL DISPERSED (ZOOCHORY).

	M	T	N	E	S	C	W
Acacia karroo (z)		•					
A. robusta (z)	•		•				
Acokanthera oblongifolia (z)	•	•	•	•			
A. oppositifolia (z)	•	•	•	•			
A. schimperi (z)	•	•					
Afzelia cuanzensis (z)	•						
Albizia adianthifolia (W)		•	•				
Aloe africana (W)				•	•		
A. arborescens (W)		•			•		
A. bainesii (W)		•					
A. thraskii (W)	•	•	•				
Allophylus africanus (z)	•	•	•				
A. decipiens (z)					•		
A. natalensis (z)	•	•	•	•			
Apodytes dimidiata (z)	•	•	•	•			
Azima tetracantha (z)	•	•		•	•		
Balanites maughamii (z)	•	•					
Baphia obovata (x)	•						
B. racemosa (x)			•				
Bauhenia tomentosa (x)	•	○	•				
Bequaertiodendron natalense (z)		•	•				
Berchemia discolor (z)	•	•					
Bersama lucens (z)		•	•				
Blighia unijugata (z)	•	•					
Brachylaena discolor (W)	•	•	•	•			
Brexia madagascariensis (z)	•						
Bridelia micrantha (z)		•	•				
B. schlechteri (z)	•						
Buddleja salviifolia (W)					•		
Caesalpinia bonduc (V, Y)	•	•					
Calodendrum capense (V, Z?)		•	•				
Canthium inerme (z)	•	•	•	•			
C. locuples (z)	•	•	•				
C. obovatum (z)	•	•	•	•	•		
C. setiflorum (z)	•	•					
C. spinosum (z)		•	•	•	•		
Carissa bispinosa (z)	•	•	•	•	•		
Casearia gladiiformis (z)	•						
Cassia abbreviata (z)	•						
Cassine aethiopica (z)	•	•	•	•	•		
C. crocea (z)				•	•		
C eucleiformis (z)	•	•	•	•	•	•	
Bridelia cathartica (z)	•	•					

	M	T	N	E	S	C	W
Cassine maritima (z)					•		
C. papillosa (z)		•	•	•	•		
C. peragua (z)		•	•	•	•	•	
C. schlechteri (z)	•						
C. tetragona (z)			•	•	•		
Cassipourea gerrardii (z)		•	•				
Celtis africana (z)	•	•	•				
Chaetacme aristata (z)		•	•				
Chrysanthemoides monilifera (z)	•	•	•	•	•	•	•
Chrysophyllum viridifolium (z)			•				
Cladostemon kirkii (V, z)	•	•					
Clausena anisata (z)	•	○	•	•	•		
Clerodendrum glabrum (z)	•	•	•	•			
C. incisum (z)	•						
Cliffortia ilicifolia (W?)					•		
Clutia daphnoides (x, z?)				•	•	•	
Coffea racemosa (z)	•	•					
Cola greenwayi (z)	○	•					
C. natalensis (z)		•	•				
Colpoon compressum (z)	•	•	•	•	•	•	
Colubrina asiatica (Y, z?)	•						
Combretum bracteosum (W?)			•	•			
C. kraussii (W)		•	•				
Commiphora harveyi (z)		•	•				
C. neglecta (z)	•	•					
C. schimperi (z)	•						
C. schlechteri (z)	•						
C. serrata (z)	•						
C. woodii (z)			•				
C. zanzibarica (z)	•	•					
Cordia caffra (z)	•	•	•	•			
Cordyla africana (z)	•	•					
Craibia zimmermannii (x)	•	•					
Croton gratissimus (x)	•	•					
Cryptocarya sp. (z)		•					
Cussonia arenicola (z)	•	•					
C. nicholsonii (z)			•				
C. sphaerocephala (z)		•	•				
C. spicata (z)		•	•	•			
C. thyrsiflora (z)				•	•	•	
C. zuluensis (z)	•	•	•				
Dalbergia obovata (W)		•	•				
D nitidula (W)	•	○					

	M	T	N	E	S	C	W
Deinbollia oblongifolia (z)	•	•	•	•			
Diospyros dichrophylla (z)				•	•		
D. inhacaensis (z)	•	•					
D. natalensis (z)	•	•	•	•			
D. rotundifolia (z)	•	•					
D. scabrida (z)		•	•	•			
D. whyteana (z)		•	•	•			
Dodonaea viscosa (w, y)	•	•					
Dovyalis caffra (z)		•					
D. longispina (z)	•	•	•				
D. rhamnoides (z)		•	•	•			
D. rotundifolia (z)	•			•	•		
Dracaena hookerana (z)		•	•	•			
Drypetes arguta (z)	•	•					
D. gerrardii (z)		•					
D. natalensis (z)	•	•	•				
Ehretia rigida (z)	•		•	•			
Ekebergia capensis (z)	•	•	•	•			
Encephalartos ferox (z)	•	•					
Enterospermum littorale (z)	•	•					
Ephippiocarpa orientalis (z)	•	•					
Erica chloromela (w?)					•		
Erythrina caffra (z)		•		•			
E. lysistemon (z)		•	•				
Erythrococca berberidea (x, z)	•	•					
Erythroxylum emarginatum (z)	•	•	•	•			
E. gerrardii (z)	•						
E. delagoense (z)	•	•					
E. pictum (z)	•	•	•	•			
Euclea natalensis (z)	•	•	•	•			
E. racemosa (z)				•	•	•	•
E. schimperi (z)	•	•	•	•			
E. undulata (z)	•	•					
Eugenia capensis (z)	•	•	•	•			
E. natalitia (z)		•	•				
Euphorbia confinalis (x, z)	•						
E. ingens (x, z)			•				
E. mauritanica (x, z)					•	•	•
E. tirucalli (x, z)	•	•	•				
E. triangularis (x, z)		•		•			
E. tetragona (x, z)				•	•		
Ficus burtt-davyi (z)	•	•	•	•			
F. natalensis (z)	•	•	•				
F. polita (z)	•	•	•				
F. sansibarica (z)	•	•					
F. tremula (z)	•	•					
F. vogelii (z)	•	•	•				
Flacourtia indica (z)	•						
Garcinia gerrardii (z)		•	•				
Gardenia amoena (z)	•	•	•				
G. thunbergii (z)	•	•	•				
Grewia caffra (z)		•	•				
G. occidentalis (z)	•	•	•	•	•		
G. sulcata (z)	•						

	M	T	N	E	S	C	W
Guettarda speciosa (y)	•	•					
Harpephyllum caffrum (z)				•			
Helichrysum kraussii (w)	•	•	•				
Heteromorpha arborescens (w)				•			
Hymenocardia ulmoides (w)	•	•					
Hyphaene natalensis (v, z)	•	•					
Ilex mitis (z)		•					
Inhambanella henriquesii (z)	•	•					
Kraussia floribunda (z)	•	•					
Lebeckia cinerea (w?)							•
Leucodendron coniferum (w)						•	
L. muirii (w)					•		
L. salignum (w)					•		
Limonium perigrinum (w)						•	•
Linociera foveolata (z)	•	•		•	•		
L. peglerae (z)		•	•				
Lycium cinerea (aggr. sp.) (z)	•	•		•	•		•
L. ferocissimum (z)							•
L. horridum (z)							•
Macphersonia hildebrandtii (z)	•						
Maerua cafra (z)				•			
M. nervosa (z)	•	•					
M. triphylla (z)	•						
Manilkara concolor (z)	•	•					
M. discolor (z)	•	•					
Maytenus acuminata (z)		•					
M. heterophylla (z)	•	•	•	•	•	•	•
M. lucida (z)						•	
M. nemorosa (z)	•	•	•				
M. oleoides (z)						•	
M. procumbens (z)	•	•	•	•	•	•	
M. senegalensis (z)	•	•					
M. undata (z)	•	•					
Metalasia muricata (w)				•	•	•	
Mimusops caffra (z)	•	•	•	•			
M. fruticosa (z)	•						
M. obovata (z)	•	•	•	•			
Morus mesozygia (z)	•	•					
Myrica cordifolia (z)				•	•	•	
M. quercifolia (z)					•	•	
Myrsine africana (z)					•	•	
Nylandtia spinosa (z)				•	•	•	•
Ochna arborea (z)	•	•	•	•			
O. barbosae (z)	•	•	•				
O. holstii (z)		•					
O. inermis (z)		•					
O. natalitia (z)	•	•	•				
Olax dissitiflora (z)	•						
Olea capensis (z)	•	•	•	•	•	•	
O. exasperata (z)				•	•	•	
O. woodiana (z)		•	•				
Olinia radiata (z)		•					
Ozoroa obovata (z)	•	•					
O. paniculosa (z)	•	•					

	M	T	N	E	S	C	W
Passerina paleacea (z)						•	
P. rigida (z)		•	•	•	•	•	
P. vulgaris (z)						•	
Pavetta capensis (z)		•					
P. delagoensis (z)	•	•					
P. gerstneri (z)		•					
P. lanceolata (z)		•					
P. revoluta (z)	•	•	•	•			
Peddiae africana (z)		•	•				
Pemphis acidula (w,y)	•						
Phoenix reclinata (z)	•	•	•				
Phylica ericoides (z?)						•	
P. littoralis (z?)					•		
P. parviflora (z?)						•	
P. selaginoides (z?)						•	
Phyllanthus reticulatus (z)	•						
Pittosporum viridifolium (z)		•					
Plectroniella armata (z)	•	•					
Podocarpus falcatus (z)		•		•			
P. latifolius (z)			•				
Protea cynaroides (w)					•	•	
P. obtusifolia (w)						•	
P. susannae (w)						•	
Psorospermum febrifugum (z)	•						
Psychotria capensis (z)	•	•	•	•			
Pteroxylum obliquum (w)		•					
Pterocelastrus tricuspidatus (z)				•	•	•	•
Pteronia divaricata (w)							•
Putterlickia pyracantha (z)				•	•	•	•
P. verrucosa (z)	•	•	•	•			
Rapanea gilliana (z)					•		
R. melanophloeos (z)		•	•		•	•	
Rawsonia lucida (z)	•	•					
Rhamnus prunoides (z)					•		
Rhus crenata (z)				•	•	•	
R. glauca (z)				•	•	•	•
R. guienzii (z)	•	•					
R. laevigata (z)				•	•	•	•
R. longispina (z)				•	•	•	•
R. lucida (z)						•	
R. macowani (z)	•						
R. natalensis (z)	•	•	•	•			
R. nebulosa (z)		•	•				
R. schlechterana (z)					•		
R. tomentosa (z)		•	•				
R. undulata (z)				•	•		
Rinorea ilicifolia (z?)		•					
Rothmannia globosa (z)		•	•				
Ruschia frutescens (w,z?)							•
Salvia aurea (w? z?)				•	•	•	•
Sapium integerrimum (z)	•	•					
Scolopia mundtii (z)		•					
S. zeyheri (z)	•	•	•	•			
Schotia afra (z)				•	•		

	M	T	N	E	S	C	W
Schotia latifolia (z)				•			
Scutia myrtina (z)	•	•	•	•	•		
Securinega virosa (z)	•						
Senecio halimifolia (w)						•	
Sideroxylon inerme (z)	•	•	•	•	•	•	
Sorindeia juglandifolia (z)	•						
Spirostachys africanus (x,z)	•	•					
Stoebe plumosa (w)				•	•	•	
Strelitzia nicolai (z)		•	•	•			
Strychnos decussata (z)	•	•	•	•			
S. henningsii (z)	•	•	•				
S. madagascariensis (v,z)	•	•	•				
S. mitis (z)	•	•					
S. spinosa (v,z)	•	•					
Suregada africana (x,z?)	•	•	•	•			
S. zanzibariensis (x,z?)	•	•					
Suriana maritima (z)	•						
Tabernaemontana elegans (z)	•	•	•				
Tapura fischeri (z)	•	•					
Tarchonanthus camphoratus (w)				•	•	•	
Tarenna neurophylla (z)	•	•					
T. junodii (z)	•	•					
Teclea gerrardii (z)		•	•				
T. natalensis (z)		•	•				
Terminalia boivinii (z?)	•						
Thespesea acutiloba (z?)	•	•					
Tournefortia argentea (z,y)	•						
Trachylobium verrucosum (z?)	•						
Trema orientalis (z)	•	•	•				
Tricalysia capensis (z)	•	•	•				
T. lanceolata (z)		•	•				
T. sonderana (z)	•	•	•				
Trichilia emetica (z)	•	•					
T. dregeanus (z)		•					
Turraea floribunda (z)	•	•	•				
T. obtusifolia (z)	•	•	•				
T. wakefieldii (z)	•						
Tylecodon paniculatus (w)						•	•
Vangueria esculenta (z)	•	•	•				
V. infausta (z)	•	•					
Vepris undulata (z)	•	•	•	•			
Vitellariopsis dispar (z)		•					
V. marginata (z)	•	•					
Warburgia salutaris (z)	•	•					
Widdringtonia nodiflora (w)					•		
Xeromphis obovata (z)	•	•	•				
X. rudis (z)	•	•	•	•			
Ximenia americana (z)	•	•					
X. caffra (z)	•	•					
Xylopia parviflora (z)	•						
Xylotheca kraussiana (z)	•	•					
Zanthoxylum capense (z)	•	•	•	•	•		
Z. schlechteri (z)	•						
Ziziphus mucronata (z)	•	•	•				

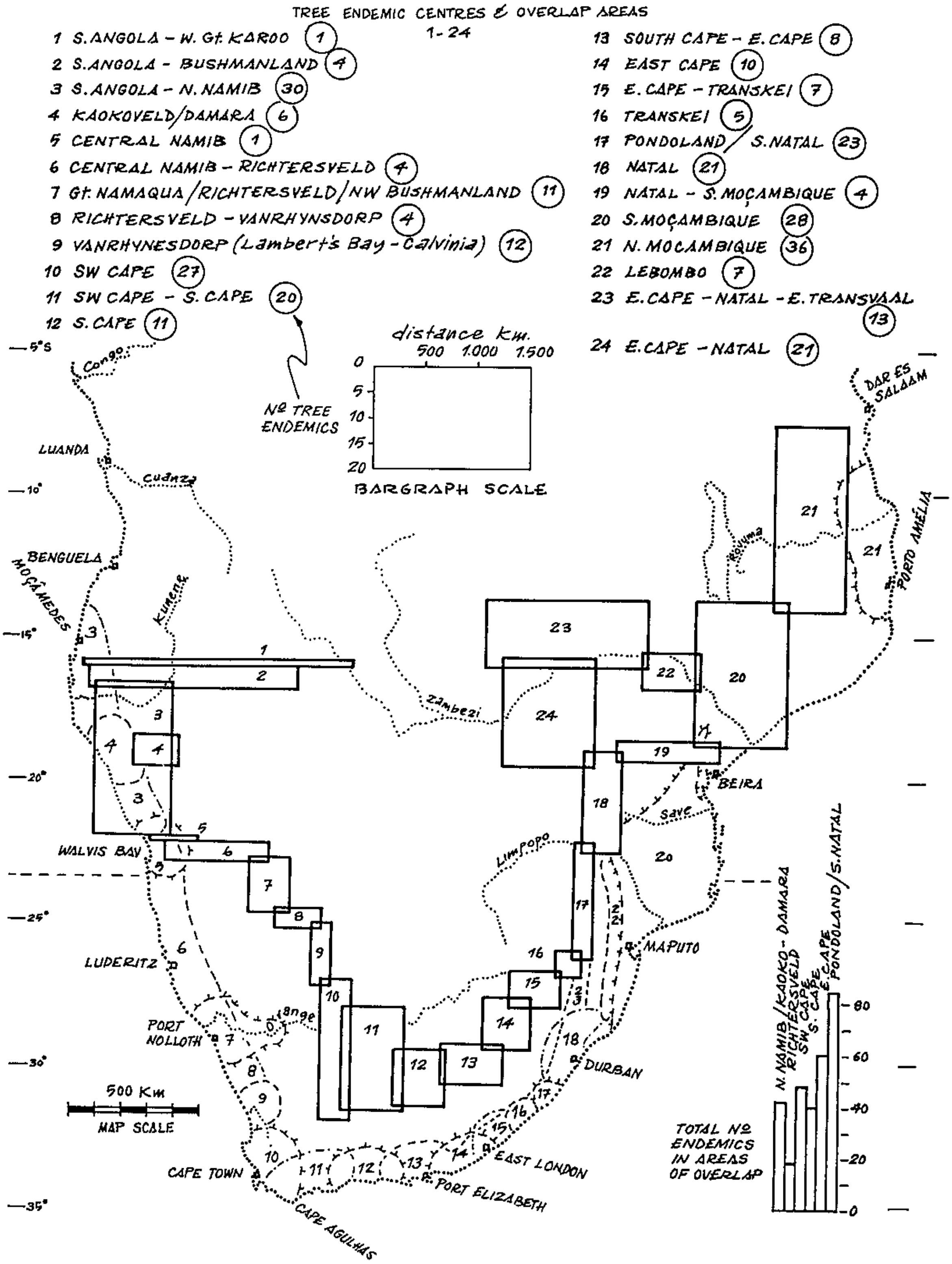


FIG 24 TREE ENDEMIC CENTRES & OVERLAP AREAS ALONG THE COAST & COAST HINTERLAND OF SOUTHERN AFRICA. (1st APPROXIMATION).

LINKED BARGRAPHS OF ENDEMIC TREE SPECIES DIVERSITY ON THE VERTICAL SCALE X APPROX. Km DISTANCE OF OCCURRENCE ON THE HORIZONTAL. Distributional data from Sousa 1960, Giess 1971, White 1962, Wild & Fernandes 1967, Lucas 1968, Polhill 1968, Barbosa 1970, Palgrave 1977, Moll 1981, Zimbabwe Tree List (Natl. Herbarium, Salisbury), pers. data for S. Moçambique. (KCT 82) species concentration areas are thus made up of endemics, those with tropical, temperate and other affinities, as well as from ecotonal enrichment from overlapping ecosystems or communities.

The highest coincidence of all these tree elements is in the coastal bottleneck filter area between south Natal and the east Cape. In this region the highest number of tree endemics overlap in the area between south Natal and Pondoland (87 species) and the second highest in the eastern Cape (65 species).

The high number of endemics amongst the tree components alone, totally refutes the conclusion of Gibbs Russell and Robinson (1981) who contend that because the east Cape is a zone of transition and overlap it is low in endemics (they reckoned there were only four). There is a high endemism in other groups as well, such as the succulent euphorbias for example where some 32% of the South African species occur in the eastern Cape, of which about 50% are endemic (Mrs M Court, Botanical Research Institute, Grahamstown pers com 1983). On one mountain summit alone in the Amatola Mountains nine endemic wild flowers occur in the grassland on Mt Kemp (Mrs A Batten, East London, pers com 1983).

Is it not precisely because of this close juxtaposition and overlap of seven biomes in a tension zone with high aspect, edaphic and ecotonal diversity that high endemism should rather be suspected? In common with the remainder of the continental margins this region has experienced a succession of contrasting changes in climate, sea-level and geomorphology.

Unlike the remainder of the continental margins, however, the south-eastern monoclinal coast has a unique trellis pattern of linear topographic features produced by the stepped series of escarpments roughly parallel to the coast, and linked at right angles to the coast dunes by patches of forest in the deeply incised meander valleys of rivers. Patches of savanna/thicket on slip-off slope bottomlands alternate with thicket/forest on the cliffed undercut slopes which have geologically long been separated or islanded by the intervening pure, edaphically determined, grasslands of the interfluves (Tinley 1977, 1982).

On all other coast sectors the thicket/forest communities are linked by shrubland or savannas. Each of these woody patches would act alternatively as initials in colonization or refuges, or nuclear sites from which outward expansion would occur.

In a tension zone each biome, its communities and individual components would respond differently to changes in the environment by either contracting, expanding or combining (mixing) with elements from the juxtaposed biomes. The thicket formation in particular has undergone massive expansion in the eastern Cape, recombining in a plethora of floristic permutations with subdesert, grassland, savanna, forest and heaths.

Although the terms thicket and forest are used in tandem here due to the mosaic occurrence of true forest patches within a greater closed thicket cover of essentially heliophytic species on calcareous soils, it must be emphasized that thickets provide a two-way path of migration, carrying arid and moist elements in opposite directions; arid elements into moist regions usually on base-saturated soils (eg Salvadora persica) and moist elements into arid regions typically of understorey and forest initial components (Tinley 1975a, 1977). Thickets form refuges for forest elements during arid periods, are initial sites from which these elements expand during wet periods, and provide dispersal links either linearly along rivers, valleys, scarps and coast dunes, or across the stepping stones of bush-clump archipelagos.

3.6 HUMAN INFLUENCES

3.6.1 Human succession and its exponential impact on coasts and catchments

Human activities affect both geomorphic and biotic changes in habitats. These influences are direct (on site) and indirect at a distance involving, for example, modification of catchment surfaces with consequent changes in runoff and sediment discharge which in turn affects the sand supply to the littoral active zone.

Man has been associated with coastal dunes for more than a million years as indicated by the presence of Early Stone Age (Sangoan) hand-axes and cleavers shaped from cobbles in high beach deposits subsequently covered by red dunes (Davies 1970, 1971a,b, 1973). These relate to stillstand shorelines of seas receding in the Early to Mid Pleistocene from their high stand of about 300 m above present level in the Mio-Pliocene (Maud 1982; Table 3).

It is likely that succeeding generations of hunter-gatherers followed the recurring sequences of Late Pleistocene changes in sea level, of falling glacial sea levels out towards the edge of the exposed continental shelf, and back landwards with the recovery of sea level rising to above the present coastline in warm interglacial periods (Inskeep 1978). The great abundance of shell middens and associated artifacts along the coast were accumulated since the beginning of Holocene times and continued into the present where tribal subsistence cultures remain on the coast. That is from about 10 000 years ago when sea level had risen back to near the present shoreline (Table 3).

Since the Last Glacial of the Upper Pleistocene the hunter-gatherers were Later Stone Age people ancestral to the Khoi (Hottentot) and San (Bushman) that peopled most of southern Africa in Holocene times (Inskeep 1978). About 2 000 years ago stock and pottery first appeared on the south Cape coast amongst the Khoi people at about the same time that Early Iron Age cultivator-pastoralist people ancestral to the Bantu appeared on the eastern coasts and hinterland. Although the Khoi groups specializing in shellfish gathering were referred to as strandlopers by European sailors and settlers, this food source was also utilized seasonally or periodically by all coastal people including the Hottentot herders and the Iron Age people (Rudner 1968; Speed 1969; Derricourt 1977; Inskeep 1978; Hall 1980, 1981) through to the present day by tribal subsistence communities which remain on the eastern coasts (Oatley 1959; Bigalke 1973; van der Elst and Tregoning 1984).

Added to the advantage of the year round availability of shellfish as a source of food readily at hand, tidal fish traps were also used by the coastal Hottentot people between St Helena Bay and Cape St Francis, but mainly concentrated in the area between Gansbaai and Arniston. The oldest of these, some of whose submerged remains can be seen from the air, may date back to 6 000 years ago, but are reckoned to have been more likely in use since about 2 000 years ago to the present as judged by the effective critical height relationship between the pebble and boulder weirs and the tidal range (Avery 1975). These structures would probably have enhanced the use of the dune country bordering the coast of the Agulhas Plain, which was a major game concentration area up to the end of the 1700's as reported in the journals of Sparrman, Lady Ann Barnard and Lichtenstein for example (van Riebeeck Society series).

The arrival of domestic stock to the south Cape coast some 2 000 years ago from across southern Africa and the appearance shortly after of Iron Age cultivators marked the beginning of the end of hunting-gathering as the major lifeway since more than 2 million years ago (Inskeep 1978). These cultural and habitat perturbating factors were exponentially compounded by the arrival of technically advanced European settlers to the south-west Cape in 1652, who spread from there and later from the south-east coast to the interior during the 1700's and 1800's (South Africa Yearbook 1977). This time, especially the late 1800's, saw the vast game populations of the country massacred by the settlers (Player 1972) and replaced by ever increasing numbers of domestic stock which eventually surpassed those of the Hottentot and Bantu herders. The settlers' searching and appetitive activities increasingly affected all natural resources and impinged on the indigenous subsistence cultures contributing to the demise of the Khoi-San peoples (Maingard 1931; Inskeep 1978).

The Hottentot shellfish-gathering peoples of the coast survived to about 1820 on the east Cape coast in St Francis Bay and between Algoa Bay and Port Alfred, to about 1858 near Port Nolloth and 1903 near Luderitz on the west coast (Rudner 1968). Remnant groups of strandlopers remained on the Skeleton and south Angola coast of the Namib until the 1950's (Dart 1955), the last known survivor lived at Sesfontien during the mid 1960's when I worked in Etosha. Artifacts from these times abound along the coast (Plate 95).

The crucial change in this succession of cultures and technologies was that from a free-ranging nomadic use of land by pastoralists, and the shifting cultivation of subsistence farmers, to a mechanized and concentrated sedentary over-use locked in by the confines of fenced farms and tribal homeland boundaries (Jacks and Whyte 1939; Robertson 1968; Acocks 1979). With stability, mechanized farming and growing industrialization, and efficient medical and veterinary prophylaxis, a human and stock population explosion was set in train. This human succession has, particularly in the recent three to five decades, had exponential influences on natural resources, shortening the time lag between cause and effect. The magnitude of these pressures on catchment and coast resources of all kinds can be gauged by the explosive increase of human population in South Africa from about five million in 1900 to close on 30 million in the 1980's and the prediction of it doubling in the next 30 years (South Africa Yearbook 1977).

3.6.2 Coastal dunes as a human habitat

The possible role played by hunter-gatherers in modifying coastal dunes since the beginning of the Holocene some 10 000 years ago is illustrated by the continuation of hunter-gatherer practices today amongst subsistence cultivator-pastoralists such as the Xhosa, Tonga, and Shangane of Gazaland

and the hunter-gatherer Bushman of the interior sandveld regions. The influence of past herders and cultivators on coastal dunes can be readily judged from the activities of present subsistence cultures on the eastern coasts.

By listing the advantages and disadvantages of wooded coast dunes as a human habitat, perceived in the present by a naturalist family, a clearer appreciation is obtained of their value to coastal hunters and shellfish gatherers of the past. This also helps clarify the subtleties and dimensions of cumulative human influences over the long term on dune dynamics and the present-day appearance of dunes. Many of the factors listed below continue to be exploited by industrial man but almost entirely from a recreational point of view and not one of survival.

A. Subsistence cultures.

1. <u>Resources and advantages</u>

(1) Perennial availability of shellfish as a food base, readily at hand, and requiring a minimum of energy expenditure compared to hunting game.

(2) Freshwater lens usually easily available at the surface in slacks, or by digging shallowly as at the foredune-backdune junction.

(3) The groves of large milkwood trees on wooded dunes provide natural arbours for living with evergreen shade cover and an open understorey.

(4) Perennial supply of fruits and spinaches; tubers are easily dug out of the loose sand.

(5) Abundance of dense, foliaged brushwood to build shelters.

(6) Lianas, strelitzia and bark provide strong cord fibre.

(7) Abundance of firewood (depletion of this resource could force dune bush dwellers to decamp to fresh sites).

(8) Thicket/forest cover and patches are least hazardous havens in veld fires.

(9) Dune relief provides in one place contrasting microclimates under different weather conditions and lee sites out of any wind.

(10) A benign climate as temperature extremes are damped by proximity to the sea (see Disadvantages).

(11) Shoreline rains occur at intervals nearly year round.

(12) Alternation of sea and land breezes and/or of the major cyclonic and anticyclonic winds.

(13) Relatively minimal insect pests and diseases including malarial mosquitoes where water sources are subsurface (see Disadvantages).

(14) The only large carnivore in wooded dunes is the leopard.

(15) Presence of territorial non-migratory forest antelope (bushbuck and duikers) and bushpig.

(16) Abundance of prominent look-out sites with all round vistas.

(17) A high ecotonal effect - sharp junctions between wooded dunes and open bare dunes or beaches which are highly pleasurable and care-free habitats at the junction of three major elements, land, sea and sky.

(18) Close junction of open ground and dense bush (for hiding away) enhances the safety factor.

(19) In dunes it is easy to shift camp, bury something, stand pots, poles or wattles, or modify the surface.

(20) Seawater in abundance for medicinal purposes or washing.

(21) River and seaworn pebbles ideally suitable as artifacts or for shaping them.

(22) High surface humus content of wooded sands valuable for shifting cultivation.

(23) Nutritious calcareous pastures of value to game and stock where the abutting habitats are leached sands.

(24) Sandy ground favoured for camp sites by strandlopers (Rudner 1968).

2. Disadvantages

(1) In wooded dunes a superabundance of bush mosquitoes.

(2) Where high and extensive dunes occur, no surface or near-surface water is available requiring long fetch and carry of water in containers.

(3) Year round extremely high humidity.

3. Influences. That such a concurrence of favourable conditions along the coast, related to the dunes in particular, has been exploited since antiquity, is verified by the extremely high association of strandloper middens and artifacts such as stone age implements and pottery with the coast dunes (Rudner 1968), and the cave midden stratigraphy which extends back over 80 000 years (Butzer 1972; Klein 1972).

(a) Footpaths. Any activity which makes openings or bares vegetated dunes, exposing the sand again to wind action, is the prime moving influence on subsequent dune dynamics. The main natural cause of this is undercutting and slumping of vegetated frontal dunes by wave action, exposing bare sand slopes to blowout formation by onshore winds. The human activity of the most subtle and apparently innocuous kind, which eventually can have far reaching and large scale consequences, is the development of footpaths from vegetated dunes onto bare dunes or beaches in line with the prevailing and strongest winds (Plate 96).

The invasion of blowouts and mobile sand along footpaths radiating from dune bush dwelling sites was probably a major factor which forced early seashell gathering communities to decamp successively away from the flying sand encroaching along gaps in the plant cover. Shortcut footpaths across vegetated dune headlands and points either initiated or accelerated the eventual severance of the headland from the mainland, all stages of which are clearly demonstrated on the eastern coasts (see Chapter 4). The tongues of bare sand formed by parabolic blowouts breaching or superposing forested dunes are also natural lines of communication for man and animals between vegetated and open areas or from landwards to the beach (Plate 97).

Anyone who has lived on the coast or camped in dunes knows that beaches and bare dunes are enjoyable only when there is little to no wind. Fair weather middens must have been formed, but the abundance of open site middens and artifacts in bare dunes today, is seen to be more the result of sea and wind erosion, initiated or accelerated by human activities over the long term.

This conclusion is supported by the evidence of root traces and calcretized root cores and whole land snail shells from vegetated dunes associated with many midden sites in presently bare sand areas.

Three interesting phenomena result where drift sands and mobile dunes are now found in once vegetated dune areas: (1) the superabundance of sand in a median to low wind regime, similar to the present, transforms parabolic duneforms into bare transverse dunefields, (2) where middens occur, a landscape reversal on the small scale develops where deflation removes the surrounding loose sand, leaving the midden as a mound or hillock where it originally may have been accumulated in a dune hollow, and (3) confluence of once separate coarser materials in dunes such as bone fragments, pottery, stones, land snail shells (though the large achatina shells were collected as containers), which may once have been separated by intervening dune ridges. The congregating influence of such materials by the winnowing action of the wind from various sites and levels in the dune to a common depression can confuse interpretation and correlation of events and relationships in dune habitats. This is made more complex where superposing parabolic dune sequences in vegetated dunefields buried older surfaces. Some of these grey topsoil layers are sometimes exposed on the slopes of subsequently bare dunes (Plates 58, 59).

(b) Surface freshwater. The presence of surface freshwater in coast dunefields has been a major attraction concentrating trampling out and baring of vegetation on dunes by game herds, hunter-gatherer man and, much later, the nomadic pastoralists and more recent white ranchers. This impact would have been greatest where one or more of the following features pertained: waterless karst, sandveld, or saline deltaic and estuarine conditions.

In some of the larger, presently bare dunefields on the southern coast such as the Algoa Dune Sea, which is banked against a waterless karst region, and those west of Cape St Francis, dune slacks provided the only sources since antiquity of surface freshwater for animals and man. The abundance of game, stock and human remains in the former area, plus the enormous size of the shell middens, attests to concentrated use of these dune areas by game herds, hunter-gatherer man, and pastoralists up to recent times. White ranchers still water their stock in the mobile dunefields at St Francis.

The partly forested parabolic dunes of large dimension or the stubs of their lateral ridges which occur as remnants along the landward scarp of the Algoa Sand Sea and at Woody Cape, indicates that its original form was similar to the present compound ascending parabolic dunefields abutting Groenvlei Lake on the Wilderness Coast. Game herds and early man may have initiated and compounded the change from wooded parabolic dunes to a sand sea of barchanoid dunes especially with the arrival of the pastoralists, or accelerated and expanded the baring of dunefields initiated at the foreshore by a rising sea level.

In contrast, most of the bare dunefields landwards of the frontal dune zone and water-based sites appear to have been initiated by white farming activities over the last 100 years (Walsh 1968). Their sand-baring actions include: roads, paths, excessive burning, bush clearing, overstocking and trampling within the confines of fences on preferred sweet grazing of dunes, patch ploughing for cash crops and openings left by sand quarrying or mineral exploration.

(c) Cultivators. In contrast to coastal hunter-gatherers who lived in the dune bush and caves, or the nomadic Khoi (Hottentot) pastoralists who had transportable rush-mat huts, the subsistence cultivators lived in thatched mud huts ("Houses of clay" Maingard 1931) landward of the coast dune cordon (Inskeep 1978). The early Iron Age people apparently preferred to cultivate the sandier coast soils including dunes (Maggs 1980), and they and the later Bantu cultivator-pastoralists continued to visit the shore to gather shellfish, from up to 25 km inland in early times (Rudner 1968) and up to half this distance in recent times (Bigalke 1973). They also grazed and watered their stock in the dunes, thus maintaining or increasing the footpaths and openings traversing vegetated dunes to the beach.

The main destructive influence of cultivators where poor sandy soils occur landward of forested dune cordons, is in clearing patches in dune thicket/ forest for growing crops on the temporary high fertility afforded by the topsoil humus. Where these openings are exposed to wind action, blowouts are formed, and on the landward margins the secondary regrowth on fallow lands enables fire to invade from the adjacent savannas, burning back the cut up forest and expanding the secondary cover. The best examples of this are clearly depicted on the 1942 aerial photographs (Job 167) of the Tongaland and St Lucia dune cordons (see vegetation maps traced from aerial photographs in Tinley 1958a,b). The landward openings continue to be singed back by recurring veld fires today, but most of the cultivation clearings made within forested dunes have recovered since the dunes were afforded protection by the Forestry Department.

(d) Fire. As patch burning is used to attract concentrations of game to facilitate hunting, hunter-gatherers probably increased the incidence of fire in dune areas where pyrophytic communities such as fynbos heaths, grassland or savanna occurred. It is likely the increase in frequency, and thus the expansion of these communities, took a sharp upturn with the advent of nomadic pastoralists more than 2 000 years ago in their constant search for grazing.

The frequency of fire across any one area affects the amount of combustible material that can accumulate from regrowth between burns, which in turn affects the intensity and thus the damaging power of a fire in which wind velocity is a potent factor.

It may be a matter of conjecture which combinations of the above factors prevailed in the past as compared to present times (Kruger 1979a). But as the evolution, dynamics and possibly speciation of fynbos heaths are affected by fire, it seems important that some approximation of past fire regimes in the coastal dune heaths be estimated from present fire occurrence in sand regions sparsely inhabited by subsistence cultures, such as the central Kalahari and Gazaland on the Mocambique Coastal Plain. This should be facilitated by the analysis of satellite imagery.

B. Industrial cultures.

In addition to the many shared features between subsistence and industrial cultures in the above lists, the following are peculiar to the present.

1. Resources and Advantages

(1) Coast dunes are a source of building sand, lime and heavy minerals.

(2) The dune aquifer is still used by sedentary stock farmers (eg at Cape St Francis and until recently in the Algoa Sand Sea), and by towns such as Alexandria, Port Alfred and St Francis Bay.

(3) Large scale modifications of dunes for permanent structural developments are easily affected.

2. Disadvantages

(1) Almost all structures erected in dunefields are permanent and immovable in an essentially fluid malleable environment in constant flux.

(2) Mobile sands are a threat to permanent structures (the general opinion is that all bare dunes should be stabilized).

(3) Capriciousness of coast dunes when built on or modified to make room for development.

(4) Frontal dunes interfere with the view or access to the beach (general opinion is that they should be bulldozed flat and the sand sold).

3. Influences. Industrial man continues many of the more primitive influences such as footpaths, clearing or burning dune vegetation, or grazing and watering stock in dunefields. But it is the use of large machinery which effects massive changes in habitats and the imposition of permanent immovable structures in the malleable environment of the littoral active zone which set his actions apart. The greatest threats to coastal dunes today are from the invasion and mushrooming of resort townships (Plates 133-137), highways or streets, nuclear power plants, military use, and dune mining for lime, sand or heavy minerals. There are also indirect influences from dam construction and from changes in the conservation status of catchment surfaces.

As most of the coast dunefields are situated on the downdrift side of the sand supply source from river mouths, any disturbance of river catchment surfaces will be transferred downstream to the littoral active zone. All river catchments have been increasingly affected by exponentially growing human and stock populations from about 80 years ago, particularly since 1950. Such that sediment loads have been increased far beyond the geological norm, for example by 28 times in the Tugela Basin under present conditions (Murgatroyd 1979). This excess of sediment is responsible for building one of the few actively growing shorelines in South Africa, downdrift of the Tugela Mouth to Mtunzini (Plates 100B, 103).

It is likely that this prograding coast will go into an erosive phase once the proposed dams are completed on the lower course of the river (de Freitas and Begg 1981). The proliferation of dams on South African rivers (Noble and Hemens 1978) means that a large proportion of this sand supply is trapped, and thus taken out of circulation, affecting erosive changes in the sensitive dynamic equilibrium of sediment exchange processes in the littoral active zone of soft coasts. It is ironic that good land use would have similar consequences.

Also important in the changed ratio of fines and sands now reaching the coast because of dams, is the timing and extent of ploughing in relation to the arrival of the first rains as this has a major influence on the sediment volumes carried by rivers. Land is freshly ploughed over large areas or in high density patches in the winter rainfall region generally after the first rains, and in the summer rainfall region of the Highveld and the eastern seaboard before the first rains. In the latter region therefore, an abundance of readily mobilized broken-up topsoil is available for transport by rivers to the coast (Heydorn and Tinley 1980).

The present distribution and density of human populations in the subcontinent south of the tropic shows the highest maritime concentrations on the south-west and south-east coasts (Figure 25). The coast sector under greatest development pressure, however, is the Cape coast between Great Fish River mouth in the east and St Helena Bay in the west. It is the more scenic and least unspoilt coast wilderness areas that are endangered by the unrestrained proliferation of resort townships and the spread of industry from the main urban complexes entrained by thoughtless positioning of main roads and highways hard against the coastline. In the next 20 years building programmes in South Africa will have to equal or exceed that of the past 300 years (Bahlmann 1982). Responsible and sensitive land use allocations will have to be applied fast to avoid a repeat of the developmental mess on the Natal South Coast.

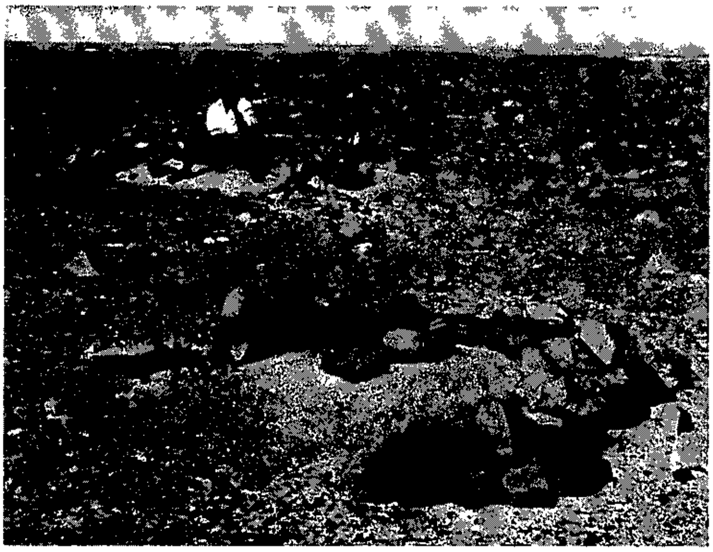


PLATE 95. Remains of strandloper shelters on the Skeleton Coast of the Namib Desert. All openings in the lee of the cold south wind off the Benguela Current. Atlantic coast and reeds for shelter construction in the background at right. Associated middens show main shellfish gathered was the sand mussel Donax serra.

PLATE 96. Incised gulley eroded along site of footpath up red sand slopes of Durban Bluff. Note slumped donga head and basal sand cone-fan.

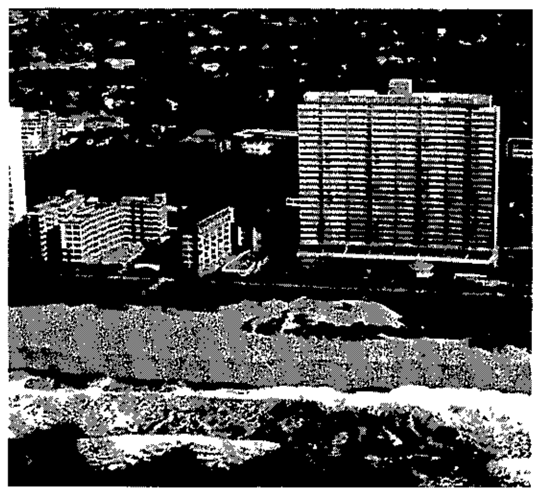


PLATE 97. High rise buildings and road developments built into Zones I and II within the littoral active zone. New parabolic dune forming. Amanzimtoti area south of Durban.

PLATE 98. Playing King Canute with a major material investment. Beach hotel built in the littoral on sand. Despite the concrete apron it has undergone repeated massive damage from waves. Xai-Xai area of Limpopo Coast, south Mocambique.

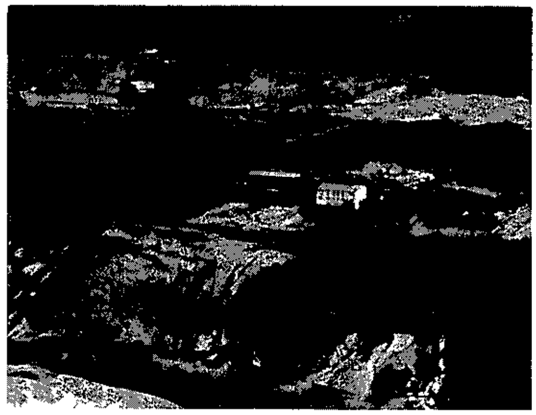


PLATE 99. Open-cast dune mining north of Richards Bay. Massive slumping of seaward slopes where mining operations have been allowed to encroach on the frontal dune zone.

To avoid such despoilation, allocation of coast-use should ensure that all resort and township developments on the coast, from the immediate future, are confined to existing development nodes. This will ensure that sufficient intervening coastline retains some pristine attributes for enjoyment, and to protect the unique combinations of coastforms, habitats, processes and other natural resources peculiar to each coast area that have formed the resource basis to human life over the millennia (see Chapter 5).

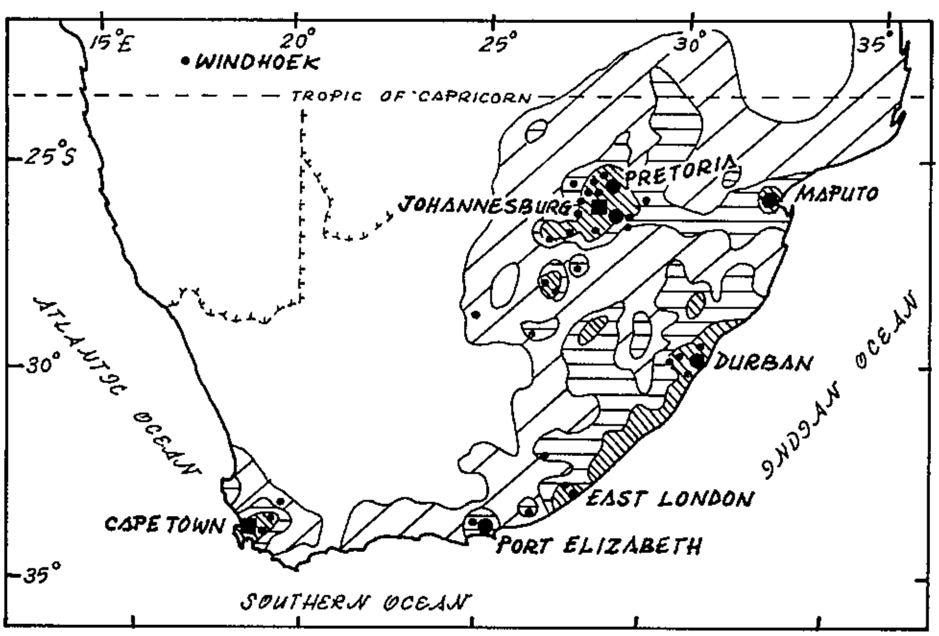


FIG 25 HUMAN DISTRIBUTION & DENSITY

No. PERSONS PER Km^2

- > 50
- 25 - 50
- 5 - 25
- < 5

MAJOR CITIES & TOWNS

- ■ > 1 million people
- ● 200 000 to 1 million
- • 40 000 to 200 000

[data from Shuter's Magister Atlas for Secondary Schools 1979]

4. DUNE DYNAMICS

This chapter highlights some of the data on dune dynamics scattered throughout the body of the report, and presents fresh material on dune succession and the erosion of wooded dunes into new landforms.

4.1 SAND SOURCES AND SAND LOSSES

The littoral active zone is a single geomorphic unit in which sand is shifted between four compartments, these are (1) beaches, (2) frontal dunes, (3) inshore or surf zone sand bars and banks, and (4) river mouths and estuaries. Any change in the sand budget in one of these can entrain changes in the others, particularly as losses occur from each compartment either seawards, landwards or into estuaries.

Sand sources are from: (1) river mouths, (2) surf zone sand banks and bars, (3) dunes, and (4) beaches. Sands are lost to the littoral active zone where they are shifted out of reach of transporting agents. These losses occur in the following situations: (a) off headlands and points projecting into deepwater where the sand accumulates to form a submarine spit (eg off Cape St Blaize, Robberg, Cape Seal and Cape Recife) (Birch 1981), (b) seawards into deepwater, particularly along rip current channels and the submerged river course extensions from river mouths, (c) where sand is blown landwards of the first wooded dune ridge or cordon, or beyond 50 to 100 m of the backbeach strand plants in bare dune areas. The exception to this is where strong to gale force offshore winds return large volumes of sand to the littoral as occurs with Berg Winds along the west coast desert, (d) sand trapped in dams on the seaward draining rivers changes the balance of sediment input from the land. It is likely that good land-use practices in river catchments which minimized erosion would have similar or parallel damping influences on the sand supply to the coast as dams, (e) sand infill of inlets, estuaries and river mouths during dry periods by the tidal race of incoming high spring tides. These sands are in temporary storage and are augmented and returned to the sea coast when high river floods occur. Where dams damp flood scour this infill becomes more permanent, particularly if the peaks of such attenuated flooding coincide with hightide conditions.

As the profile of equilibrium of beaches is constantly adjusting by eroding or eccreting in response to changes in wave regimen and sidewash currents, beaches are central in determining the exchange between compartments. Due to its constant shift by waves and longshore sediment transport, sand must be constantly augmented in the littoral active zone (King CAM 1962; Zenkovitch 1967; Bird 1969; Zwamborn 1969; Shepard and Wanless 1971; Steers 1971; Jeffries and Davy 1979; Leatherman 1979; Davies 1980).

The shortage of sand is recovered from the surf zone, or if this is bound there by certain recurring process combinations, the bank of sand in the frontal dune zone is eroded back into circulation by the sea. The transfer of sand from the frontal dune to beach is a self-regulating form of coastal protection as the dune sand input fosters long-term coast stability by retarding shore recession (Ritchie 1980; The Conservation Foundation 1980).

If the sand supply from these sources and from rivers diminish, ongoing erosion of the shore generally results, with long eroding sectors alternating with short stable or growing sectors where sand accumulation occurs. This is the pattern exhibited by the greater part of the subcontinent's coastline (Figure 33).

The time lag between loss of sand supply and erosive response on the foreshore is more sensitive and faster than is generally realized, as can be observed when dry spells or drought occur, and conversely accretionary responses following river floods. The flatter the coastland the more sensitive is the balance due to gravity inertia requiring strong river flows to replenish the sand supply.

The dimensions of sand input from the four sources naturally varies at each site in space and time. The high coincidence of both the older and younger dunes and dunefields on the downdrift side of river mouths in southern Africa however, indicates that river sediments are by far the most important source of sand in the past and today.

From the sediment divide between Cape Point and Cape Agulhas the nett longshore sediment transport is northwards up the west coast from Cape Point to Cape Lopez near the equator, and eastwards from Cape Agulhas then northwards up the east coast to 21° S at Bartolomeu Dias Point and the offshore island of Bazaruto opposite. That the equatorward sweeping effect of these wave-formed, coast-shaping, currents have predominated since at least the end Pliocene, is expressed by the unidirectional upcoast trend of half-heart bays developed on all coasts in response to the prevailing south-west swell generated in the Roaring Forties (Silvester 1960).

Temporary reversals of this littoral drift occur on the south and eastern coasts seasonally and periodically when strong easterly anticyclonic winds blow, especially in summer when they are more persistent. Much shorter reversal periods occur on the west and south-west coasts with the occurrence of prefrontal north-west winds (Section 3.2.3D).

The dimensions of longshore sediment transport along the South African coastline, past a specific point, is of the order 0,5 to 2 million m^3 per year (Swart in Heydorn and Tinley 1980). The amount of sand transported alongshore northwards to accumulate against the South Pier of Durban harbour, for example, is estimated at 650 000 m^3 per year (Swart 1981). Similar sand accumulations with prograding beaches occur against the south pier at Richards Bay harbour entrance, at East London and at Kings Beach abutting the Port Elizabeth harbour wall.

Disturbance of catchment surfaces by human and stock activities has raised the sediment supply to coasts above the geological norm. In rivers such as the Tugela in Natal this has been exceeded by about 28 times, with an annual discharge of 13 million tonnes of sediment per annum (Rooseboom 1978; Murgatroyd 1979).

This massive sediment volume is responsible for building one of the few prograding shorelines on the South African coast downdrift of the Tugela Mouth to Mtunzini (Figure 33, Plates 100B, 103). The Dwarskersbos area of St Helena Bay at the junction of the west and south-west coasts was until recently the second largest coast sector with an actively growing shoreline fed by the Berg River which drains the Swartland wheatlands (Plates 100A, 101, 102). In the last three years a slight erosive phase has begun of the shore downdrift of the Berg Mouth which relates to sediment starvation from one or more several causes. These include the construction of dams on the Berg River, dredging of the mouth area for harbour use and/or natural causes such as droughts or storm seas.

During low river flow in dry or drought periods when anticyclonic activity prevails, active erosion and cliffing of dunes downdrift of river mouths is common due to reversal of longshore currents and most of the sand is lost to estuary infilling by spring tides or rivers being sealed off by sand bars. These interactions have been well illustrated during the recent drought on the south-east coast.

4.2 DYNAMIC STATUS OF THE SOUTH AFRICAN COASTLINE

On sandy coasts backed by dunes the dynamic status of the coast can generally be interpreted from the air using geomorphic features alone or in combination with plant zonation, density and size. These are identifiable from a highwing aircraft flying slowly at low level between 150 and 200 m altitude, and plotted on 1:50 000 topographic maps.

Direct translocation of sand landwards from a deflated (eroded looking) backbeach is however difficult to identify in bare dune areas where plant indicators are absent. In sand translocation sectors the sand is blown onshore into the body of the dunefield from the backbeach without showing any dune growth features at the foreshore as the sand is being stripped away by deflation. This is well exemplified by my misidentification of the first kilometre east (downdrift) of the Sundays River mouth as eroding in a survey of the Cape Coast (Heydorn and Tinley 1980). This section is in fact an active sand translocating sector without any seaward growth of the shoreline, and accumulation of sand was only made evident by the erection of a split-rail fence in the backbeach zone (shown to me by Dr Anton McLachlan on site).

The coast immediately downdrift (north) of the Orange River mouth, and probably for the first 200 km where the coastline bulges seawards, has a similar wind stripped appearance to that east of the Sundays River mouth where sand is entrained into the Algoa Sand Sea. Both are sand source coast sectors where active translocation of sand landwards from the backbeach is occurring with little to no interference from pioneer plant growth.

The dynamic status of soft coasts comprises five main categories.

I Growing or advancing shores (prograding) typically marked by parallel beach ridges with a gradation of densest and tallest plant cover on the oldest landward ridges and open smallest plant cover on the youngest ridges above the beach. Shoreline position is shifted progressively seawards.

II Homeostatic shores where a dynamic equilibrium exists between erosion and accretion. Characterized by the persistence of a pioneer community zone between the backbeach and the mature dunes fixed by a closed woody cover.

III Eroding shores where the backbeach sand is cliffed and the pioneer zones have been stripped out by wave erosion with beaches abutting sharply against a mature closed woody cover and/or where bare transverse dunes occur above the beach in which the plant cover has been destroyed by wind erosion. Sediment removal seawards or longshore, and/or landwards by wind, without an overall change of shoreline position landwards.

IV Sand accreting backshore with shoreline quasi-stable in plan. Accreting shores where sediments accumulate on the coast without an overall change of shoreline position seawards.

V Retreating or retrograding shores where landward formed communities such as mangroves or substrates such as compacted estuarine or vlei muds, or old red dune become exposed at the lower beach in the surf zone at high tide eg on the Cheringoma Coast between Beira and the Zambezi Delta (Tinley 1971b, 1977). Shoreline position is shifted progressively landwards.

Though it is crucial to distinguish between category IV where eroding shores remain in a quasi-similar position and that of category V where the coastline is actively retreating landward, in practise the distinction cannot easily be verified from a low flying aircraft (except where conspicuous features such as those noted above strike the eye). Hence inspection on the ground is required with the aid of oldest and newest paired aerial photographs to measure the change in shoreline position against other landmarks (Stafford and Langfelder 1971).

Using the above procedures the dynamic status of the Mocambique Coast was plotted in 1969/70 (Tinley 1971b; Schwartz and Bird 1984), for the Cape coast in August and October 1979, and the Natal and Tongaland Coast in March 1982 (Figure 33).

With the limitations, for comparative purposes, of the decade and thirteen year disparity in time between the low level air survey of the Mocambique Coast and the Cape, and latterly the Natal coasts in mind, the dynamic status of the subcontinent's coast exhibits the following patterns (Figure 33).

1. Almost all plant defended soft coasts are eroding from either wave action or wind or both. Active retreat of the shoreline landwards is, however, only conspicuous on certain coasts such as the linear north-

east trending sectors of the zigzag east coast in Mocambique which face the south-east swell quadrant (Limpopo and Cheringoma Coasts). If shoreline retreat is occurring at all elsewhere on eroding soft coast sectors it is subtle, and will require more detailed analysis.

2. The longest stretches of eroding soft coast sectors occur in the following areas, (a) on the west coast north of the Orange River (see note above), (b) in the large half-heart bays of the south coast, though these may be due to rapid translocation of sand landwards from the backshore-foredune zone by deflation (see note above), (c) the southern part of the south-east coast north of Durban to the Tugela Mouth, (d) the northern part of the south-east coast north of Durban to the Tugela Mouth, (e) and the longest stretch of all is on the east coast from three kilometres east of the Mlalazi River mouth for 2 000 km northwards to Mocambique Island, except for the two short prograding sectors noted below. In the early 1950's a barrage was built on the lower Limpopo River near Trigo Morais for irrigation purposes, which has acted since then as an efficient sand trap, as has the Caborabassa Dam on the lower mid-Zambezi River since the early 1970's (Tinley and Sousa Dias 1970).

3. Exceptions to the above trends occur at two levels, (a) on the smaller scale where sand accretion or accumulation sites occur at river mouths or downdrift of them and against the updrift side of projections such as points or piers, and (b) on the larger scale where a succession of beach ridges or foredune hummocks are developing in association with coast sectors growing actively seawards. Such sites are confined to the west and east coasts.

In South Africa, recent coastal growth has occurred only at two sites: (i) at Dwarskersbos on the long curve of the massive half-heart form of St Helena Bay, and (ii) downdrift of the Tugela Mouth in the Mtunzini area.

Elsewhere in the subcontinent, short sectors of prograding coast occur on the west coast in Namibia, Angola and Gabon, and on the east coast in Mocambique (Figure 33).

4. By comparison, all rock defended coasts are relatively more stable than soft coasts. The latter's malleability may, however, match that of rocky coasts in holding a quasi-stable shoreline position where a homeostatic sediment balance is related to the persistence of particular process combinations.

These processes and the ensuing soft coast geometry engendered by particular swell directions and surf zone currents are determined by the presence or absence of pivotal points formed by rocks protruding from the shoreline. Where these points are eroded away or severed, shore straightening processes predominate (see 4.4 below). Some of the dynamic processes on rocky coasts include gravity movements such as rockfalls and landslides which are typically related to occurrences of heavy rains, undermining from karst weathering, basal sapping, and enlargement of lines of weakness by direct wave action. The conspicuousness and rapidity of erosional changes on rocky coasts depends on the relative durability or friability of the various rock types (Heydorn and Tinley 1980).

4.3 COAST CONFIGURATION AND EXPOSURE TO EFFECTIVE WINDS

4.3.1 Salient features and modifying influences

Geomorphologically effective dune-forming winds are those above the threshold velocity of 16 km/h for the transport of dry sand (Bagnold 1941; King CAM 1962; McKee 1979). The wind regimes and their diurnal variation around the subcontinent's coast are detailed above in Section 3.2D (Figures 10, 11, 12). Dune distribution patterns and characteristics resulting from the interaction of the effective winds with sand supply and coast configuration are noted in Section 2.2.1 (Figures 4, 6, 7).

The salient features of the coastal wind regime and the modifying influences are:

1. The predominant winds and the strongest winds blow from the same quarter (Figure 10).

2. Alternation of westerly cyclonic and easterly anticyclonic predominant winds from opposing quarters. On the west coast from the north-west and southerly winds (south-south-east to south-west), north-west and southerly (south-east to south-south-west) winds on the south-west coast, south-west and easterly winds on the south coast, south-west and north-east winds on the south-east coast and southerly and easterly winds on the east coast (Figures 10, 11).

3. These predominant winds conform obliquely to the changing trend of the subcontinent's coastline, ie they blow obliquely onshore and offshore along the coast, except in embayments where one or both of the winds strike the coast more directly.

4. Local relief and changes in the curve of the coastline, and hence the spatial relation of the land-sea junction, has a centrifugal effect deflecting the wind, enhancing its velocity, and causing strong wind currents to be funnelled through saddles or openings.

The most important feature affecting the orientation of dune growth axes, therefore, is the local configuration of the coastline which changes the exposure in the same area to different effective winds (Figure 7). This in turn affects the nett sand transport direction in dunes contrasting with that predicted from wind analyses alone (Figures 7, 26).

5. As a greatly increased wind strength is required to initiate movement of damp sand, the seasonality of strong and persistent winds coincident with dry or wet periods is fundamental (Figure 12). The unique feature on western coasts is that the most effective dune-forming winds occur during the torrid conditions of the summer dry season in the winter rain region, and all year on the desert coasts. The two major winds in these regions both blow persistently from the southerly quadrant (between south-east and south-west), reinforcing and thus multiplying the transport of sand in one direction. This nett trend is interrupted for relatively short periods by prefrontal north-west winds and easterly Berg Winds.

On the south coast and southern south-east coast the windiest period is from mid-winter to spring when rains occur, in which the section between Cape St Francis and East London maintains high wind velocities all year round. On the remainder of the south-east coast and east coast strongest winds occur in spring and early summer. This is coincident with the first rains in Natal which arrive generally early in September, but is the driest time of the year on the Mocambique Coast where first rains are usual only in November (Figures 10, 12, 13).

6. In the diurnal rhythm the strongest winds along the whole coast occur in the afternoons at the hottest and driest time of the day (Table 5).

4.3.2 Wind and sand roses

Where wind roses show the per cent frequency of wind in particular velocity categories for each compass direction (Figure 10), sand roses show the potential sand drift from each direction by weighting, in various ways, the frequency and velocity of all winds above the 16 km/h threshold (Figure 26).

As the above summary of features shows, the prediction of nett sand transport direction, or of dune growth axes on coasts from wind data alone, bears little relation to reality in the field, unless it is corrected by the inclusion of the exposure factor and wetness of sand.

The usual means of determining the importance values of effective dune-forming winds is by multiplying the per cent frequency by the cube of the velocity for each direction. The results from sand trap measurements, however, showed the highest correlation with wind measurements when the wind velocities are added cumulatively for winds over 16 km/h (King CAM 1962). The same experiments showed little correlation when the amount of sand moved was plotted against the third power of the wind velocity.

A more complex equation developed by Fryberger (1979) determines the amount of sand drift in vector units for each velocity category for each direction, and the resultant drift direction or nett trend of sand drift.

The sand roses constructed from this equation are broadly similar to those drawn using the third power of wind velocity in which a resultant drift direction can also be calculated or aligned by eye.

The annual sand roses constructed from Fryberger's (1979) equation show little correlation with dune growth axes except on the west coast where a unimodal wind regime persists. They are a valuable indication, however, of the reduced sand transport on the other coasts where seasonal and periodic reversals in wind direction shift the sand to and fro reducing the dimension of the nett direction (Figure 26). This is best illustrated by the East London annual sand rose where easterlies and westerlies have a similar per cent frequency.

The most valuable sand roses are those constructed for each season as these most closely correlate with the orientation of dune growth axes and hence the nett sand transport direction in accordance with the local configuration of the coast.

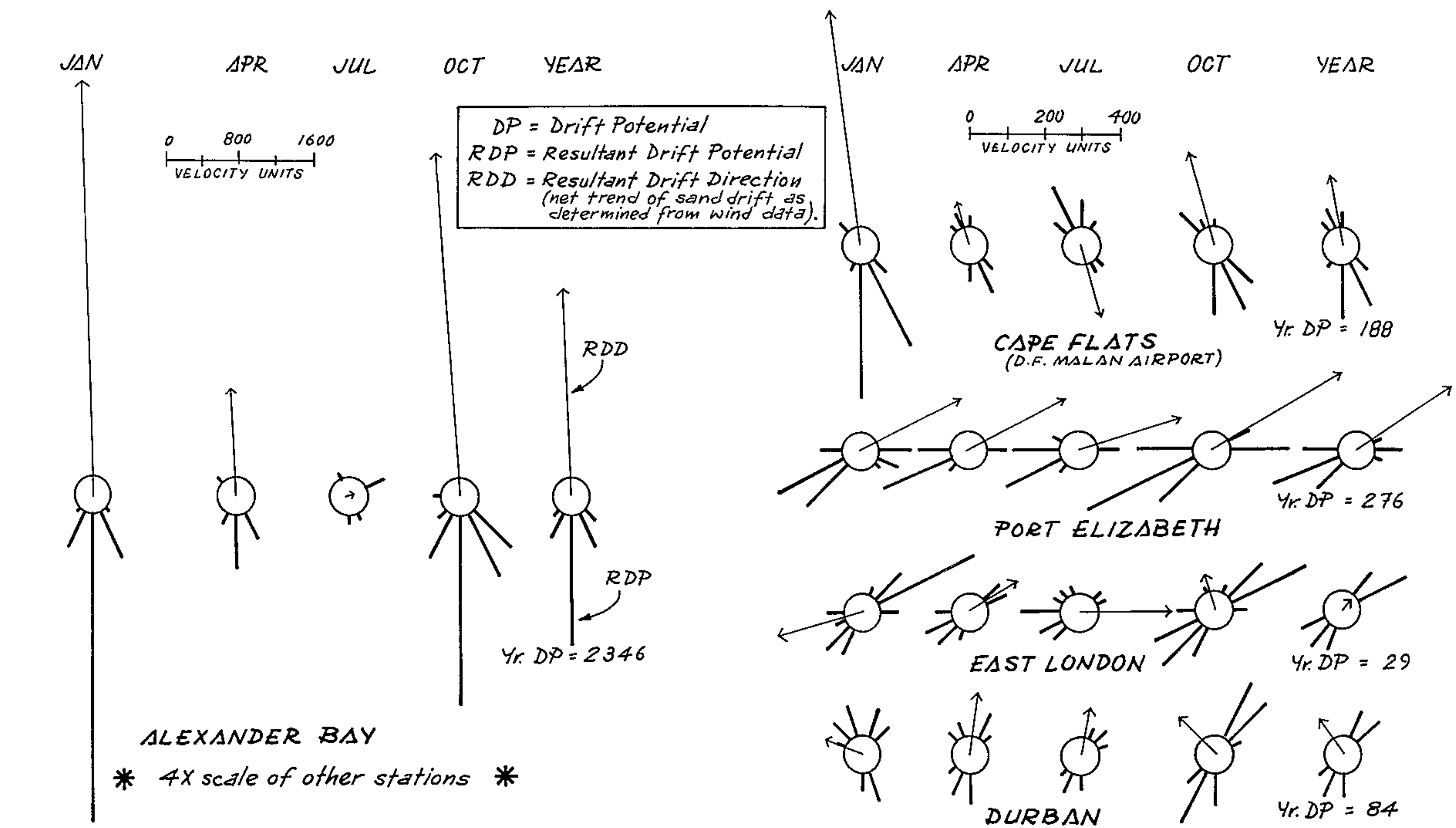


FIG 26. SEASONAL & ANNUAL SAND ROSES FOR SOUTH AFRICAN COAST STATIONS – ILLUSTRATING POTENTIAL SAND DRIFT FROM ALL 16 COMPASS DIRECTIONS.

[computed by David Berger, University of Cape Town, using Fryberger's Equation in McKee 1979]

4.3.3 Rates of bare dune movement

The only detailed measurements of bare reversing-dune movements on the coast over a period of time are those of McLachlan et al (1982) in the Algoa Sand Sea. Computed sand movements were made by Walsh (1968) for reversing dunes in his classic management study of the dunefields in the south-west to south coast junction area. No measurements are available on the advance rate of the noses of parabolic dune blowouts.

The Algoa Sand Sea data showed an easterly average advance of 4 m/yr in the backbeach, of 0,1 m/yr on an undisturbed sector of the inland dunefield escarpment, and 1,3 m/yr where disturbed by a badly sited vehicle access point (McLachlan et al 1982). In the central sand sea area island bush clumps have survived by growing ahead of the slow nett sand shift. The mean annual rainfall in the area of the Algoa Sand Sea is between 460 mm (Bird Island) and 650 mm.

In many sites, however, where sand has been kept loose by trampling, movement has been relatively rapid. Housing and other developments established in the embryo dune zone of the backbeach have been swamped by mobile sand (eg False Bay, Silversands, Stilbaai, Kleinkrantz and some east Cape resorts) (Plates 133-135). In 1927 the mouth of the De Hoop drainage, at the eastern end of the Agulhas Plain, was opened by spade. By the 1950's mobile bare barchanoid dunes three kilometres wide had sealed off the valley mouth to form a dune lake (Walsh 1968). In this region the mean annual rainfall is less than 500 mm.

In total contrast to the slow rates of dune movement noted above are those of isolated, migrating barchan dunes in the Namib Desert where rainfall is less than 25 mm over the long term with persistent unidirectional winds of medium to high velocity. In the southern sand source area of the Namib Sand Sea the distances traversed by barchans varies between 24 and 61 m (average 43 m) per year (Endrody-Younga 1982), and in the Angola Namib 100 m (Torquato 1970).

4.4 MOBILITY STATUS AND TRENDS OF DUNES

A comparative aerial photograph stereo-analysis of the South African coastline, spanning 42 years (1938 to 1980) and covered by eight separate flights at four to 10 year intervals, showed the following features. The present erosional status of dunes derived from low level air surveys are recorded in Figure 33.

(a) An increase of shifting sands all around the coast where bare transverse dune types are replacing vegetated parabolic dune types by fragmentation of the plant cover. These have been initiated in stable vegetated parabolic dune areas by baring of the sand through natural or human agency.

(b) An overall slow to medium stabilization over a 20 to 30 year period of the bare troughs of many ascending parabolic dunes by plant growth invasion from the margins. Particularly where sand movement is damped basally at the source when the deflation blowout has reached the dune water-table near the beach. Other parabolic blowouts have remained essentially the same (eg the landmark at East London), and some have expanded and grown landwards filling in barrier lakes of the Limpopo Coast in Mocambique (Plate 29).

(c) Some dune sectors, including the vegetated margins of wind eroded areas, have remained virtually unchanged over this time period.

4.4.1 Trends of bare reversing dunes

Bare transverse barchanoid dunes are typical of an excess sand supply being moved by medium to low wind velocities, hence their replacement of the vegetated parabolic dune types when the plant cover is removed (Plates 5, 9, 10-13, 25, 30, 37, 106).

Along most of the South African coastline there are two predominant winds, anticyclonic and cyclonic, which blow from opposing quarters. Due to the counter reshaping by these two winds and modification by effective winds from any other direction (eg Berg Winds, land breeze, sea breeze) the nett one-way movement of reversing transverse dunes is exceedingly slow.

However, nett sand movement in a particular direction depends on the configuration of the coast and its greater exposure to one wind, as well as to the occurrence of consecutive years with a greater frequency of strong winds from a single quarter. Under these conditions a bare reversing dune system is extremely inimicable to plant colonization and growth is rarely established except where plants may gain a foothold in hollows or slacks.

The bare reversing dunes along the South African coastline appear to have been initiated by a combination of natural and human agencies. The natural causes include truncation by a rising sea level, undercutting and slumping of bush-covered dunes by waves, and donga gullying by flood rains.

Human activities include path-making, bush clearing, living and working sites, and increased incidence of fire which all date back to Stone Age times. The added impact of pastoralists and their stock since 2 000 years ago (Inskeep 1978), and more recently cultivation, roads, sand quarrying and mining. All these factors locally damaged or opened up the dune-binding vegetation exposing bare sand to wind erosion.

On the coast the only surface freshwater available is often that in dune slacks. This may be in areas where low gradient rivers are contaminated by high tidal reach or in coast limestone areas with karst features. In these situations it is probable that game herd concentrations, man and later pastoralist stock herds, were a major cause and accelerator factor in the development of bare dunefields, as evinced by the abundance of game, stock and human remains in the Algoa Sand Sea for example. As shown by the wooded remnants, the Algoa dunefield was once composed of massive compound, bush-covered, ascending parabolic dunes similar to those abutting Groenvlei today.

In contrast, most of the bare dunes landwards of the frontal dune zone appear to have been initiated solely by human and stock activities within the last 50 to 150 years (Walsh 1968). These are apparently the most troublesome dunes to reclaim, though wind velocities are less than on the immediate coast, as the sands are drier and more easily blown, and plant growth is under greater stress (Walsh 1968).

4.4.2 Trends of parabolic blowouts in vegetated dunes

As parabolic dunes are unidirectional, formed by winds from a single quarter, sufficient periods of quiescence occur for plant growth on the advancing nose and lateral slopes to keep pace with sand movement. Most ascending parabolic dunes of the south and eastern coasts advance relatively slowly. The migrating hairpin parabolic type typical of the west coast (eg Bitter-Spoeg dunefields) and some headlands on the south coast (eg Cape St Francis) appear to have the fastest rate of advance of all dunes in South Africa. Parabolic dunes exhibit even-aged sets of blowouts originating from undercutting and slumping erosion of the frontal dune base by exceptionally high storm seas which occur at irregular intervals.

Younger sets are smaller in size and superimpose the older and larger plant-stabilized sets (Plates 29, 31, 108). Parabolic dunes develop through a series of stages from active blowouts to an ascending or migrating (hairpin type) mature stage, to a self-arresting sinescent or stable phase. This stage is reached either where the ascending nose and slope of the blowout becomes so steep that only gale force winds are effective and/or where a high water-table or hard layer is reached - both conditions allowing for successful plant colonization (Plates 107, 109, 110).

The stable phase can be destabilized by any disturbance which bares the plant cover. A major natural perturbation includes the die-back of plants along dune crests on the drier coasts from consecutive years of extreme drought resulting in sand remobilization.

The natural trend of blowout colonization by plants in many eastern coast parabolic dunefields was enhanced by the Forestry Department through the simple expedient of removing all human and stock activity from the coast dune cordon.

On the east Cape coast between the Tshalumna and Kiwane River mouths a long parabolic blowout became totally self-vegetated over a 20 year period merely from the protection afforded by a fence along the landward base of the dune range. Similar recovery of vegetation occurred on high forested parabolic dunes, cut to pieces by clearing for shifting cultivation, when Forestry declared the Zululand and east Cape coast dunes a forest reserve (Plate 107). The secondary succession back towards forest on the Cape St Lucia sector of the above area is detailed by Weisser (1978a,b) and Weisser and Marques (1979).

4.5 DUNE FORM SUCCESSION

The relationship between sand supply, wind velocity and vegetation in the formation of families of dune types is illustrated by Figure 27 (Hack 1941; McKee 1979).

4.5.1 Bare dune sequences

In bare dunefields where there is no influence from plant growth on dune development the interaction of sand supply and wind velocity relates to the position of the sand body in the windfield and to firmness of substrate. The sands of dunes and dunefields pass through four major zones of influence on the coast: (1) the sand source area in the upwind position originating at the seashore, (2) zone of sand translocation from the source to the main dune body, (3) the sand accumulating zone in a mid-downwind position, and (4) a sand dissipating or attenuation zone where the windfield either loses its effective dune-forming velocity, where winds are more variable or change their angle of incidence (eg in the Zone IV sector of the Namib Sand Sea - Harmse 1982), in wind shadow sites or where dunes become so steep that only strong to gale force winds are effective in carrying the sand over the crest (eg east coast parabolic blowouts).

The typical sequence in bare dunes is from isolated barchans in Zone II to linked barchans or linear dunes on firm substrates which form interdune flats or streets, to transverse types over loose sand. At the downwind end in Zone IV the succession tails off into a repeat of isolated barchans again. This sequence is a function of increasing then decreasing sand abundance and its potential transport (Mabbutt 1977; McKee 1979). A similar sequence is shown on the microscale by sand ripples on a firm substrate (Plate 4). Linear dunes on the microscale have not been encountered on the coast.

The development of transverse dune types in response to the exposure of a superabundance of sand is well illustrated where parabolic dunes are devegetated. This reverse successional sequence from vegetated parabolic dunes to bare transverse dunes of various kinds is typical on the coast wherever the dune plant cover is bared by erosion or human activities. Once established reversing dunes inhibit plant colonization and growth and hence the recurrence of parabolic dunes. This can only take place when consecutive periods of high rainfall enables a plant cover to develop, and perhaps if the sand supply is reduced.

4.5.2 Vegetated dune sequences

The form of vegetated dunes is changed in a number of ways by the combined interaction of external and internal processes. These include A. progressive or advance succession, B. retrogressive or reverse succession, C. bisection of dune headlands, D. surface mass slides and dongas, E. deep weathering gravity slumps and ravines, and F. cementation of dunes.

The first three involve waves, wind, rain and any other actions which bare dunes of the plant cover, even temporarily, such as fire (eg Agulhas-Renosterkop dunes), trampling and clearing. Slope failure adjustments of sand beyond its angle of repose from basal undercutting by waves or wind scour on the one hand, and oversteepening of wetted slipfaces and gravity slides on the other are continuing changes. But it is in D and E, however, that gravity movements reach their most dramatic expression where it combines with (i) either excessive surface runoff, or deep surface wetting, and (ii) with deep core wetting of kaolinized dunes.

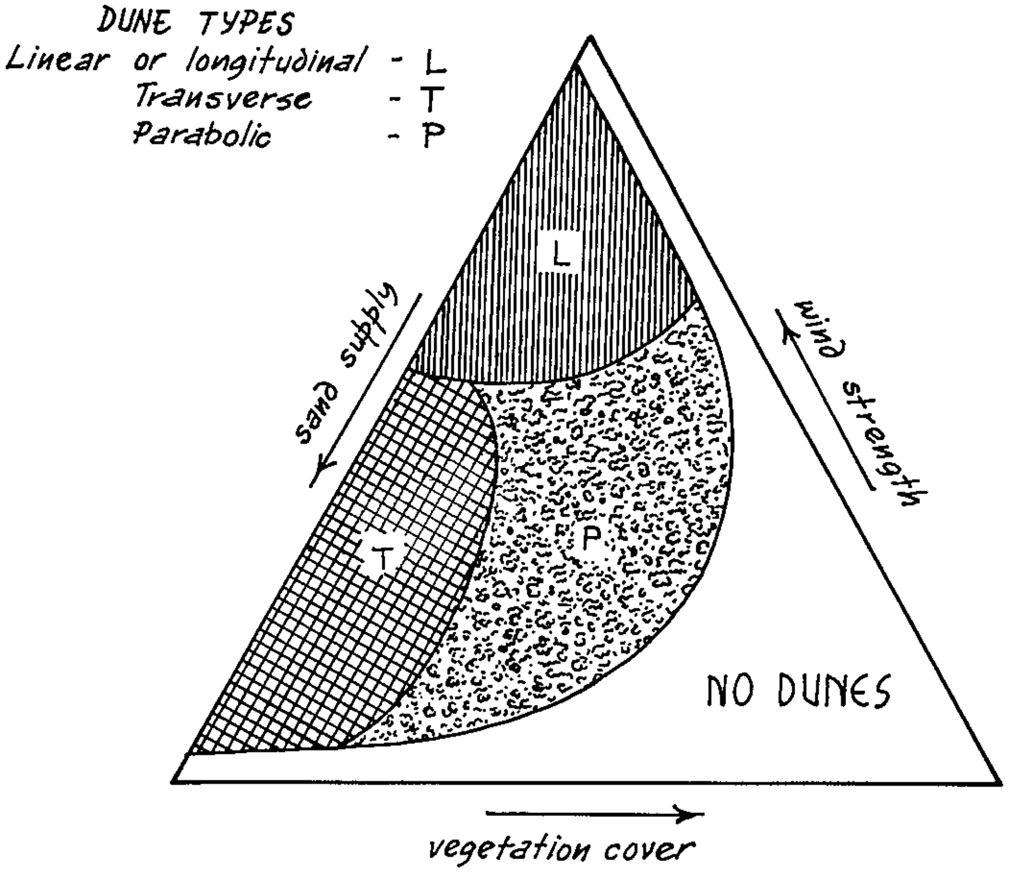


Figure 27. Dune form dynamics and succession (after Hack 1941). Figure shows relaionships between sand supply, wind velocity and vegetation in the formation of various dune types on the Great Plains of the United States of America.

A. Advance succession.

The typical sequence of plant succession on coast dunes is described in 3.4.1 B above. The development of wind and plant-formed dunes originates on the backbeach as isolated mounds of sand building up around individual pioneer strand plants. These eventually coalesce by lateral expansion and upward growth with the continued accumulation of sand, and deflation hollows are scoured out between plant growth patches. In this way a definite hummock and hollow relief is developed. Wherever openings or weak points occur at right angles to the shore, from high swash reach or along the junctions of adjacent plant clumps, onshore winds breach larger openings and initiate blowouts (Plates 23, 104). As these grow landward they superpose and bury the hummock dunes in their path and the dune plants grow up through the advancing slipfaces of the leading nose and trailing edges.

These transgressive dunes build upwards and forwards burying older wooded backdune ridges and continue landwards where strong winds from the right quarter have a high frequency and if there is an abundance of sand. Where storm wave erosion or a slowly rising sea level repeatedly cliffs the frontal dunes new sets of parabolic dunes are formed on the fresh exposures and these override the older sets (Plates 29, 104, 108).

Each time the woody vegetation covering previous dunes is partially buried, that at the edges grows up through the slipfaces of the superposing dunes. The occurrence of active ascending parabolic blowouts or of precipitation dunes advancing mainly by upward growth burying vegetated dunes on a broad front parallel to the beach, are thus indicative of continued dune building and not signs of erosion as may commonly be thought. Erosion of vegetated dunes is indicated by the change from upward forward transgressive growth to a purely forward migratory movement of sand drift, and where vegetated dunes are increasingly bared of their plant cover.

If deflation at the source of parabolic blowouts exposes a firm substrate or high water-table the blowout may either become (1) less active and in time completely stabilized by plant colonization, or (2) begin an erosive phase of incision from wind scour with the nose migrating horizontally forwards transforming an ascending parabolic into a hairpin dune.

In the forward migration of hairpin dunes lateral trailing slipfaces, hindered by plant growth, and with steep inner wind-scoured slopes, are left as paired parallel ridges. Here plant colonization and succession is up the lee slopes and from the floor of the trough near the beach advancing landwards towards the windward slope of the nose. The opposite zonation and succession results where pioneer and other seral communities colonize from landward mobile dunes back seawards where mature dune forest remains (Plate 71).

While transgressive dune building processes are continuing, or have become stabilized by plant colonization, vegetated dunes are subjected to ongoing erosion and internal weathering processes which result in further changes of form.

B. Reverse succession.

In vegetated coast dune systems reverse succession is most commonly initiated from cliffing of foredunes by wave action setting in train an ongoing phase of slope recession and exposure of bare sand to the wind. This involves the erosion, fragmentation and contraction of the plant cover exposing increasing areas of bare sand which supplies new transgressive blowouts and/or is transformed into transverse dunes (Plates 9-13, 25, 30, 37, 89, 94, 100A, 106).

If parabolic blowouts predominate, these may become stabilized when a deflation base level is reached, or by consecutive years of high rainfall when plant growth expansion exceeds sand drift (Plate 109, 110). Where bare reversing dunes are the predominant replacement of wooded parabolic dunes, however, this duneform will persist over the long term as they are continually shifted by any wind thus inhibiting plant colonization or its successful establishment. In this way sand seas are formed and maintained under relatively high rainfall conditions (Plate 5).

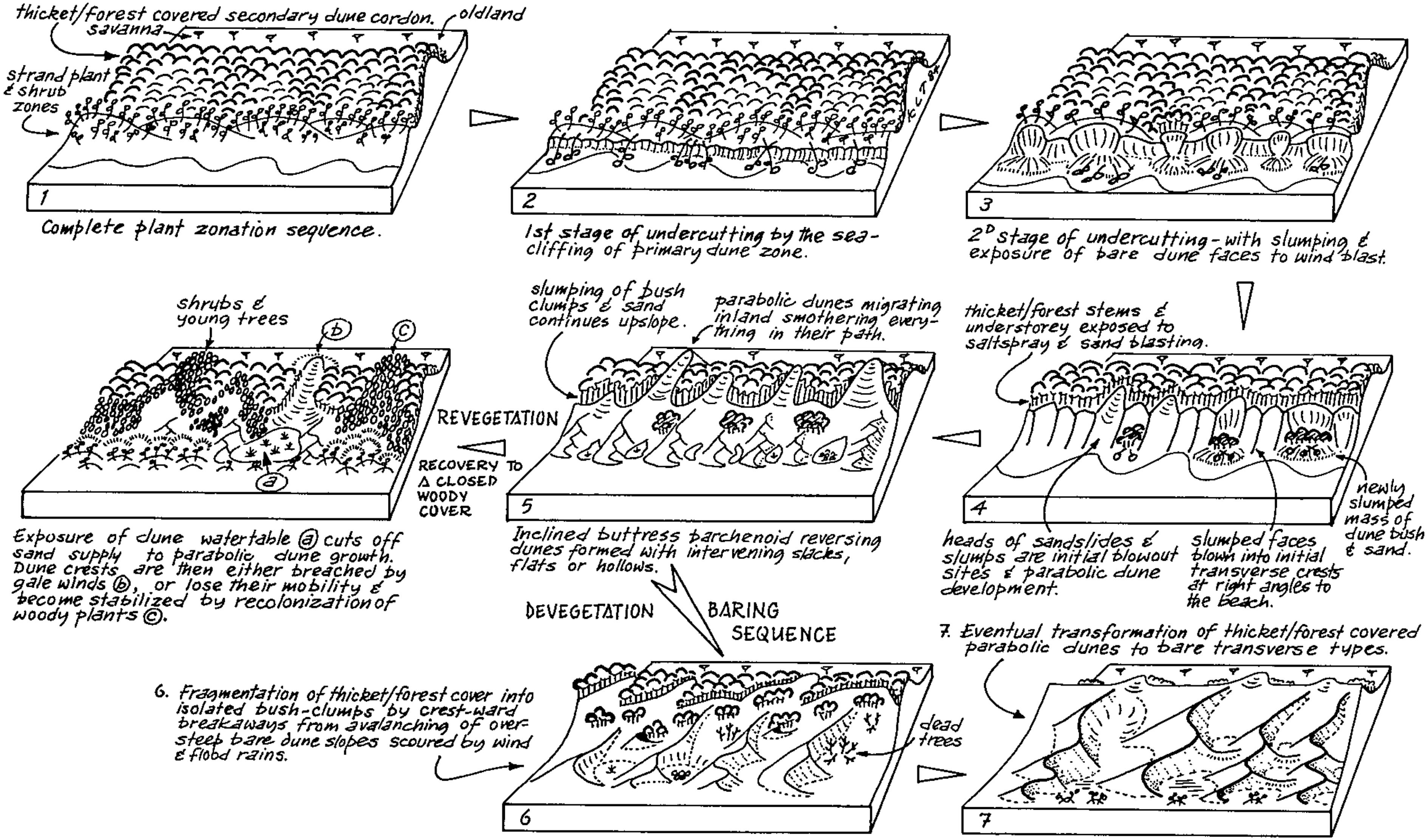


FIG 28. REVERSE & RE-COLONIZATION SUCCESSION ON FORESTED EASTERN COAST DUNES.

A significant moisture balance pattern is exhibited by ephemeral plant growth on desert dunes in the Namib after a rare rain has fallen. The most dense growth is in hollows and troughs with a more sparse cover up dune slopes with the crests left bare. This extreme dryness of crest sites is also inimicable to thicket/forest on the higher rainfall south and south-east coast dunes where they are colonized by low fynbos heath vegetation.

Hence outside of desert areas only a changed rainfall regime with consecutive years of higher rainfall or better year-round distribution would enable plant colonization of bare transverse dunes to occur. The crests would probably remain bare and provide initial sites for blowouts resulting in a similar dune topography to that in the Agulhas-Renosterkop area.

The latter dunes are a unique dune type on the subcontinent's coast where blowout hollows are initiated on dune crests temporarily bared of vegetation by fires. With each reversal of relief the two sides of the blowout become the new high points exposed to the wind, and with the recurrence of fire, two further blowout hollows are initiated, probably by gale winds, and so on. Where the hollows are excavated by deflation to below effective wind scour level they are colonized by plant growth. This hollow and hummock dune relief is superposed over older vegetated hairpin and transverse dune forms (Plates 41, 84-86).

The reverse successionary sequences in vegetated dunes as drawn from field examples is illustrated in Figure 28.

C. Bisection of dune headlands.

On the southern sector of the east coast between Pebane (17° S) and Mtunzini (29° S) the country rock is buried deeply beneath Late Tertiary to Recent sediments. Some of these are cemented but the greater part are unconsolidated. The only outcrops of rock on the coast are exposures of dune rock and beach rock south of Bazaruto which typically form points subtending half-heart bays. As these jut obliquely at about 65° from the shoreline in a north-east direction, the opposing winds have built bipolar ascending parabolic dunes against each other to form high, steeply rounded, forested dune headlands overlying the dune rock exposed at the shore.

The rock outcrops act as pivots diffracting the predominant south-south-east swell. This sets up predominant surf zone currents which diverge against the long curve of the bay and converge in the corner or along the short curve to form a rip current. The opposing easterly wind and swells set up contrasting longshore currents along both sides of the bay which converge again in the corner to form an outgoing rip current (Tinley 1981). The alternations of these surf zone currents are responsible for the changes in supply and availability of sand on the backbeach for onshore winds to build dunes. Either sand accumulates in the corner of the bay and the long curve is cut back and cliffed by waves or the opposite condition results, each affecting when and where dunes are built or eroded (Figure 29).

These features naturally are common to all half-heart bays. On dune coasts, however, these current, sediment and windfield relationships are completely altered by shore straightening processes when the dune headland is eroded and the dune rock outcrop becomes separated from the mainland.

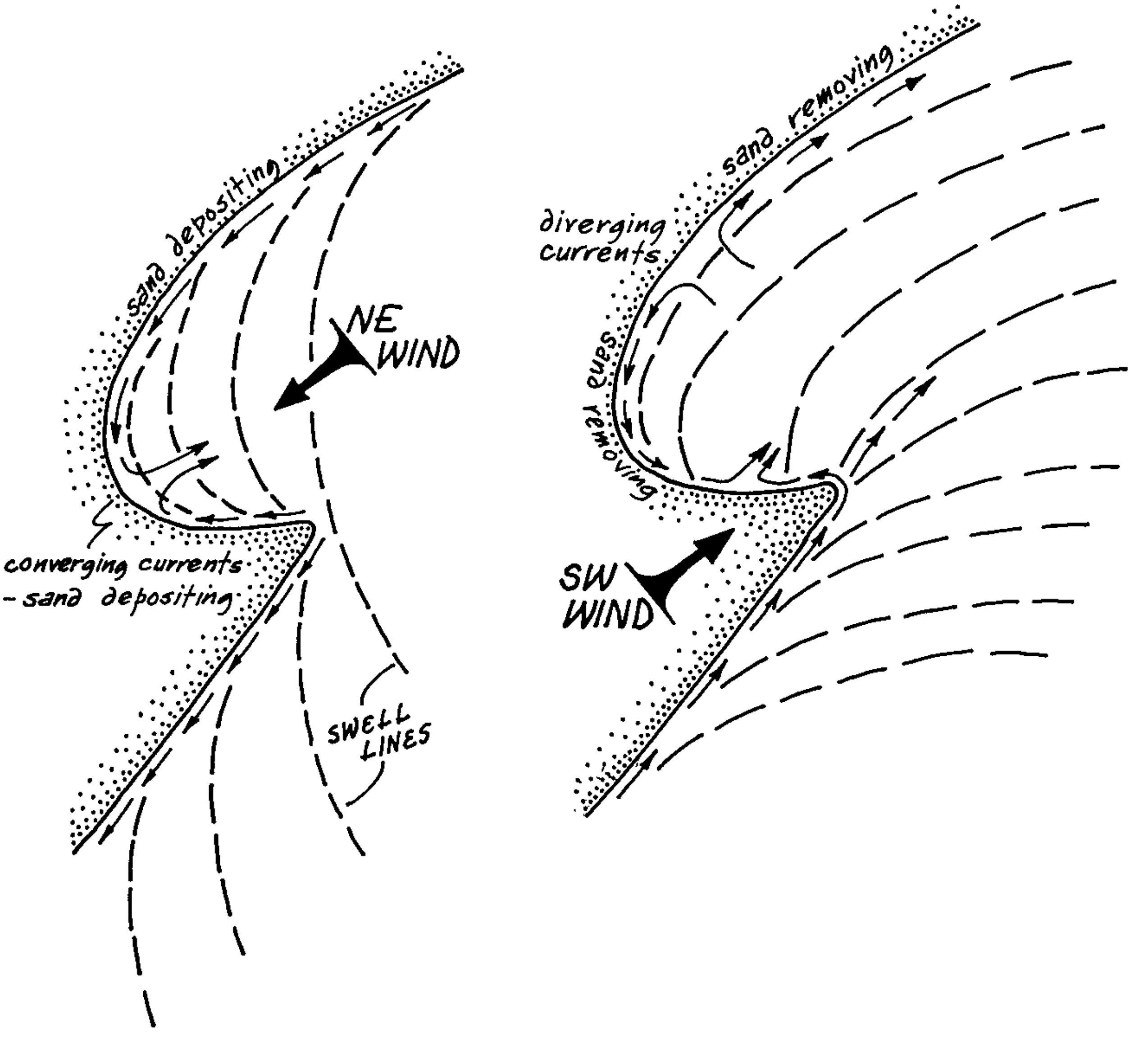


Figure 29. Contrasting swell refraction patterns and surf zone longshore currents generated by the opposing predominant winds in half-heart bays on eastern coasts (Tinley 1981).

The forested dune headland becomes bared of its forest cover in several ways. It is either eroded at the base by wave action causing slumping and baring of the dune face, or is damaged by hurricane winds and torrential rains, or has been used as a shortcut footpath to the other side since Stone Age times by shellfish gatherers where the dune rock promontory was within high tide reach or abutted deepwater.

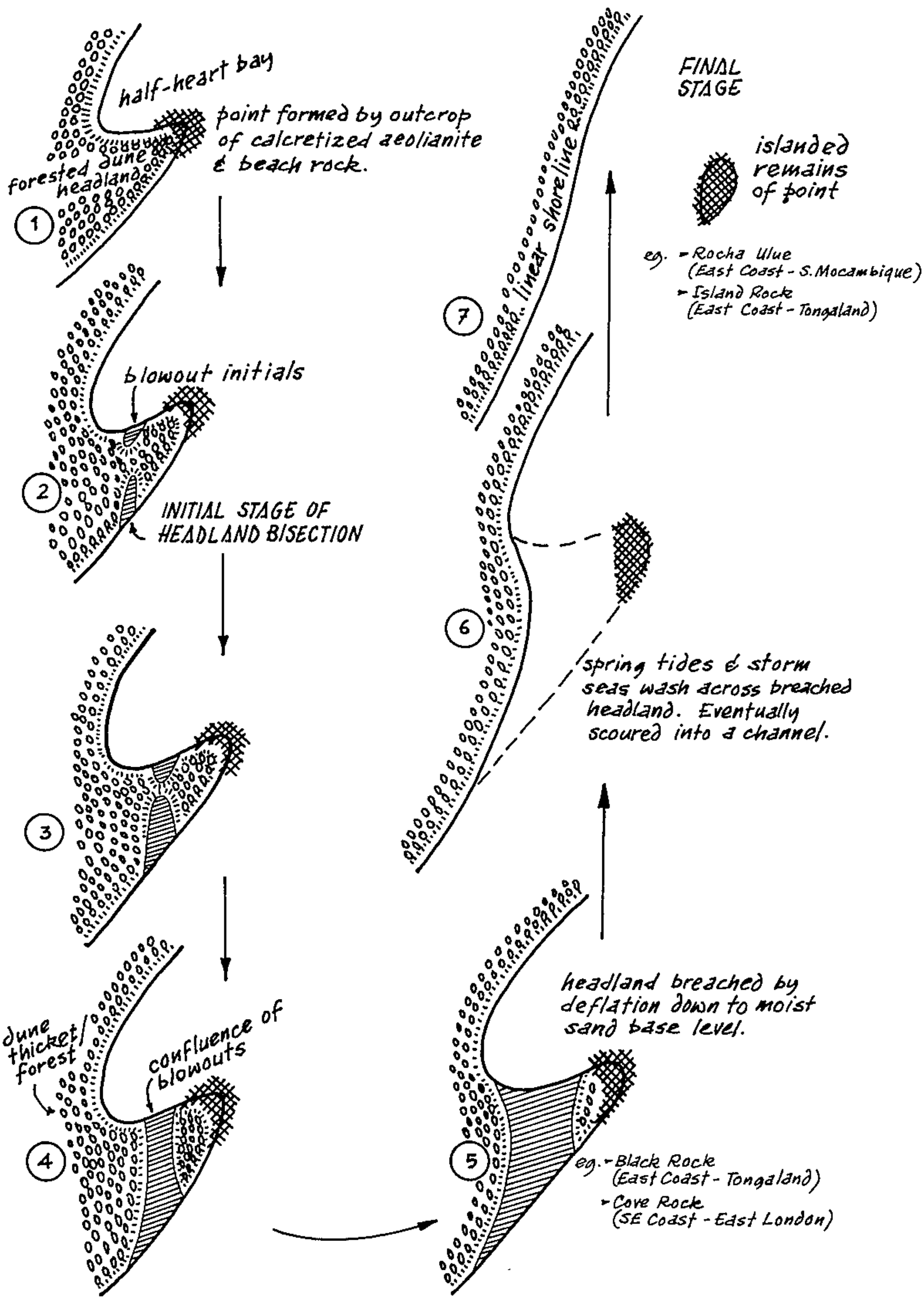


Figure 30. Loss of half-heart bay form and truncation of dunefields from bisection of forested dune headlands and coast straightening processes.

One or all of these resulted in breaching of the headland along the bared strip by wind and rainwash incising the dune down to beach level. Bisection of the headland is completed when high tides begin to wash through the gap scouring a channel. In this way the headland becomes an island or offshore reef, and the half-heart bay is worn away and replaced by a linear shoreline with a faint indent marking its original position for a while. In other sites the sea does not immediately separate the point after the dunes have been eroded away and it remains linked by broad areas of windswept sand flats and small bare transverse dunes (Figure 30).

All stages of these coastform replacement sequences and the effects they have on vegetated dunes is exemplified by four points on the Tongaland Coast. Stage 1 by the initial blowout scar on the south slope of the remnant forested headland stub at Mabibi, Stage 2 at Black Rock, Stage 3 at Island Rock, and the intermediate bare dune and sand flats stage at Lala Neck and other points (Plates 113, 114).

D. Surface mass slides and gullying.

On calcareous dunes with water repellent sands there are two major ways in which wooded dunes are eroded, in addition to the continual downslope surface creep. These are by sand slides of forest patches on steep slopes and donga gully formation (Plate 118).

Where seaward slopes are undercut by wave action, slumps of the vegetation cover and the sand profile bound by its roots occur (Plate 120). This exposes steep bare slopes basally to further erosion by waves and wind scour.

Flood rains, after previous light rains overcome the repellency of the topsoil, wet the profile through to about three metres depth. Above steep slopes no longer held in place basally by plant cover, large areas of forested dune break away with the added weight of rainwater. The overlying compacted wet sand skids on the underlying dry sand and comes to rest some 10 m or more downslope, held across the new slipscar opening by roots and lianas as taught as guitar strings. The plants continue to grow in the slide clump though the canopy trees usually die back (Plates 115-117).

Wind scour removes the displaced sand below the slide clump and re-establishes the steep bare dune slope. This process is repeated at intervals fragmenting forested seaward slopes into relict slide clumps with increasingly larger areas of steep bare dune slopes (Figure 31). Parabolic blowouts are initiated wherever breaks reach a dune crest (Figure 28).

Heavy rains immediately following a dry spell with no previous wetting results in massive runoff from the water repellent surfaces of wooded dunes and cause donga incision of slopes with sandfans at their base. The gully is incised at the same angle as the slope, unlike those cut into oxidized dunes as noted below (Plate 118).

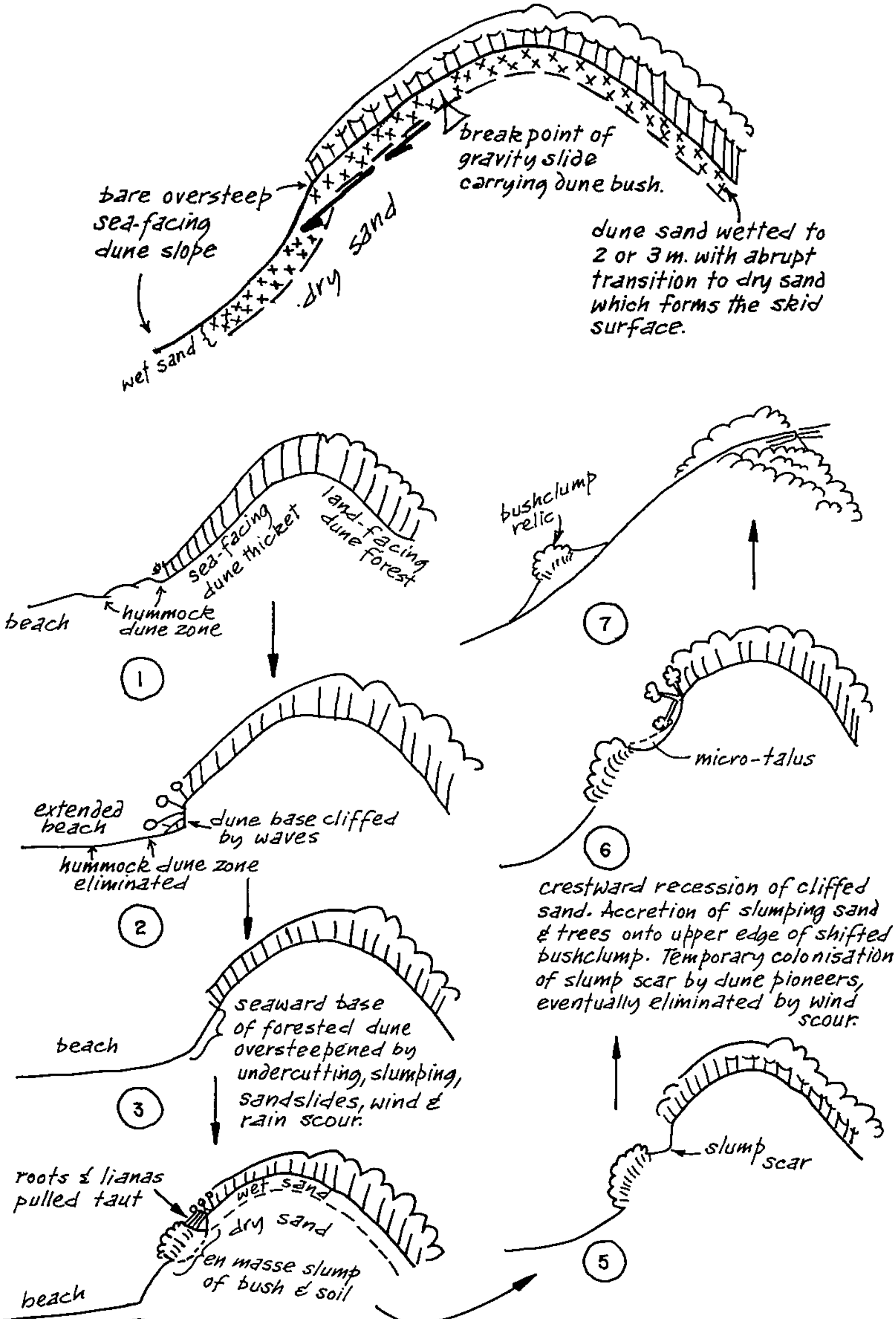


FIG 31. GRAVITY SLIDE OF BUSHCLUMPS ON STEEP SLOPES OF FORESTED PARABOLIC DUNE CORDONS ON EASTERN COASTS (see Plates 115 – 117).

The water absorbing subsoil sands are exposed in the gully and at its head, and these remain bare with a few low growing plants colonizing the new surfaces. On the south-east and south coasts these are typically fynbos heath plants. Once formed, the water from heavy downpours is directed into these gullies though their erosion is slowed by quick absorption and the trees and shrubs that have toppled into the gully from undermining.

Where the donga opening faces a prevailing wind they are either invaded by shrubs such as bietou where the slope angle has been flattened, or become fresh sites for blowout development. Similar processes are triggered by quarrying sand from the base of vegetated dunes on the landward side.

E. Deep weathering slumps and ravines.

Though related, quite different landforms are produced by gravity slope failure on deeply weathered ferruginized dunes with a kaolin clay layer. Such dunes abut the seashore only at a few sites on eastern coasts. For example on either side of Richards Bay, on several parts of the adjacent coast between the Tugela Mouth to south of Durban (eg near the Mvoti River mouth), on the Tongaland Coast at Ochre Hill, and on several parts of the Mocambique coast between the Limpopo River mouth and Bazaruto.

Wetting of the deep white or pallid kaolin layer by rain percolation and/or from lateral pipe drainage acts as a skid under the main body of the dune where its front is unstable. The result is cavitational slumping forming either a steep basin-shaped scar with nearly flat floors (Plates 121-124) or deep steep-sided ravines much like that left by the removal of a cake slice (Plate 125). The floors of these incisions are marshy as the perched water-table of the pallid zone is exposed at the surface. These become stabilized by the growth of herbaceous vlei vegetation of reeds and grasses and/or with swamp forest trees (Plate 126). At the head of the ravine or donga one or more sinkholes or incipient depressions often occur above the nickpoint indicating the direction of underground pipe drainage (Figure 32).

Amphitheatre-shaped erosion cirques (Buckle 1978) and vertical sided ravines are typical landforms developed on massive duplex sediments where sands overlie clays and on deeply weathered lateritic soils in which there is lateral underground drainage associated with slope instability.

F. Cementation of dunes.

Lithification of dune cores by lime and later by iron in the upper horizons controls subsequent coastform development including the configuration of the coastline. The diversity of landforms derived from lithified dunes and the geomorphic influences they exercise are noted in 2.3.5 above.

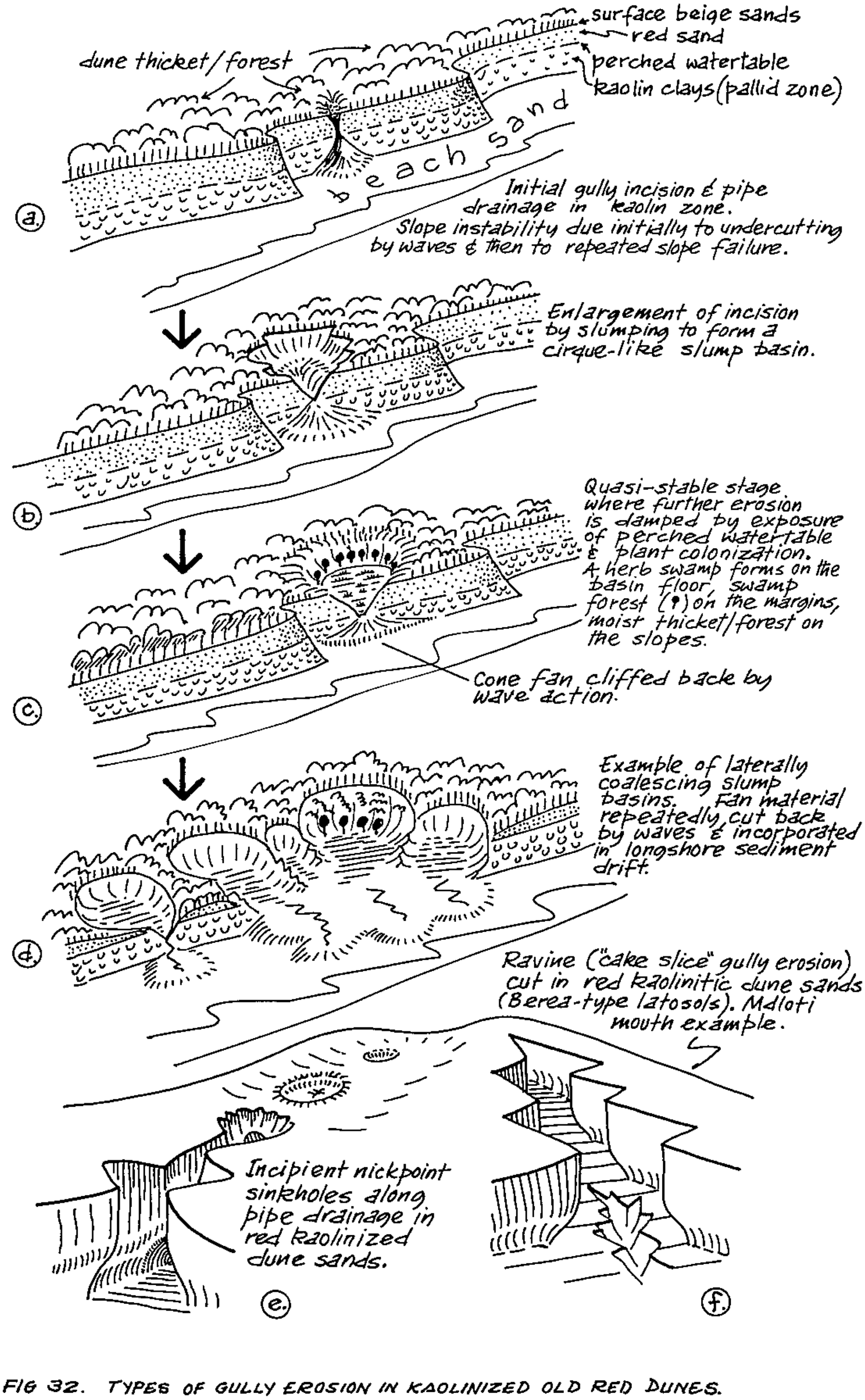


FIG 32. TYPES OF GULLY EROSION IN KAOLINIZED OLD RED DUNES.

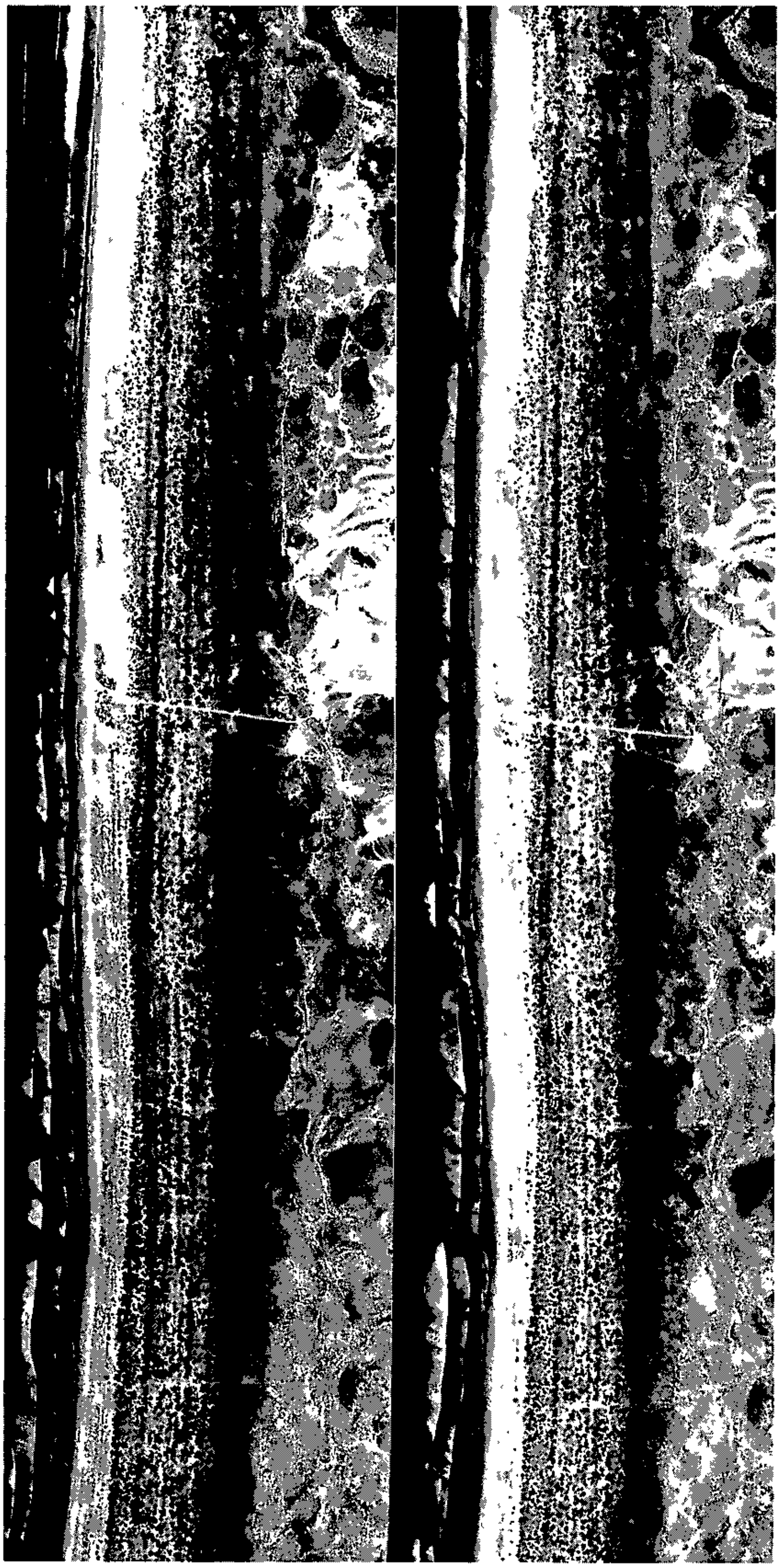
a-d gully cirque development on the East Coast near Richards Bay.
e-f ravine erosion with pipe drainage & sinkhole initials.

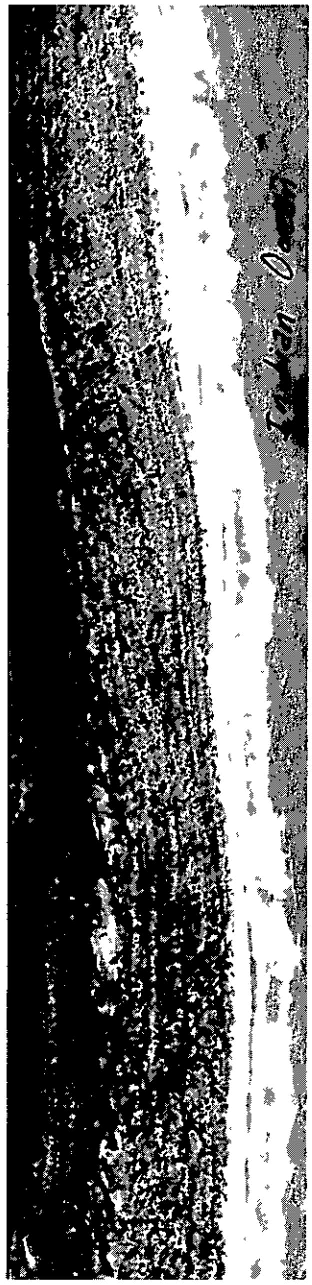
PLATE 100. Examples of the only two prograding shoreline areas on the South African coast.

(A) Dwarskersbos sector of the west coast between Rocher Pan and the Berg River mouth.

(B) Mtunzini sector of the eastern coast between the Tugela and Mlalazi River mouths. Parallel beach ridges with incipient or old transgressive blowouts, and increasing size and density of plant growth from the backbeach landwards (see Figure 33 inset).

(Airphotography of 1977 reproduced under South African Government Printer Copyright Authority 7811 of 25.5.1982).





B. Mtunzini sector of the eastern coast.

A. Dwarskerskbos sector of west coast in St Helena Bay.

1 km

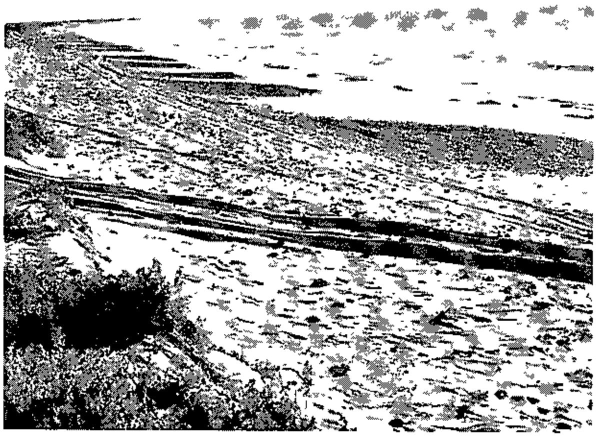


PLATE 101. Strongly developed beach cusps with intervening cusp horns and ridges normal to the shore composed of coarse shingle, with freshly cliffed foredune. Long curve of St Helena half-heart bay near Dwarskersbos, west coast.

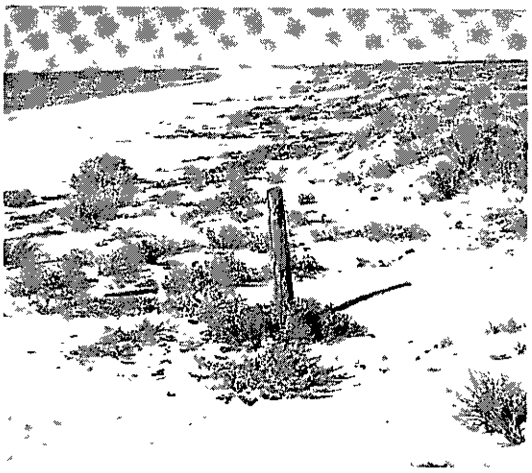


PLATE 102. Primary seaward advance of strand plant colonization of growing shoreline at Dwarskersbos is along the higher fingers of the cusp ridges.

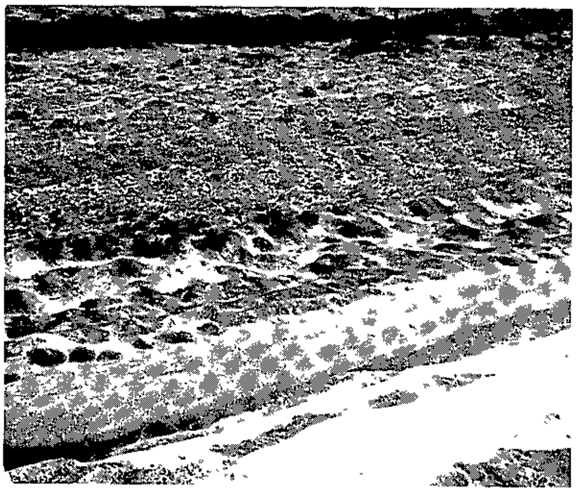


PLATE 103. Advancing parallel beach ridge hummocks on the Mtunzini sector of the south-east coast. Wind scour accentuating the dune relief between the third and fifth ridges.

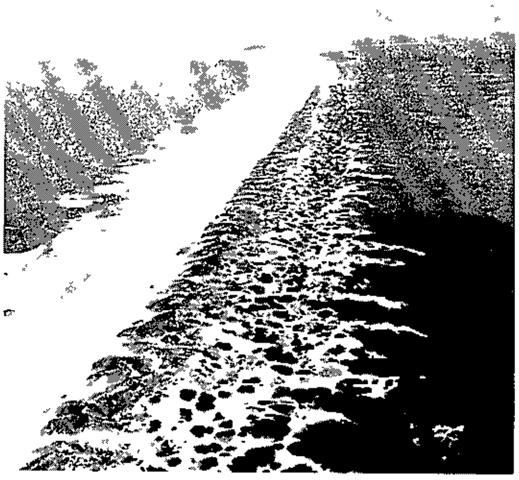


PLATE 104. Prograding coast immediately south of the Zambezi Delta mouth. Sand derived from actively retreating Cheringoma coast updrift in the distance. Delta floodplain grasslands of Marromen on the right.

PLATE 105. Catena sequence of forested dune ridges and vlei slack lines parallel to the coast. Mangrove forest on muck soils seawards (left) of the distributory. The only chernier ridge type on the subcontinent's coast. South sector of Zambezi Delta, Central Mocambique Coast.

PLATE 106. Dunefields west of the Sundays River mouth, Algoa Bay. Old vegetated hairpin parabolic dunes in the process of replacement by bare reversing barchanoid dune types. A relict drainage with seasonally wet pans occurs on the low plateau at the bottom of the stereo-pair of photographs. Dark coarse textured vegetation is thicket of two kinds, a) lower left, thicket on clayey calcrete soils (Valley Bushveld), b) upper right, dune thicket on calcareous sands, and between them, c) fine textured, pale, dune heath vegetation. (Airphotography of 1958 reproduced under South African Government Printer Copyright Authority 7811 of 25.5.1982).

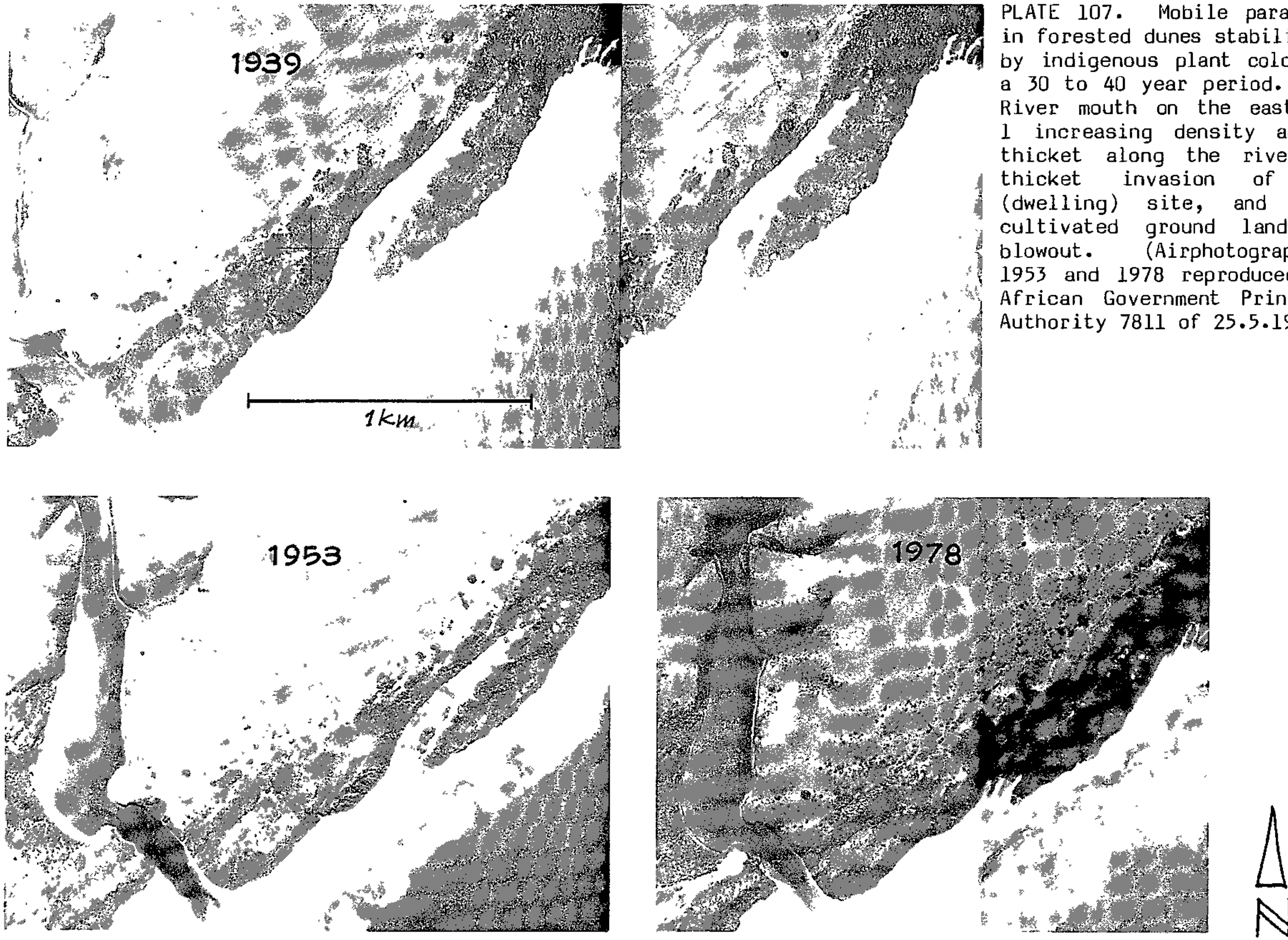


PLATE 107. Mobile parabolic blowout in forested dunes stabilized naturally by indigenous plant colonization over a 30 to 40 year period. Near Kiwane River mouth on the east Cape coast. 1 increasing density and spread of thicket along the river valley, 2. thicket invasion of old kraal (dwelling) site, and of abandoned cultivated ground landward of the blowout. (Airphotography of 1939, 1953 and 1978 reproduced under South African Government Printer Copyright Authority 7811 of 25.5.1982).

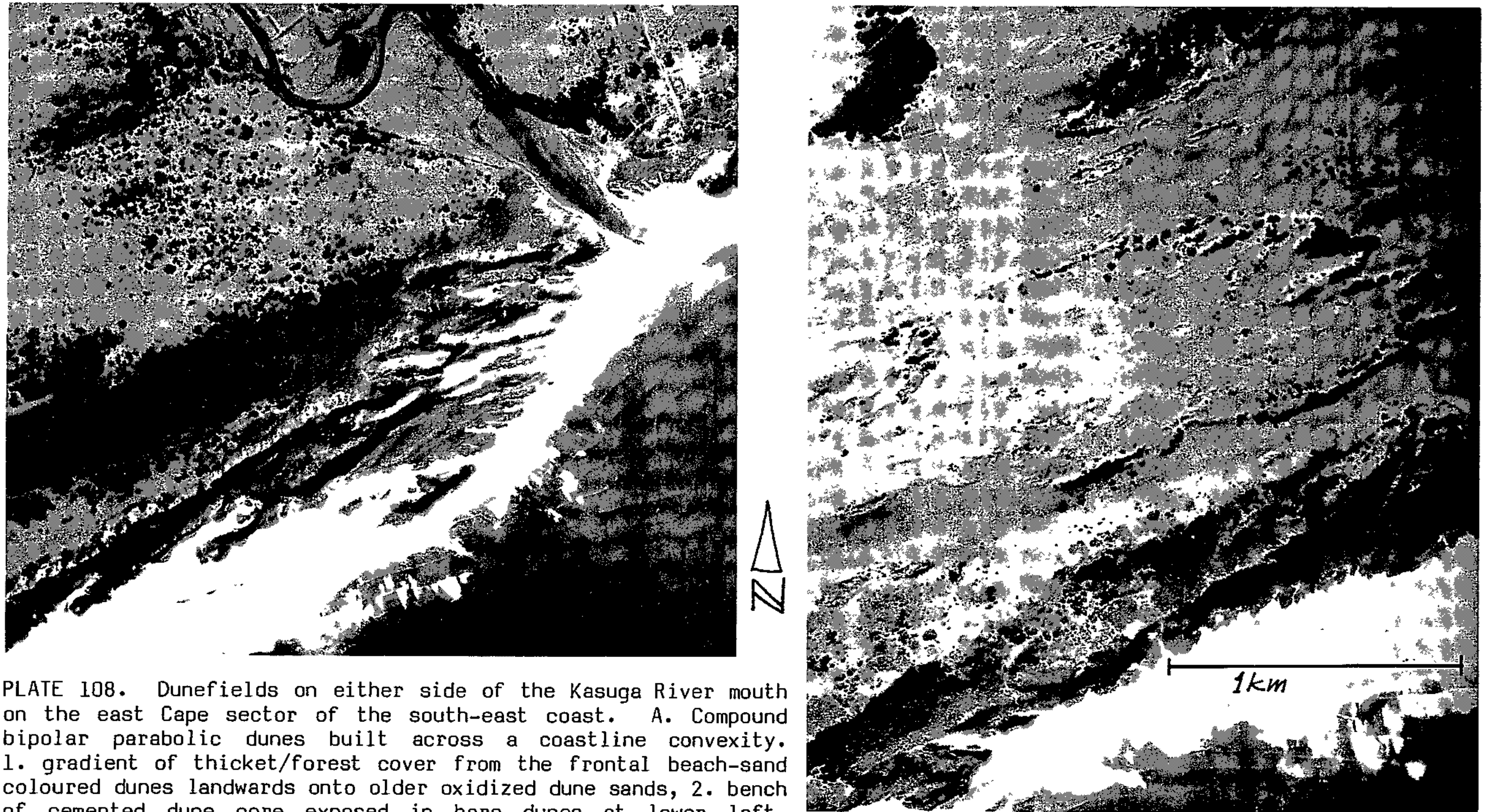


PLATE 108. Dunefields on either side of the Kasuga River mouth on the east Cape sector of the south-east coast. A. Compound bipolar parabolic dunes built across a coastline convexity. 1. gradient of thicket/forest cover from the frontal beach-sand coloured dunes landwards onto older oxidized dune sands, 2. bench of cemented dune core exposed in bare dunes at lower left, 3. alternating and clumped pattern of thicket/forest occurrence up the river valley, 4. radial pattern of blowouts from the coastal indent. B. Forested and eroded dune cordon with traces of old hairpin ridges and healed blowouts landwards on oxidized sands. North-east of Kasuga River mouth. (Airphotography of 1965 reproduced under South African Government Printer Copyright Authority 7811 of 25.5.1982).

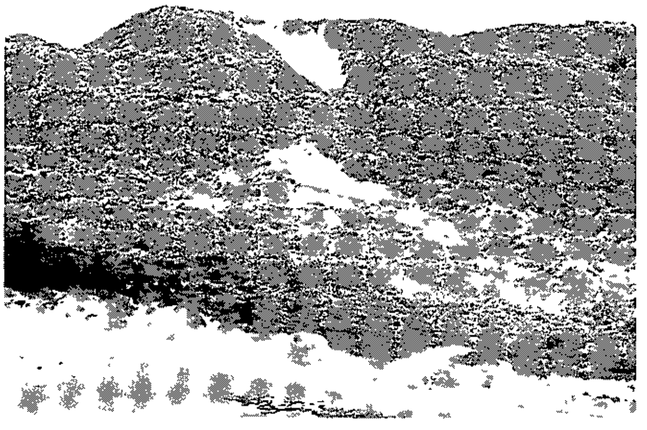


PLATE 109. Self-stabilization of a climbing parabolic blowout which was completely bare to the foredune line in 1965. St Mary's Hill, Lake St Lucia behind.

PLATE 110. Complete self-stabilization of high parabolic blowout by dune thicket. Ntabende Hill south of Sodwana, Tongaland Coast. Bangazi North Lake behind.

PLATE 111. Nahoon Estuary. A typical example of a sand-trap in longshore sediment transport formed by river mouths.

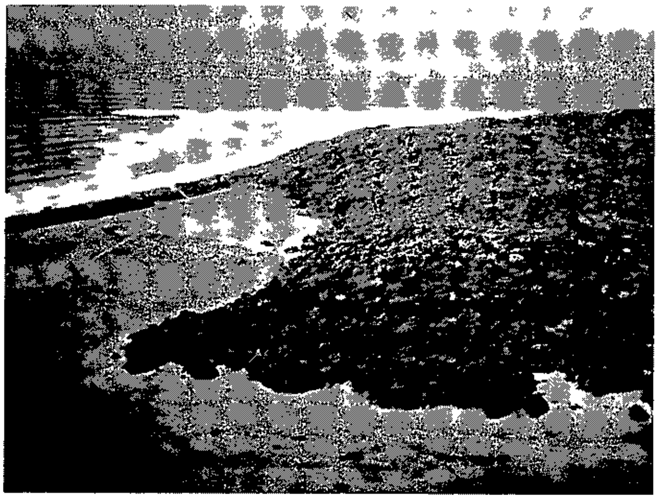


PLATE 112. Swell diffraction pattern in half-heart bays on the east coast. Swell approach from south-east onto fulcrum of Milibangalala Pt. Forested dune headland abutting high water-table grassland.

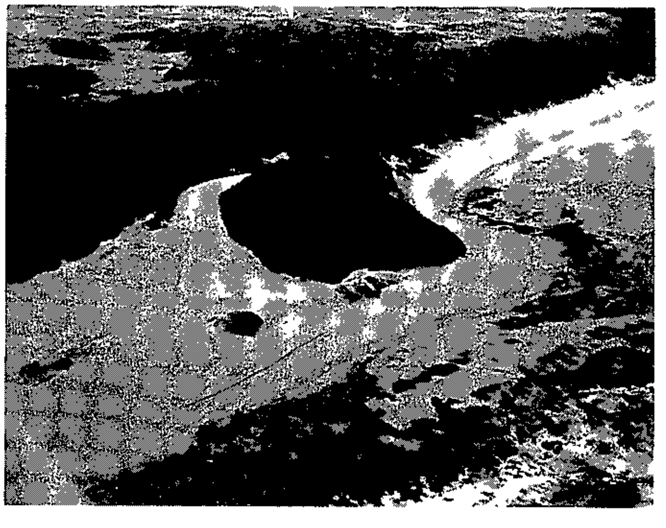


PLATE 113. Initial stage of forested dune headland bisection at Mabibi, Tongaland sector of east coast.

PLATE 114. Penultimate stage of dune headland bisection and shore straightening resulting in island stack or reef formation and loss of half-heart bay form. Black Rock, Tongaland.

PLATE 115. Massive surface slides of forested dune slopes after flood rains, leaving bare actuate scars subsequently enlarged by wind erosion. Nahoon-Quinera dune cordon, east Cape coast.

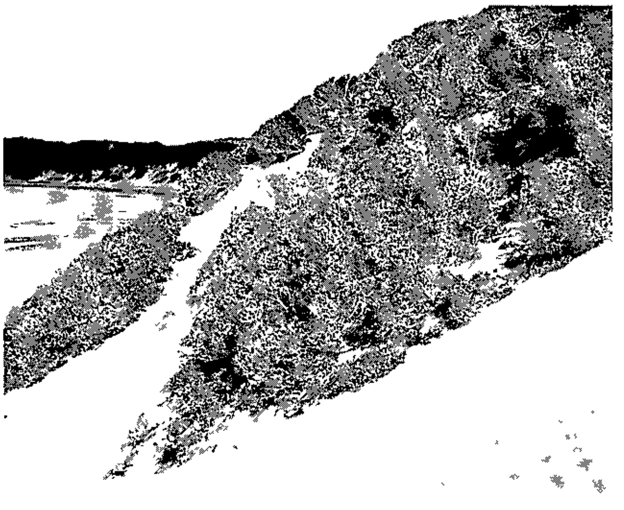


PLATE 116. Lateral view of slide patches and arcuate scars. Nahoon half-heart bay at left.

PLATE 117. Internal view of slide scar with colluvial infill.

PLATE 118. Surface gulley incision with basal sand fan, in forested dunes with water repellent surface sands. Nahoon Bay.

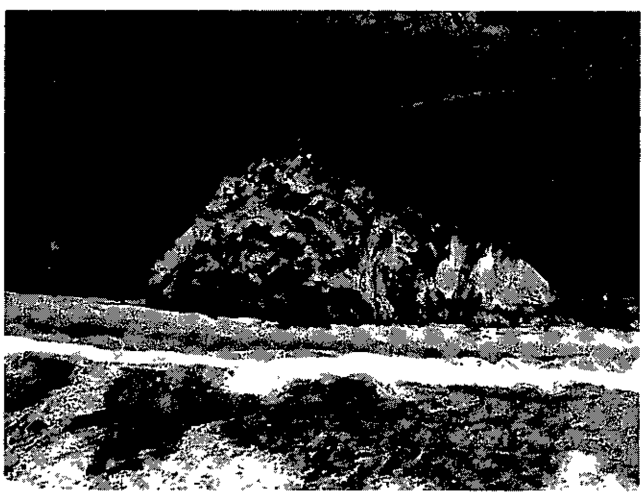


PLATE 119. Massive slumping of oxidized and kaolinized dunes near Richards Bay, east coast.

PLATE 120. Wave cliffed second foredune line covered in dense scrub-thicket. Note first strand creeper colonizing footslope of sand cliff. North of Banga Neck, Tongaland.

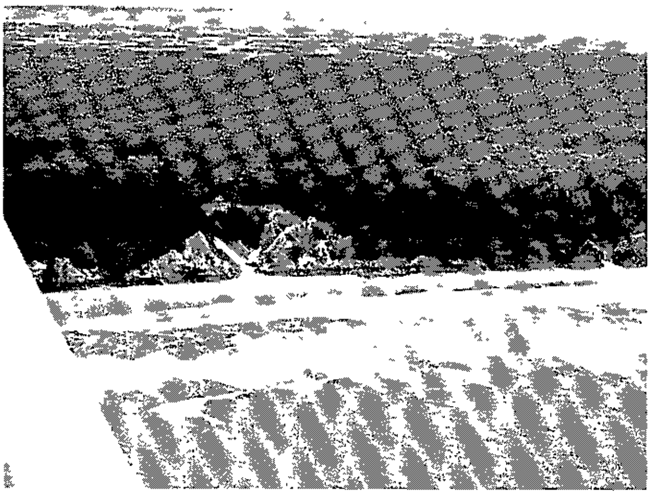


PLATE 121. Deep steep-walled ravine cut in kaolinized dunes north of Richards Bay. Initial stage of cirque formation.

PLATE 122. Stabilized cirque with continuing slumping on the flanks. Cirque slopes colonized by forest, and the floor by vlei grasses.

PLATE 123. View seawards of a cirque mouth undergoing a new phase of erosion by slope retreat from slumping.

PLATE 124. Completely stabilized cirque mouth viewed from the floor of the example shown in PLATE 122.

PLATE 125. Massive 'cake slice' ravine cut in red kaolinized dune and colonized by moist forest near Mvoti River mouth, Natal North Coast.

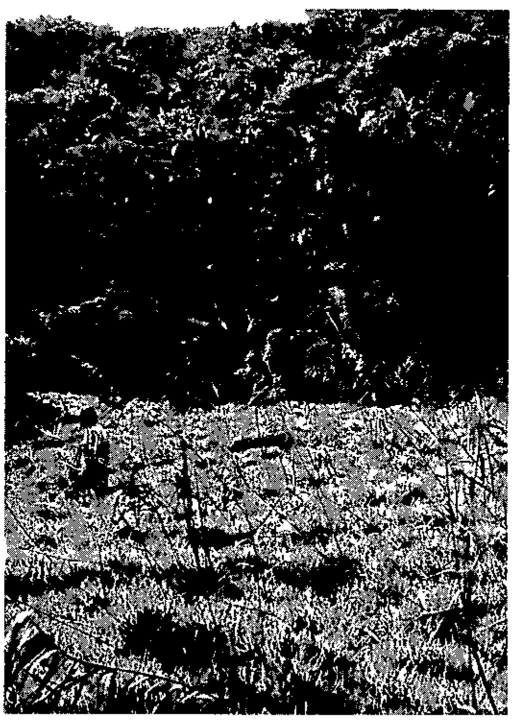


PLATE 126. View of forested cirque head, swamp forest trees along the edge of the vlei grass floor. Same site as PLATE 122.

5. PROTECTION AND UTILIZATION OF SOFT COASTS

The material for this chapter has been obtained through on-site field experience from around the southern African coastline. In addition to specific references mentioned in the text the formulation of the collected data has benefited from the findings of other coastal workers, including: Bayley (1960), Bascom (1964), Coaldrake and Beattie (1974), Cook and Doornkamp (1974), Bish et al (1975), Liddle (1975), Odum (1976), Godfrey (1978), Heydorn (1978), Leatherman and Godfrey (1979), Bickerton (1981), Fetherston (1982), and Warren and Mainguet (1982).

5.1 CHARACTERISTICS: NATURAL FEATURES AND PROCESSES

Soft coasts are those composed of unconsolidated sediments, contrasting with hard coasts which are rock-defended. Soft coasts comprise beaches, dunes, salt-marshes, vleis, deltas, lagoons and estuaries which occur in a large variety of forms, combinations and sequences. Sedimentary coastforms are all closely related by shared features and processes.

The three major properties which all soft coasts share are (1) their malleability, (2) their temporary stabilization and protection by plant growth, and (3) their hypersensitivity or vulnerability to disturbance (seemingly trivial features such as a wrongly sited footpath can have far reaching and large scale erosive effects).

Soft coasts, however, have a high durability due to the persistent coincidence of certain formative processes (eg a predominant swell and thus littoral drift direction) and to their unique property of malleability. "Beach and frontal dunes exist in a state of dynamic tension, continually shifting in response to waves, winds and tides, and continually adjusting back to equilibrium" (The Conservation Foundation 1980). Depending on the influences predominant at a given time a continuum of dynamic or everchanging equilibria results. In short, soft coasts are by definition in a constant state of flux.

The greater part of the South African seashore (more than 80%) is soft coast held in place by the tenuous stability imparted by plant growth. The chief coastform combination is that of sandy beaches and dunes, interrupted at varying intervals by rock-defended shorelines of various dimensions. The highest frequency of hard coast sectors occurs on the south-west and south coasts and again in the Transkei to south Natal area.

---

*The views expressed in this chapter are not necessarily those of the Committee for Nature Conservation Research or the CSIR.

It is on the soft coasts, especially in the bays and adjoining river mouths, "where human pressures are greatest, and increasing fastest, where exploitation is at a maximum and the potential for abuse is greatest" (Ritchie 1980). Thus the major conflicting problem on soft coasts is between increased access on the one hand and protection of their uniquely malleable features and specialized plant cover which is sensitive to damage by human usage on the other. The crux of the matter is thus one of resource protection versus increased human activity.

Sandy coasts are composed of four features closely related by the interchange of sand supply between each. These are (1) beaches, (2) frontal dunes, (3) inshore or surf zone sand bars and banks, and (4) river mouths and estuaries. Together these form a single geomorphic system referred to as the littoral active zone. The sand is shifted between these four, and any change in one of them entrains changes in the others. Hence sand should never be removed from the active zone unless continued erosion of the coast is acceptable. Permissible removal of sand should thus only be allowed from deeper water below 12 m or from the most landward margin of dunefields containing more than one cordon. A constantly rising sea level and/or a decreased volume of sand (eg trapped by dams on rivers) to sustain the littoral active zone results in the landward shift of the beach system and erosion of sand from the frontal dunes (The Conservation Foundation 1980).

Sand bars and banks of the inshore zone dissipate the main wave energy especially at low tides. Beaches dissipate wave, swash and uprush or surge energy at all tides, and frontal dunes dissipate storm wave energy at high tides and greatly reduce the direct impact of onshore gale winds. Beaches of all kinds are thus the main wave energy dissipating aprons on land margins in the absence of coral reefs.

Beaches also play a central role in the transport of sand as they are constantly adjusting their profile of equilibrium to the wave regime of the moment. Dunes are a bank of sand eroded back into circulation by the sea and used at times of sand shortage, and restored when an excess of sand occurs. Once sand is taken out of storage, however, it is usually returned to the shore downdrift of where it was removed. Hence sand must be continually added to the littoral active zone (Ritchie 1980; The Conservation Foundation 1980). Transfer of sand from dune to beach is thus a self-regulating form of coastal protection (Ritchie 1980). "In this way, dunes foster long-term stability of the shore-front by retarding beach recession" (The Conservation Foundation 1980).

Potentially some of the most destructive human activities therefore are those which damage or remove the frontal dunes and their stabilizing plant cover, particularly as frontal dunes are generally looked upon as being in the way of development. They are either levelled to build on, removed to obtain a view, or the sand is used as fill elsewhere, or for building construction. However, because of their malleability, dunes can be modified into any desired shape as is done by the elements, if the scar is immediately stabilized using interplanted brushwood mats. But because of the many subtle interactions and hidden repercussions involved with the changing mix of process relationships from place to place, such modifications should only be done with expert guidance on site.

Discontinuities in the nett equatorward longshore transport of sand around the coasts of South Africa, or sand loss from the sediment exchange in the active zone, occurs in several sites: (1) off headlands and points projecting into deepwater, (2) seawards into deepwater, (3) landwards of the first vegetated cordon or beyond 100 m of the backbeach where dunes migrate inland, (4) sand trapped in dams of seaward-flowing rivers changes the balance of sediment input from the land, and (5) temporary infill of inlets, estuaries and river mouths during dry periods by the tidal race of incoming springtides and by wave action. These latter sands are in temporary storage and are augmented and returned to the sea by river floods, but where dams damp flood scour, the infill is more permanent.

The present worldwide rise in sea level of 10 cm per 100 years (King CAM 1962), and particularly the varying weather sequences of gales, storm seas, flood and drought, are the chief natural causes constantly modifying soft coasts during a human life span (Bird 1969). For example, a 15 cm relative rise in sea level on a 1° sloped beach will result in the coast receding 100 times the increase in sea level ie 15 m landwards (The Conservation Foundation 1980).

The littoral active zone is tough and effective as long as it is free to alter within its natural boundaries ie where its malleability and plant fixing responses are unrestrained by the intrusion of immobile man-made structures, or damaged by excessive trampling and vehicle traffic. Furthermore such structures generally aggravate the erosional tendency or initiate new cut and fill processes. Any factor that could affect frontal dune and backshore stability is a threat to its value as a store of sand, a buffer resource and a unique habitat. Coastlines, particularly soft coasts, are a dynamic entity. What is modified at one point by artificial structures of any kind will, in time, entrain downdrift shoreline changes over a considerable area (Steers 1966, 1971; Clark 1977; Usher 1977; Ritchie 1980; The Conservation Foundation 1980).

The above synopsis has disclosed, briefly, the intrinsic vulnerability of unconsolidated soft coasts, and the implications of interfering with their natural processes of continual shoreline adjustments. In particular, with the sediment exchange relationships of the littoral active zone and the delicately poised plant cover stabilizing dunes.

The constant state of flux which characterizes the littoral active zone highlights and emphasizes one simple rule in the use of soft coasts. If you want to retain the diversity and viability of their unique resources and attractions and simultaneously protect developments from damage or destruction, do not allow any development within reach of the littoral active zone. In estuaries this means not only within reach of storm seas, equinox or normal high spring tides but also that of 50 or 100 year river flood levels. The worst flood damage on coasts occurs when high spring tides coincide with river floods.

Although there are features and processes common to all soft coasts, the ingredients are combined in a large variety of different ways from one site to another. Hence the first obligatory question that any developer must ask is for a specialist in the field of coast dynamics to identify the outer limits of the littoral active zone prevailing at each site, and in which direction if any, the tendency is for change.

5.2 USES, CONFLICTS AND SOLUTIONS

The main uses to which soft coasts have been put can be grouped under three main categories, (1) economic, (2) recreational, and (3) educational, cultural and scientific (Clark 1977; Usher 1977; van der Maarel 1979; Vogt 1979; Ritchie 1980).

In the first are forestry, agriculture (cash crops, pasture), residential, industrial, transport (harbours, roads, highways, bridges and railways, public access and parking lots), water extraction, sand and mineral extraction, military use and location of lighthouses and beacons, sewage, rubbish and waste disposal. The common error repeatedly made in the exploitation of soft coasts is the attempt to establish fixed immovable structures in a malleable or essentially "fluid" environment (Ritchie 1980).

The second category is self-explanatory and includes such activities as general access to the sea and estuaries, hiking, sand-skiing, access for hang-gliding from high dunes, major picnicking and trampling of backshore-frontal dune zones by holiday makers. In the third group are specially protected conservation areas of outstanding scenic, historic, cultural or ecological value. These include national parks, wilderness areas, floral reserves, ecological reserves, marine reserves, and nature reserves run by provincial, municipal or private authorities (refer to Figure 33).

The basic conflict between protection and increased access can only be resolved by coast resource allocation. Coasts should be divided into various land use or land capability categories and zoned according to the intrinsic properties of the various coast habitat combinations.

Certain uses on soft coasts are antagonistic (eg industry with recreation and extraction of potable water), whilst others are compatible (eg hiking and conservation). Whatever single or coexisting land uses are decided upon the protection of the backshore-frontal dune zones must remain as a coast buffer zone of countrywide importance.

Allocation of coastland, as elsewhere, should be guided by three criteria. Whether the virtues of the area are of national, regional or local asset. In the first category a national coast buffer strip should be recognized which would receive the same protection status as water catchments. A vital component of this coastland allocation is the identification of "free-use" or "sacrifice areas" (Vogt 1979). Ideally these should be confined to already degraded areas. For example, ideal sites for military use on the coast are those already reduced to a wasteland status by surface mining, as on parts of the Namaqualand Coast.

To enable responsible and objective land use allocation a data base for decision making must be derived from an inventory survey. On the one hand this would include a summary of natural features and processes, and the identification of unique elements requiring special protection. On the other, a summary of existing uses and of public requirements and ideas (Tinley 1971b; Usher 1977; van der Maarel 1979; Vogt 1979; Heydorn and Tinley 1980). The survey must also include a hazards or catastrophe identification which will indicate the least vulnerable sites (ie nodes of least change) for development, the landward boundary of the littoral active zone, and risks from slumping, landslips, and cave-ins in dune limestone areas (eg on the southern coast).

Where shorelines are receding, a recession line must be predicted by comparing oldest and most recent aerial photograph coverage to determine the setback distance required for any envisaged development (The Conservation Foundation 1980). In South Africa such a comparative analysis has so far only been done of a growing shoreline on the eastern coast at Mtunzini in Zululand (Weisser et al 1982).

An important concept in management planning is that of carrying capacity. Two definitions are applicable, one resource orientated and the other user orientated (quoted by Vogt 1979).

Ecological Carrying Capacity: "the amount of use that land can support over a long period without damage to the resource (measured in terms of use per time unit)".

Perceptual Carrying Capacity: "the level of use an area can withstand while providing a constant or sustained quality of recreation". 'As "quality" means different things to different people, the effects of crowding and of visitors on the site must also be measured'.

The key to resource protection is therefore more by indirect selective control of access than by policing on site. Particularly as the kinds and quality of facilities available are often as important as the array of coast resource values themselves. For example a carpark should be adjusted in size to fit the appropriate carrying capacity of a particular beach.

The distance of the main transport line of communication (eg main highway) along the coast from the seashore is the single most critical factor affecting all coast resources and the entrainment of developments. Where it is sited hard up against the coast, as on the Natal South Coast and many parts of the Cape coast, it is directly responsible for damaging coast resources and attractions, and for interfering with the natural processes and responses of coastal landform dynamics. In this position it promotes industrial spread to resort areas by confusing these traffic needs with those of scenic recreation access facilities winding through sensitive environments (Heydorn and Tinley 1980).

Ill-suited developments are thus engendered which snowball the proliferation of further wrongly sited structures, many of which require repeated maintenance, compounding further damage to coast resources in a multiplicity of ways. Not least of these is the transformation of unique scenic areas into an eyesore by thoughtless ugly development. Under such an irresponsible invasion, most of the soft coastforms are seen as wasteland. Mudflats are filled in with rubble from road cuttings and old buildings, dunes are flattened and estuaries are pinched off by causeways, floodplains are used for industry, necessitating the construction of protective dams on all tributaries to reduce the flood threat. Examples of this type of development may be seen at Groot Brak on the Cape south coast (Heydorn and Tinley 1980) and on the Natal coast.

In summary the positioning of main road and rail lines hard against the coast is careless of the consequences, with no realization of the far reaching implications on landscape processes, on resource viability, on protection of material investments, or on the quality of human habitat.

In complete contrast is the simple precept of positioning along coast transport lines at a minimal distance of about five kilometres inland from the seashore, with tangential access roads to each coast site along watersheds.

This fundamental strategy avoids inflicting most, if not all, of the major damage to coast resources, and promotes or allows the opportunity for constructive uses. These include the husbanding of resources, maintenance of habitat quality and the conscious development and siting of structures to blend with the natural features, for example:

1. Protection of natural processes and thus the viability of resource productivity in estuaries, marshlands, mudflats, floodplain and the littoral. Processes are values in themselves which should be a major criterion of any land use analysis (McHarg 1969).

2. Protection of coast scenery and hence the quality of maritime habitats. Maintenance of the integrity ('wholeness') of coastforms important in process relationships and in the spatial ambient of living and recreation (eg estuaries or lagoons not pinched-off by filled in causeways). "A thing is right when it tends to preserve the integrity, stability and beauty of a biotic community. It is wrong when it tends otherwise" (Leopold 1949).

3. Protection of frontal dunes so that they remain as part of the malleable buffer defence of the littoral active zone.

4. The siting of main coastal routes further inland is generally more economic in the long term because of the high cost of maintaining wrongly sited structures.

5. User selection of coast sites for particular interests or amenities is made on the main road several kilometres inland, ie the position of the main road acts as a selector of interest groups and the degree of impact. It also does away with the snowballing mess of conflicting needs, demands and troubles generated by mixing industrial and recreational usage on the coast itself.

5.3 VALUES OF COASTAL DUNES

These resolve into four main categories of resource values: (1) coast buffer zone, (2) economic uses, (3) recreation, (4) cultural, educational and scientific.

5.3.1 Coast buffer zone and local weather modification

Significant dune characteristics include the following:

1. Frontal dunes are a major component of the littoral active zone. With beaches they form the most important sea and wind energy dissipating front to the land. They store and yield sand, damping coast recession by maintaining the sand supply to shores and beaches. This protective buffer shields all landward resources and developments from the direct impact of the elements.

2. Dunes contain a diverse and specialized flora adapted not only to each geographic area, but also to each facet of the dunes and backshore zones, and to the environmental features peculiar to the littoral (eg high salt spray input, very porous sands). There are three major roles this vegetation plays: (i) as living organisms they respond reciprocally to changes in form of the sediments (ii) stabilization of shifting sand and other unconsolidated sediments, (iii) enhances sediment accretion by reducing surface velocity of wind or water.

3. Due to their varied topography dunefields exhibit important microclimatic differences to the prevailing local weather conditions particularly of exposure, temperature and rainfall.

(a) In dunefields the alternating relief of ridges with hollows and slacks provide high microclimatic diversity. Aspect sequences of hot and cool, exposed windward and protected leeward sites, open sunny or shaded cover. The high year-round humidity of the immediate coast, the ocean-damped temperature extremes and protection given by dunes provide a benign habitat for living.

(b) High dune cordons induce a higher rainfall belt along the immediate coast where longshore rains are a feature of all seasons. This phenomenon is most striking where high dune cordons are backed by plains or valleys (eg the Mocambique Plain south to Cape St Lucia, parts of the east Cape coast, southern coast sectors as at Algoa Bay-Alexandria, Langekloof west of Cape St Francis, Buffalo Bay-Wilderness Lakes sector).

The significance of this relief-trigger phenomenon is that the effective moisture status is heightened within about three kilometres of the coast. The rain shadow effect landwards from the coast is, however, most abrupt where dunes are highest. Conversely low rainfall isohyets reach the coast where there are low dunes and gaps in the dune range, or where there are no other orographic triggers to shower formation (eg Delagoa Bay, Kosi Mouth, Sodwana Bay, St Lucia Estuary, Algoa Bay, St Francis Bay, Agulhas Plain and False Bay).

(c) Advective sea fog and surf zone mist is banked up against the seaward slopes of the higher dunes over 50 m by onshore winds. This aerosol is concentrated further by the development of an inversion in the shadow cast by steep relief over the littoral on eastern and southern coasts in autumn and winter.

5.3.2 Economic uses

1. Potable water source for man and stock (eg water extracted from coast dunes to supply Alexandria and Port Alfred towns).

2. Calcareous sweetveld pasture for herbivores (game and stock), especially valuable where they abut sourveld.

3. Sand and mineral resource.

4. Afforestation.

5. Strategic use (lighthouse, beacon and fire look-out tower sites).

6. Older dune sands landward of the active dune zone used for crops, housing, industry and military purposes.

7. Important subsistence resource for rural people. An idea of the multiplicity of products important to rural economies which can be obtained from vegetated dunes is illustrated by the following list: plant and animal foods - drought foods, fruit, seeds, tubers, spinaches, spices; timber, weaving materials, twine, dyes and tannins, gums and resins, oils, medicines, scents, honey, wax, hunting materials including poisons; shellfish from adjacent rocks and beaches, humus-rich sand for shifting cultivation, living sites (cover from the elements) and freshwater from dune hollows and slacks.

What makes vegetated coast dunes extraordinary is that where they combine with sandy beaches and rocky shores they provide the highest coincidence of favourable year-round living conditions. There is greater local habitat choice, for the short or the long term, greater year round availability of shellfish, and of fruits, spinaches and cover (Figure 18), and the possibility of producing a variety of crops from the redsands and vlei margins. Dune vegetation is one of the closed woody habitats least affected by extreme aridity as revealed by the recent 1982/83 summer drought.

That such a concurrence of favourable conditions in coast dunes has been exploited by man since antiquity to the present day is verified by the presence of Early Stone Age implements and the high association of Strandloper middens and pottery with coast dunes all along the South African coastline (Rudner 1968; Inskeep 1978). Today highest concentrations of subsistence populations remain along the dune coast of the Mocambique Plain (Tinley 1971b), and in the Transkei.

5.3.3 Recreation

Dunes form an intrinsic part of the coast environment, which is the greatest free recreation amenity in the country. Frontal dunes and beaches in combination with estuaries have the highest recreation value of all. The greatest diversity of recreation habitats, however, are afforded in bays where the above features are contained by rocky headlands or points which offer a further array of interest and activities.

Dunes are a unique landform and have a very high scenic value, especially on coastal plains where other eminences are absent. Their main recreational uses with the adjacent beaches are activities which involve the sheer enjoyment of a soft sand medium surrounded by the open sea, sky and dunes, activities such as walking, playing, picnicking, sunbathing, natural history interest, exploring, sand yacht sailing, hang-gliding, golf, and wilderness experience.

Whether the uses are restful or zestful they are at once refreshing and a balm. In built up countries such as Britain the main preference (82% from a questionnaire survey) was for the peaceful and aesthetic surroundings afforded by dunes and beaches (Usher 1977).

Bare dunefields especially, as best exemplified by the Algoa Dune Sea, are an extraordinary wilderness resource of the highest value. Like few other landscapes in South Africa such as Bushmanland, the Tanqua Karoo and our high mountain summits, bare dunefields impart a singular experience of infinity, solitude and spatial freedom.

5.3.4 Cultural, educational and scientific

1. The cultural roots of people are steeped in the totality of their individual surroundings from birth. Though the degree of awareness, influence or meaning this ambience has is different things to different people, even to those unable to express themselves, the singular combination of landscape features impinging on all the senses distinguishes the country they indentify with from all other land. The essence of the different landscapes of a country is best obtained by means of personal wilderness experience. The resource make-up of a country's landscape permeates everything - life ways, policies, folklore, and is the wellspring of all creativity most strikingly captured in literature, music, art and photography.

   As noted long ago by the eminent American ecologist Aldo Leopold "one of the fastest-shrinking categories of wilderness is coastlines .... no single kind of wilderness is more intimately interwoven with history, and none nearer the point of complete disappearance". Hence the vital need for protecting the remnants of natural coastline unmodified by man for "... the edification of those who may one day wish to see, feel, or study the origins of their cultural inheritance" (Leopold 1949).

2. Dunes have an extremely high aesthetic, wilderness and education value. They are important prehistory (archaeological) sites and palaeoenvironmental markers recording changes in climate and sea levels. They are important outdoor laboratories significant for the range of geomorphic processes and ecological responses which occur over a relatively short time. They portray both past and present dynamics and succession.

3. The practical value of the above attributes is in their application for protecting coast resources; in guiding the siting and development of material investments and human activities, their subsequent protection; and the maintenance, redirection or enhancement of natural processes.

4. The plant and animal species which make up the various dune communities are a valuable genetic resource of actual and potential value in medicine, food provision, agriculture and forestry.

5. Though discontinuous, the linear distribution of dunes along the coast provides a vital link and pathway for the migration of plants and animals between similar or related habitats around the intervals formed by contrasting arid or extreme moist geographic regions (eg (a) the moist coastal bypass in Mocambique around the front of the arid Limpopo Valley, (b) Tropical Arid Zone and burrowing fauna supported by calcareous dune sands banked against a high rainfall, leached (dystrophic) region with acid grasslands and Afrotemperate forest (ie *Podocarpus* forests)).

6. Where dunes have contrasting relief they exhibit a high local micro-climatic, edaphic, biotic and biogeographic diversity related to the variety of distinct slope aspects, crest-slack catena sequences, to the age of dunes and their proximity to the sea. This is overlain by the larger regional geographical gradients of which rainfall and the content of the immediately abutting ecosystems, are major determinants of the biotic mix and relationships of communities on coastal dunes.

7. Unique ecosystem types are represented in coastal dunes containing rare and endemic plants, animals and biotic communities. The coastal fynbos of the south-west and south Cape on calcareous dunes and aeolianites is a distinct heath type with a high degree of active speciation (Taylor 1978). Coast dunes also contain many biotic elements at their geographical limits of distribution, as well as outlier species (relict or initial).

8. Dunes are unique mobile geological landforms, which grow into many different shapes. These are regulated by the interaction of the wind transported sand with obstacles, amount of sand, density of plant growth and wind speed regime.

5.4 KEY ON-SITE GUIDELINES FOR PLANNERS AND USERS OF SOFT COASTS

5.4.1 Introduction

More than 80% of the South African coastline is composed of soft coasts. Of this more than 98% of the sand dune coasts are eroding from ongoing wave and wind action, the inexorable slow worldwide rise in sea level and the demise of sand from the surf zone, and from misuse by man and his stock.

With the exception of speculators, it is presumed that most developers and owners are sufficiently concerned and interested in protecting their land's resources and property from damage by the elements. Before embarking on any development action, care should be taken to consider:

1. Whether the site is of scenic, cultural, educational and/or scientific value at national, regional or local level.

2. The erosional status of the coast at the chosen point, ie is it (a) growing seaward (b) "stable", (c) eroding, (d) accreting or (e) retreating actively landwards.

3. The position of the outer limits or boundaries of the littoral active zone at the site.

4. The location of the nodes of least change (sites or positions of greatest relative stability).

5. The converse - what parts are the most vulnerable to the elements and/or to human activities.

To reiterate - all soft coasts are composed of unconsolidated shifting sediments which are unstable and in a constant state of flux. They are subject to highly variable spatial and temporal change. Erosion and/or accretion occur in the duration of a single tide or storm, in medium contemporary time and over the longer term.

A false impression of stability is imparted to frontal dunes where they are covered by bush (thicket/forest). This cover merely attests to an extended temporary balance in dune dynamics. Of all soft coast forms the embryo dune line of the backbeach being built up by creeping plants is the most transient and requires special protection against damage from trampling and vehicular traffic.

The golden rule for development on soft coasts is to avoid the littoral active zone, especially the frontal dunes and backbeach which is the country's coastal buffer.

5.4.2 Specific guidelines

1. Roads, railways, bridges, powerlines, parking lots, houses and any other immovable structure must not be placed within reach of the littoral active zone. Especially not within the coastal buffer zone and in estuaries.

   Major roads, railways and powerlines must be kept more than four to five kilometres landward of the coastline. Ideally even further inland so that the main transport routes act as a primary filter in separating user and interest groups (a modern planning principle - see McHarg 1969; Clark 1977; Heydorn and Tinley 1980). Bridges and traffic ways that have absolutely no alternative but to cross a floodplain must be built on piers. Not on filled-in causeways as habitually practised.

2. Where bush covered coast dunes form a distinct series of ridges and troughs parallel to the beach, only camping and caravanning can be permitted in the first trough behind the first definite dune ridge. Permanent structures such as log cabins should be confined to the landward-most third and fourth dune trough and ridge zone.

3. Where multiple small dune barrier ridges occur on shorelines which are growing seawards, the closest that permanent buildings, of any kind should be permitted to the sea, is where the oldest landward ridges are already covered in bush (eg Mtunzini area on south-east coast, and Dwarskersbos area in St Helena Bay on the west coast).

   The younger ridges are colonized by dune pioneer plants and are still in an extremely unstable state. The increase of dams on the Tugela and Berg Rivers, which are the main sources of excess sediment input in the above areas respectively, will alter the sand budget, and ongoing erosion could result in the shoreline receding again (as already initiated north of the Berg River mouth in St Helena Bay).

4. Bare mobile dune areas must either be left alone, or stabilized before or at the time that any development takes place (refer to Section 5.5 Reclamation at key sites).

5. Where relatively small vegetated dunes occur as a single or double ridge only, all development should be confined to the landward base of the dunes. Dunes stabilized by indigenous forest or bush should not be removed merely to obtain a view. Ideally houses should be built upwards to obtain a seaview where the height of the dune allows it. Dunes covered by rooikrans or bare dune can, however, be reformed to any shape required, and stabilized using the brushwood mat method (see 5.5.3). What must be expected in the last case is that phases of sand accumulation will recur, building upwards or landwards again, necessitating repeated removal of sand and restabilization to maintain the desired condition.

6. In high, steep and broad vegetated dune cordons as in the Wilderness Area and the Tongaland Coast, all permanent development should again be confined to the landward base of the dunes. However, as there is a wide range of possibilities the pros and cons must be analysed on site in each case.

   For example camping and caravans can be permitted in the first wooded trough behind the first bush covered dune line above the backbeach. Log cabins can be erected in the second dune trough and on the dune slopes and ridges where they are heavily forested. Again on-site placement using natural gaps in the canopy, and ensuring no possibility of donga erosion in access footpaths is fundamental for success. Otherwise mass slumping can occur at times of torrential rains. In the troughs all that need be done is to clear beneath the canopy trees. The canopy trees must always be left in place and replaced if damaged or dying.

7. Where dunes are poorly developed or where only a gradual rise occurs landward from the backbeach zone (Figure 1E), the closest any permanent development should be permitted, eg resort housing, is between 40 and 50 m back from the seaward edge of the completely vegetated sands. A perfect example of what not to do is illustrated by the housing development at Albatross, Jeffreys Bay (Plates 136, 137).

8. Before planning a resort township a comparative analysis must be made between the oldest and most recent aerial photographs to determine the setback line for development. This will ensure the long-term protection of buildings and keep the littoral active zone free of interference by wrongly sited structures.

   The landward boundary of the littoral active zone is generally indicated by dunes completely covered with bush (thicket/forest).

9. All footpath and vehicle access onto beaches must be orientated away from the predominant and gale force wind directions. Along the South African coastline these are coincident and blow from two opposing quarters, access should thus be at right angles to the two major opposing winds (see Section 3.2.3D and Figure 10).

10. Considerate housing construction should be planned so that everyone can get a view of the sea, ie on flat or gently rising terrain smallest houses in front grading landwards to highest buildings such as high rise apartments and not the reverse as is frequently the case.

11. If living areas are being serviced by freshwater from the dune aquifer, it is strongly advised not to use French-drain or pit forms of sewage and rubbish disposal as the dune aquifer is easily polluted and will become a health hazard.

12. Overgrazing or thinning out ('staring' appearance of bush) of dune bush by stock or game should be prevented as this initiates blowouts and donga slumping.

13. In the southern and south-western Cape large areas of dunes are vegetated by low dense growths of highly inflammable fynbos, and the alien rooikrans. Housing must therefore be adequately protected against run-away fires which occur with gales and the hot, dry, Berg Winds which blow seawards from the interior. There are two main peaks of fire occurrence, in the summer dry season and in winter when Berg Winds have their highest frequency. On the eastern seaboard where grassland and savanna abuts bush-covered dunes, a similar fire hazard occurs with offshore winds during dry spells.

14. An important point for planners of all kinds, which has far reaching implications and repercussions, is the growth of a resort to municipal township size. At this stage the "city fathers" begin wooing industry (eg at Jeffreys Bay) as a means of obtaining more cash to run the town services.

    In most cases industry cannot be supported by the local water supply or other infrastructural demands. Industry should be kept out of resort areas at all costs otherwise it spreads the blight of pollution and ugliness, downgrades habitats and initiates new problems, damaging the original sensitive attractions which brought people to the area in the first place. Residents should be involved in their own self-sufficiency if the running costs cannot be carried by the rates, eg by removing their own rubbish, by having their own solar heaters and wind generated electricity (eg Betty's Bay). Any "industry" in resort townships should rather be of the homestead or "cottage industry" type.

15. An essential feature of responsible planning is a feedback of data from the public for whom the planning is being done. Only by exposure can obscure and covert activities inimical to resource viability be eliminated (McHarg 1969).

16. Before any development or property and building speculation is permitted anywhere on the coast and estuaries a proposal should be forwarded to the Department of Environment Affairs for on-site ratification.

    Resort housing development plans sent to the Cape Provincial Town Planning Department are apparently passed without inspection on site, eg the new beach houses built hard against the beach at Albatross, Jeffreys Bay, and the continuing intransigence of the Department of Community Development to go ahead and establish a township for squatters on the Kleinkrantz dunes in the Wilderness area and now modified to be an elite resort (Heydorn and Tinley 1980).

17. All coast developments must first be subjected to the test "least cost - least environmental damage - maximum benefit" (McHarg 1969). "Least cost" should be calculated over the long term (including the waste on maintenance of wrongly sited structures), and must include the impact or cost to resource viability. Likewise "maximum benefit" is not only the financial advantages to the community in savings and unnecessary developments, but also in resource benefiting terms (eg attraction qualities, protection and enhancement of coast buffer zone, dune aquifers, mudflats, floodplain soils, springs and fountains, indigenous forest; and unique elements such as strandloper middens, rock paintings, rare plants and animals, historical and scenic areas).

5.4.3 Dune mining

Surface mining is an extreme form of dune utilization which totally destroys the vegetative cover and the form and content of dunes. There are two areas of concentrated surface mining on the South African coast in which the original vegetation is totally removed, (a) strip mining for diamonds along the west coast in Namaqualand, and (b) for heavy mineral extraction from the forested coast dunes of the east coast immediately north of Richards Bay (Plates 138-140). Lime extraction from coast sands is relatively small at present, but there are increasing demands to exploit dune sands on a large scale.

On the Namaqua Coast no attempt is made to reclaim the bared landscape and large derelict wasteland areas of shifting sands and hard bare deflation floors have resulted (Heydorn and Tinley 1980, Colour Plate A7).

By contrast the dune mining operation on the east coast has been a responsible one, with an outstandingly successful programme of dune reclamation. The uneven dumps of bare sand, left in the wake of the suction dredger, are rounded into a gently undulating landscape by bulldozers. Parallel rows of nets are erected at right angles to the predominant wind to trap windblown sand, and the bare areas between nets are then planted up with indigenous vegetation (Plates 140-142).

A. A fundamental error.

A major mistake made at the Richards Bay dune mining operation is that they have been allowed to encroach into the frontal dune line and main seaward slope of the dunefield above the beach. This has resulted in increased sand slides and slumping (Plate 99). The excessive addition of water to the clay layer under the dunes from the suction dredger pool has aggravated underground pipe erosion and greater cave-ins where the clay layer emerges along a sand-cliffed seashore already subject to an ongoing phase of wave erosion.

The present arbitrary contour limit used by the mining company on the seaward slope of the frontal dune line is quite unacceptable for reasons noted in 5.1 above. Apparently in profile the clay layer beneath the dunes slopes seawards and landwards with its crestline quasi-parallel to the coast.

Ideally it would be preferable to mine up to this aquifer divide so that the freshwater input from the dredger pool (Plate 138) is directed to recharge landward aquifers (vleis and high water-table sands) rather than being wasted into the sea. In this way an adequate frontal dune zone will be left intact and the freshwater resource will be protected.

B. Ideal method of reclamation.

Biotic and biogeographic richness in coast dunes is directly related to the diversity of contrasting relief and slope aspects. The reclamation approach therefore should ideally try and recreate such conditions at far less cost than present by using the wind again as the main formative agent.

The orientation of the forested parabolic dunes axes on this oblique curve of the east coast between Richards Bay and Nhlabane Mouth shows that the formative wind is from the south-south-west (between 200 and 204°). By establishing bands of plant-stabilized sand alternating with narrower bare strips of sand parallel to the formative wind direction, the dynamics of a parabolic dune system will once again be initiated and restored. The vegetated bands and bare sand strips can either be in a single group or in series so that those downwind override the successive sets. If the bare strips are too wide a transverse dune system will result, which must be avoided as transverse dunes are shifted by any wind and natural plant colonization is made impossible.

For practical purposes the open-cast mining operation in vegetated dunes should begin at the downwind end of the area to be worked. By moving upwind, mining activity is protected by the remaining vegetated dunes and reclamation can follow in its wake.

By reinstating parabolic dune dynamics a multiple of creative features are set in train, (a) maximization of relief diversity, (b) rewinnowing of the remaining sand fraction, (c) as sand transport is mainly unidirectional, active phases are followed by relatively quiet phases allowing for successful plant growth on leeward faces, (d) a steepening blowout slope means only strongest winds are effective, and the exposure of moist sand at the blowout source promotes self-stabilization, (e) control of dune mobility is thus greatly facilitated, and (f) it is a least cost-maximum benefit approach.

The above method is also the basic approach recommended wherever reclamation of bare dunefields (usually transverse types) is required. Reclamation can be speeded up by collecting the surface 10 cm of forest topsoil from areas about to be cleared, and spreading this on the bared sites where wetting from sprinklers or a brushwood mat can hold the dressing.

C. Permissible extraction sites.

(1) <u>Evaluation</u>

Before any dune mining, or other developments, are permitted on soft coasts the following criteria should form the basis for responsible decision making. Land use allocation should first identify and map (a) existing and proposed coast reserve sectors and the landward limit of the recommended national coast buffer zone, (b) define the coast sand areas which are important aquifers (Tinley 1971a), (c) the coast sands and dunes of value for husbandry, and (d) permissible dune mining areas, after alternatives have been investigated and the impacts in each evaluated. For example building sand can be recovered in abundance from all sanded-up dams by draining them temporarily, and in this way also restore their main purpose of storing water.

(2) Mining Limits

Once the above analysis has identified permissible exploitation areas, the next most important step is to be able to recognize on site the limits within which activities may take place.

A 100 m broad horizontal distance landwards from the backbeach frontal dune junction, or the whole of the first dune cordon to its landward base, whichever is the greater, should be left intact. This applies equally to seashore, coast lake and estuarine frontage. This belt should be joined to the beach to form part of a national coast buffer zone.

These limits are based on the fact that all dune sand blown landwards of them is out of reach and thus lost to the littoral active zone (except in three cases (a) where there is active recession of the actual coastline, (b) where sand in bare dune areas blown back in to the littoral active zone at intervals by strong offshore winds is essential for beach maintenance, (c) where the sand forms part of an effective headland bypass dune train).

In high forested dunes alternative methods of mining and site use should first be explored fully even within the permissible sites, so as to minimize damage or disturbance. For example on the Tongaland Coast adequate heavy mineral resources are apparently available along the landward base of the high forested dune range (L t Hunting and Associates 1969). On this basis permissible dune mining sites in this region have been identified (Tinley and van Riet 1981).

The vegetated dune areas bared by open-cast mining should be reclaimed using vegetation indigenous to the area, and particular care must be taken not to smother or pollute vleis and other water resources. Vegetationless dunes that have been worked should be left in their bare state. As decalcification of dune sands will convert them to acid substrates the most successful means of their reclamation will be with brushwood mats interplanted with dune fynbos plants.

Ideally pristine dune areas should be used last within the permissible extraction areas identified, and secondary areas already modified or damaged should be used first (including those under suger-cane, pines or gums which are most easily replanted).

5.5 MANAGEMENT OF COASTAL DUNES

5.5.1 Introduction

The two main conclusions made by Walsh (1968) are substantiated by the experience of forestry field staff elsewhere along the coast and by the present survey. These are: (1) high cost of reclamation operations and low intrinsic value of the reclaimed land for farming, hence (2) reclamation of driftsands can only be justified where they endanger resources such as productive farmland, wetlands and rivers or structures which cannot possibly be located elsewhere (eg lighthouses). The dune features themselves indicate the most economic and ecologically effective choice of methods to use for a particular drift-sand problem.

Bare dunes should not be stabilized merely because they are bare. They must be threatening something of value as noted above. Some of the bare reversing dune seas on the coast, such as those of Algoa Bay, are of sufficient antiquity to have provided an arena for speciation in animals (McLachlan et al 1982). An important feature so far only recognized by a few (Cowling 1980; Boucher 1981; McLachlan et al 1982), is that different kinds of dunes are unique geo-ecological systems and landforms in their own right. In bare coast dunefields typical desert features develop and a wealth of archeological and fossil remains are exposed. They are a unique wilderness resource in South Africa.

The conflict between industrial demands and protection use of coast dunes exists because a clear decision on land use allocation has not been made. Conflicting land uses are given attention only when a threat appears or after the damage is done. Conversely where dune forest reserves and other protected coast areas have been proclaimed their survival is not assured because change of control to urban authorities or decisions at high-handed levels can annul this use status. A land unit approach should be used for analysing and categorizing use allocation on coasts (The Conservation Foundation 1980; Ritchie 1980).

5.5.2 Salient features

In any dune reclamation programme the prime factors that must be identified are:

1. What is endangered or threatened by sand-drift and dune encroachment (resources and/or man-made structures). If nothing, leave alone. If something of value, identify the next six points.

2. The landscape, shoreline position and relationship of the mobile dune (eg bayhead, river mouth, headland bypass etc).

3. The landward limits of exceptional storm seas, and/or ongoing processes.

4. The type of dune.

5. Which processes are active.

6. The trend and direction of change.

7. Determine an action priority of most-least urgent or threatening.

As most of the mobile dunes are either of the reversing type or unidirectional parabolic blowouts their nett one-way movement is relatively slow. Hence they can generally be left while more urgent sites are given concerted attention.

A. Reclamation of key sites.

After the first decision has been made, whether a particular drift-sand requires stabilization or not and which require priority attention, the next step is to investigate the two key sites common to all coast dune areas: (1) the littoral sand source zone, and (2) the advancing landward margin of the dunes.

Using a land unit approach to analysis of coastal areas, the two main dune types, parabolic and transverse, are used to define the minimal reclamation actions required in each to promote the natural processes towards attaining the desired condition, either (1) complete or partial stabilization, or (2) maintenance, or (3) enhancement of existing conditions, eg greater mobility of sand required as across headlands to maintain continuity of sand supply to beaches.

1. Parabolic dunes. If a migrating parabolic dune, typically of the hairpin type, is threatening valuable resources it can usually be easily contained by (a) covering both the advancing crest zone and the sand source area near the beach with a one metre deep cover of densely packed brushwood, or a single layer of closely packed reed stems, (b) local dune pioneer plants should be planted during the rains immediately ahead of the brushwood laying so that they receive immediate protection. Otherwise interplanting with dune plants must be done subsequently after rain.

Ideally only problem plants should be cut and used as brushwood eg sweet-thorn or renosterbos which has invaded adjacent farm lands, and especially the alien Australian acacias (rooikrans and port jackson) only if they are used without green or ripe pods. Where abundant, the stems of the common reed are also a valuable sand stabilizer and more efficiently maintains a high moisture content in the sand than does brushwood. Most of this work can be done by labourers on foot with minimal transport requirements, especially if the materials are close by.

(c) Where a littoral dune is absent, an artificial one should be initiated along the driftline either by planting dune pioneer plants (including seawheat on the temperate coast) and/or first erecting a brushwood, or reed or slat fence parallel to the driftline (Plates 127-131, 133). As these become covered by the accumulating sand further slats can be worked into the sand ridge if required. Dune pioneer plants are planted on the artificial littoral dune in the same sites as they occur normally. Details of littoral dune construction are given by Walsh (1968). (d) If finance allows for the use of earth moving machinery then where a high water-table occurs the surface sand at the seaward base of the parabolic dune can be skimmed off to expose the moist sand. This alone will stabilize the source area. Indigenous slack plants should however be introduced to the site.

The advantageous unidirectional and self-arresting characteristics of parabolic dunes noted above are significant from dynamics, diversity, economic and management points of view.

Probably the most economic and labour-saving means of restoring high coast dunes in a relatively narrow cordon, is to set in train conditions for re-establishment of ascending parabolic dunes. The simplest method, as noted in the dune mining section above, is to lay a one metre thick mat of brushwood underplanted with local dune pioneer plants, leaving a bare hairpin-shaped opening of sand aligned in the same direction as, and with a narrower width than the original parabolic dunes. Allow the wind to reshape the transverse dunes left exposed in the parallel-sided opening. The opening should be inclined seawards and windwards, ie the lowest part nearest the beach or sand source and the highest slope landwards. The most effective approach would be to initiate succeeding sets of such parabolic openings as occur in nature, from the downwind end consecutively upwind behind the mining operation.

2. Bare transverse dunes. As the crests of these dunes are moved by effective winds from any quarter, their hyper-mobility makes them the most difficult type to reclaim. However, as they are all reversing types it is possible to establish indigenous dune colonizing shrubs and herbs in the slacks between dunes and in dune hollows against the compact semistable dune base (plinth). Again attention must first be given to the landward encroaching margin and to the sand source area. Where immediate results are required on their encroaching front the most successful method seen is the one described above using brushwood and cut reeds as a stabilizing mat through which dune pioneer plants can be established.

3. Indigenous strand plants. Ideally only locally indigenous strand plants should be used in dune reclamation. It must be pointed out however that some of the creeping herbaceous and soft shrubby plants of Zone I die back en masse after two or three years (eg dune cabbage *Arctotheca populifolia*). Where backbeach hummock dunes have been built up over this period by the even-aged colonization of a single species, the synchronous die-back results in complete loss of the foremost dune line by deflation. In Zone I the strand plants should be planted in mixed clumps and not as single species communities. The most effective or vigorous plants in each dune zone in various coast sectors are noted in Table 15.

B. Rebuilding dune headlands.

The significance of the relatively rapid loss of bays on unconsolidated coastlines by shore straightening processes which leave the calcified sandstone outcrops as island reefs or stacks is noted in Chapter 4.

TABLE 15

KEY DUNE PIONEER PLANTS IN VARIOUS COAST SECTORS.

PLANT SPECIES	DUNE ZONE	COAST SECTOR							
		M	T	N	TK	EC	SC	SW	W
GRASSES									
Agropyron distichum (seawheat)	I						+	+	
Ammophila arenaria (marram)	II-IV						+	+	
Dactyloctenium australe (dune kweek)	I-IV	+	+	+					
Digitaria macroglossa (finger grass)	III-IV	+	+	+					
Ehrharta villosa (pypgras)	III-IV					+	+	+	
Eragrostis cyperoides (steekriet)	I-II								+
Halopyrum mucronatum	I	+							
Imperata cylindrica (lalang, cotton-wool gr.)	II-IV	+	+	+	+	+	+		
Sporobolus virginicus (beach dropseed)	I	+	+	+	+	+	+	+	+
SEDGES									
Cyperus maritimus (dune sedge)	I-IV	+	+	+	+	+	+		
RESTIOS									
Restio eleocharis (katstertriet)	II-IV						+	+	
R. leptocladus (besemriet)	II-IV						+	+	
HERBS & SHRUBLETS									
Arctotheca populifolia (dune cabbage)	I-II		+	+	+	+	+	+	
Canavalia maritima (creeping bean)	I	+	+	+					
Gazania rigens (gousblom)	I-IV	+	+	+	+	+	+		
Hydrophylax carnosa	I		+	+	+				
Ipomoea brasiliensis (dune morning-glory)	I-II	+	+	+	+	+			
Launaea sarmentosa	I-II	+	+	+					
Psoralea repens	I-III						+		
Scaevola thunbergii (seëplakkie, scaevola)	I	+	+	+	+	+			
Tetragonia decumbens (klappiesbrak)	I-II					+	+	+	+
SCRUB									
Acacia karroo (sweet-thorn, soetdoring)	III-IV		+						
Brachylaena discolor (dune silverleaf)	II-IV	+	+	+	+	+			
Chrysanthemoides monilifera (bietou, tick-berry)	II-IV	+	+	+	+	+	+	+	+
Diospyros rotundifolia (dune jackal-berry)	II-III	+	+						
Euclea racemosa (dune guarri)	II-IV					+	+	+	+
Eugenia capensis (dune myrtle)	II-IV	+	+	+	+	+	+		
Helichrysum kraussii (sand helichrysum)	II-IV		+	+					
Maytenus procumbens (dune kokoboom)	II-III	+	+	+	+	+	+	+	
Metalasia muricata (blombos)	II-IV					+	+	+	
Mimusops caffra (dune milkwood)	II-IV	+	+	+	+	+			
Myrica cordifolia (wasbessie, waxberry)	II-IV					+	+	+	
M. quercifolia (oakleaved waxberry)	II-IV						+	+	
Olea exasperata (sand olive)	II-IV					+	+	+	
Passerina rigida (dune gonna)	II-IV		+	+	+	+	+	+	
Pterocelastrus tricuspidatus (kershout)	II-IV						+	+	+
Rhus crenata (duinekraaibessie)	II-IV					+	+	+	
R. glauca (bloukoenibos)	III-IV					+	+	+	+
R. laevigata (duintaaibos)	II-IV					+	+	+	
R. natalensis (Natal karee)	III-IV	+	+	+	+	+			
R. nebulosa (sandtaaibos)	III-IV	+	+	+	+				
Salacia kraussii (ibonsi)	III-IV	+	+	+					
Salsola spp.	II-III								+
Scutia myrtina (drogie, cats claw)	III-IV	+	+	+	+	+	+		

M = S. MOCAMBIQUE • T = TONGALAND • N = NATAL • TK = TRANSKEI •
EC = EAST CAPE • SC = SOUTH CAPE • SW = SOUTHWEST CAPE • W = WEST COAST.

To restore the half-heart bay form with its high forested dune bluff which protects the bay from the direct effects of southerly gales, it is necessary to build up a dune jutting from the main cordon towards the point at an angle of about 65°.

The methods used are similar to those for establishing an artificial littoral dune, except a much broader plinth or base must be established to support the crestline as it grows upward. Once a certain dimension is attained, ascending parabolic dunes should be artificially entrained on both north and south slopes, orientated similarly to those existing on the other headlands. In this way dune headlands are restored by the growth of opposing parabolic blowouts building up against each other as in nature.

The main coast sectors where dune headlands should be restored are on the points of half-heart bays, especially in Tongaland (eg Black Rock, Island Rock) and the east Cape (eg Cove Rock, Gt Fish Point, point south-west of Kleinemond West, and Rietpunt).

C. Promotion of sand drift plumes in headland bypass dunes.

In certain situations quite the opposite condition, of enhanced sand mobility, may be required as in the case of headland bypass dunes. These dunes occur as bands of bare migrating dunes which cross (short-cut) rocky headlands to the embayment on the opposite side of the promontory.

The best examples to be seen of these dunes are the large-scale plumes across the Cape St Francis and Cape Recife peninsulas, and from Ysterfontein past Langebaan Lagoon (Boucher 1981). These are replicated on the smaller scale at points such as Quion, Struis, Nahoon and Mendu. Many of these blowouts across points are of considerable geological age as evinced by the abundance of wind faceted rocks and stones shaped by sand blasting (eg St Francis Point, Mendu Point).

The headland bypass dunes maintain the sand supply to beaches on the downdrift side, which otherwise accumulates in deep water off the ends of the points as submarine spits (Birch 1981) out of reach of, and thus lost to the littoral active zone.

A classic example of the beach and frontal dune erosion incurred by stabilizing headland bypass dunes is recorded from the Port Elizabeth-Cape Recife shoreline (Hydraulic Research Unit, CSIR 1970). A parallel episode has occurred at St Francis where the key bypass dune from Thysbaai, on the opposite side of the peninsula, through to the corner of the bay has been stabilized for housing, an airstrip and a main road crossing. In fact luxury homes have been built on the high sand nose at the downdrift tip of the dune in the most unstable position immediately above the beach.

The damming of the rivers entering these bays will further aggravate the shortage of sand for the maintenance of beaches. Ongoing erosion and recession of soft-shores will probably continue here within the bounds of process interrelationships.

It is recommended therefore, that where possible, key headland bypass dunes are not stabilized, but must be aided in transporting sand into the bays on the opposite side, ie sand must not be removed, and sand disturbing factors must be encouraged if there are signs of self-stabilization (eg by exposure of the water-table).

The one at Cape Recife requires clearing of alien and other plants, and an open invitation to all motorbike scramblers to use the bare dune strip as an arena. This alone will help promote sand mobility to feed the beaches of Summerstrand and provide an amenity at the same time.

D. Fire - pros and cons.

Whilst fire is generally bad or damaging to dune vegetation, especially of forest and thicket, there are certain instances when a controlled burning regime at intervals may be required to maintain or enhance the viability and spread of desired plant species, or of whole biotic communities, and in one case that of a unique duneform.

Example 1. The Cape Agulhas-Renosterkop dunes

The use of fire in vegetated dunes of the south and south-west Cape to provide a flush of grazing is apparently a long practised custom (Walsh 1968). This practise possibly originated with the first herders to reach the southern tip of the continent nearly 2 000 years ago (Inskeep 1978), but as they were nomadic and unfettered by the confines of farm fences it is likely that the dune vegetation has been burnt most regularly since white settlement, particularly as the calcareous sands proved to be more nutritious pastures than those on the adjacent acid quartzites.

The unique blowout-hummock or mounded dunes west of Cape Agulhas at Renosterkop, and found nowhere else in South Africa, are formed by blowouts initiated on the crests of dune convexities after fire has temporarily bared the sand of its stabilizing fynbos heath and grass cover. This vegetation is seral to thicket and/or forest which is initiated as isolated bushclumps of bird dispersed woody species. The recurring patchwork of fires has probably also played a significant role in speciation of the fynbos heaths by multiplying microgeographic and phenological diversification (see Section 3.5).

In this part of the Cape there is a bimodal peak in fire frequency, one in the summer dry season and the other when dry hot Berg Wind conditions interrupt autumn and winter wet season conditions (Kruger 1979a). The problem then is either to cool-burn the inflammable fynbos cover at suitable intervals so that a dangerous build up of fuel does not occur, or to institute large-scale firebreak programmes (Kruger 1979a).

A similar decision has to be made on the eastern coasts where grass covered dunes occur. Either maintenance of the grassland community may be required as a representative seral dune habitat, or cool autumn burns after rain are applied to minimize damage to the seral woody plant stages towards a forest cover.

Example 2. Cycad thickets on Tongaland and south Mocambique dunes

On three known areas of the forested east coast dunes is another extraordinary feature as a result of fire, this time affecting an endemic plant and not a dune form. These sites are (a) on the peninsula south of the Bazaruto Islands (Tinley 1970), (b) on the coast south of Inhaca Island, and (c) the largest area six kilometres south of Banga Neck in the Kosi Lake System. Where the tree-strelitzia S nicolai occurs in pure patches on the seaward slopes of the dune range, they are burnt out by tribespeople at intervals of four to five years to obtain a durable cord for rope-making using the singed and now pliable leaf petioles. Unburnt, the petiole breaks when bent and cannot be tied and knotted. Fire in the seaward dune climax area burns back thicket and promotes the invasion of Strelitzia, and simultaneously enhances the habitat for the large cycad Encephalartos ferox which is a south Mocambique-Tongaland Coast endemic (Figure 14, Plate 78). Further burning of the Strelitzia weakens these plants by killing the larger stems, resulting in coppicing. Under these circumstances the light-demanding cycad becomes increasingly abundant until it forms dense pure species stands on seaward slopes.

As such a unique occurrence is found only in two other smaller sites on the Mocambique Coast it is important that this community is maintained by burning. In a rural landuse study of Tongaland it has been recommended that the local tribespeople continue to harvest the fibre from Strelitzia at intervals and in this way maintain the cycad community and protect it from extinction on the seaward dune slopes by shading from the natural succession to forest that would occur if the areas were completely protected from fire (Tinley and van Riet 1981).

In most other situations dunefields require to be protected from fire, particularly where they are forested or where they contain highly inflammable shrubs and tree species such as blombos Metalasia muricata, Tarchonanthus camphoratus, Olea exasperata and Euclea racemosa which colonize old man-made scars on the landward slopes of dunes. These slopes are vulnerable as they are exposed to the full impact of grass fires fanned by hot dry Berg Winds.

E. Least management and interference.

Where mobile dunes pose little or no threat either to natural resources such as productive soils, forests, wetlands and estuaries or to material developments the option is to leave them alone (ie protect from extraneous disturbances such as trampling and vehicle traffic or from expensive stabilization schemes).

Left alone bare dunes may remain essentially the same over many decades or centuries if of the transverse type. Parabolic blowouts, however, may self-stabilize over a 20-30 year period as shown by the aerial photograph record, ie natural colonization by dune plants from the vegetated margins. This principle of least management and interference is one recommended for many lake management situations (Weisser and Howard-Williams 1982), and is applicable to many dune habitats.

Success of the "hands off" approach, however, may still require some specific management aid to key factors by re-establishing, triggering, promoting, deflecting, damping or removing particular elements or process influences, eg (1) establishment of dune plant nuclei in a barren dunefield where seed sources are downwind or at a great distance. Or the reverse, removal of plant colonies where a special duneform or dunefield is protected for its unique sand features, (2) excessive trampling in most dune situations is deleterious and can initiate blowouts. Under certain conditions it can be a valuable aid to dune stabilization as exemplified in East London. Nahoon Bay is one of the town's premier recreation sites where heavy concentrations of people occur over weekends and holidays. On the north side of the river which enters the bay are high bush-covered dunes with oversteepened bare seaward slopes little used by people. Here wind scour, sand slides and slumps inhibit plant colonization. Heavy intermittent trampling by people up and down a similar bare dune slope south of the river mouth, while inimical to the pioneer dune creeping plants of Zone I, has flattened the slope to a more stable angle and has been instrumental in the effective colonization and spread of Zone II shrubby plants as Chrysanthemoides monilifera. Here effective dune stabilization occurs in contrast to the ongoing contraction of the woody cover which prevails under completely "natural" conditions on the dunes north of the river mouth.

F. Coast buffer along entire seashore.

The single simple rule for the longterm sustained use of soft coasts defined in 5.1 above is: to put all developments out of reach of the littoral active zone. This alone will obviate most, if not all, problems by protecting the diversity and viability of coast resources and attractions, and at the same time secure developments and property from wasteful damage or destruction.

The prerequisite for responsible use of the coast is therefore to identify a national coast buffer zone, which includes the littoral active zone to the backbeach plus 100 m horizontal distance landwards, all the whole first vegetated dune cordon back to the first trough whichever is the greater, and existing dune forest reserves where they occur. Such a zone should be proclaimed, or at least made a directive that must be recognized in practice by everyone. The 100 m buffer represents a generalized minimum width, as particular objectives or situations will naturally require a broadening of the buffer zone.

The landward boundary of the littoral active zone can be recognized where the completely vegetated ground begins (ie a closed plant cover). Scattered patches of plants with bare sand between indicates part of the active zone even if it is four kilometres inland as in the case of the Algoa Dune Sea.

Any development envisaged within 100 m on the landward side of this closed cover boundary should be submitted to the Department of Environment Affairs for scrutiny and on site assessment by a professional ecologist (with geomorphological and plant ecological field experience). Where permission is granted any material development should not encroach closer than 40-50 m from the seaward end of the completed vegetated growth.

The coast buffer should be linked from the estuaries to the riverbank protection zone through to the water catchments protected in legislation by the Soil Conservation Act of 1946. The Seashore Act 21/1935 proclaims the zone between low and high water marks as stateland. This should be expanded to include the coast buffer zone as defined above.

5.6 CONTINUED DAMAGE TO COAST RESOURCES

5.6.1 Introduction

Maltreatment of the coast is multiplying as pressures for more recreation and living areas increase exponentially with the population explosion. What is disquieting is that pressure is so far only from the white segment of South Africa's peoples, and apart from three short coast sectors within homelands one needs to ask whether adequate provision has been made for the much larger non-white population.

Coast resource abuse is a feature both of certain government agencies and of the private sector. The heedless damage of sensitive dunelands on the Wilderness Lakes coast at Kleinkrantz is one example. Worse, this particular development will entrain further environmental problems and human social ills. The invasion of wrongly sited roads, housing and resort developments involves property and building speculators, divisional councils, municipal councils, construction and engineering contractors, provincial town planning departments and roads departments all of whom have no input or guidance (except in rare instances) from professional environmental specialists.

The roads departments and associated construction and engineering firms are often the worst culprits of resource abuse because of the huge capital investment in earth-moving machinery that has to be kept in continuous action. Features such as estuaries, floodplains, vleis, pans, catchments and coast dunes are apparently not recognized by engineers as valuable natural resources and they fail to comprehend that while they may be contributing to the development of the country and their own financial advantage it is at great cost to the country's water-based resources. Continued damage to resources along the coast by ill-sited lines of communication are legion (for photographic evidence refer to the Head of the Coast Unit, NRIO, CSIR, Stellenbosch and the Director of the Oceanographic Research Institute in Durban).

Although in 1984 with massive population pressure demands on all natural resources, both for living and for recreation (particularly on water related habitats), there was yet no sign that the various roads departments and their associated private engineering and construction firms had even begun to attempt to meet the aims ennunciated in paragraph two of the Circular Policy Statement on Environmental Evaluation and Assessment of Roads (Circular 29/1981). Ironically this was sent out by the Cape Roads Department itself and quotes the directive of the White Paper of 1980 on a national policy regarding environmental conservation, yet has recently commenced road building on the vlei coast at Pearly Beach.

5.6.2 Some of the problems

1. Legislation and laws are useless unless effective and they are only effective if their relevance is understood.

2. So far the findings of all the excellent Commissions of Inquiry on land matters, starting with the Soil Conservation Act of 1946, have not been strongly applied.

3. The lack of a CONSERVATION LAND ETHIC relegates to government many functions eventually too large, too complex, or too widely dispersed for it to efficiently perform (Leopold 1949) ie the tendency in South Africa is to relegate to government all conservation activities that private land owners fail to perform.

4. Leaders and managers, although well informed in many ways, are generally uninformed or misinformed in respect of sustainable resource use, ie those actions that bring the economy and the ecosystems into a dynamic, self-sustaining equilibrium (Caldwell 1972; Wagar 1972).

5. The main danger to the land and its resources, especially conspicuous along the coast, is the application of urban-industrial principles to landuse by city-orientated economists, planners, politicians and engineers. The result is preconceived development which is not based on reality of resource distribution and fluctuations. The rapidly increasing urbanization of all groups in South Africa implies the acceleration of wastage of resources due to lack of an ecological approach.

6. In South Africa biological scientists are still too involved in amassing extremely detailed data requiring years to analyse and assess, before providing ecolgical guidelines for developers to act upon. This frustrates any attempt to ensure the viability of landscape resources. Due to the high cost of delay, engineers, for example, consult other engineers resulting in both client and consultant seeing the environment as an engineering problem.

7. There is inadequate control of property and building speculators so that unrestrained and insensitive invasion of highly unstable waterfront ground along seashores, estuaries and rivers continues. The situation exists where naive buyers are paying exhorbitant prices for half acre plots on eroding frontal dunes. Such irresponsible land uses must be condoned by the town planning departments and municipalities involved who pass the plans.

8. The invasion of the coast for recreation, space, clean air and water, quiet places and rest must be seen against the predicament of exploding human populations and escalating needs, demands and accelerating wastage. From about five million in 1900 it is estimated

that the population of South Africa will pass the 50 million mark by the year 2000. Over the next 20 years there will be an influx of more than 20 million people to the cities requiring 40 new cities, 20 of which will be the size of Johannesburg. In the next 20 years building programmes in South Africa will thus have to equal or exceed that of the past 300 years (Bahlmann 1982).

All this has direct impact on coast dunes - increasing demand for building sand, housing, hotel and beach cottage sites, tapping of dune aquifers, removal of whole dunes and/or dune bush cleared in resort and township areas to eradicate hideouts for marauding bush-dwellers, increased incidence of fires, massive increase of rubbish dumps and other damage to the vegetated frontal dune zone.

9. The major problem in administration and control of coastal resources is too much delegation and redelegation of authority to lesser authorities who have no training or experience of the subject. There are too many agencies all without environmental expertise. There has been unconstrained damage to dune forelands by resorts, and resort municipalities where the Directorate of Forestry has relinquished its control (Heydorn and Tinley 1980).

10. A great danger to the conservation of the natural, least modified, ecosystems left in the country which should be protected as national parks, nature reserves, forestry wilderness and unique recreation areas etc is that they are seen by other government agencies as banks of free government land waiting for "better uses" (eg Kruger National Park for coal mining, Garden Route and Wilderness for massive highway, St Lucia for rocket testing site, Arniston-De Hoop-Potberg wanted for military experimental area, the Woody Cape area of the Agulhas Sand Sea a suggested site for a nuclear power plant, and so on).

5.6.3 Some solutions

1. We have the knowledge and data at our disposal to effect creative development through multidisciplinary planning, to replace obscure, subjective and covert criteria with evidence derived, in the main, from the exact sciences using explicit and replicate methods of planning (McHarg 1969).

2. One of the quickest ways of changing the present arrogant attitude to landuse to an approach in empathy and in cooperation with environmental processes and relationships is to utilize the visual medium of television. Water saving tips during drought crises have been flashed on television. In like fashion 'do's and don'ts' of resource use and examples of the fragility and the importance of resources can be shown. Similarly the public can be involved in conservation vigilance via the media.

3. Geological courses for engineers at universities are strong on structure, foundation and materials and weak on landscape processes and relationships (geomorphology and ecology). What they require to be exposed to are socio-economic and resource implications of wrongly sited lines of communication and structures.

4. There is an immediate requirement for a team of professionals trained in geomorphology and plant ecology with field experience to be available for on-site problem solving anywhere along the South African coastline. Before any final planning or development starts they must be fielded on site to provide prescriptions of use, advice, guidance or to assess alternatives (which may require further study). This would include road route and bridge site alternatives, sites for housing on coasts and rivers, least damaging position for powerlines across the land, permissible areas for dune mining, etc.

   What is desperately required if continued wastage and damage to coast resources is to be contained is for one coast ecologist to be based at each major coast centre for monitoring coast dynamics and to provide on-site guidance in the conservation use of the coast, viz Port Nolloth, Cape Town/Stellenbosch (existing), Mossel Bay, Port Elizabeth, East London, Port St Johns, Durban and Richards Bay. These individuals should form a team under the leadership of a central overview group such as the Coastal Unit of the National Research Institute for Oceanology (CSIR).

5. As ecological systems are held together by key factors, scientists or managers must produce on-site salient factor analysis of situations for synoptic assessment on which action and prediction can validly be postulated.

6. Anticipatory planning is required which takes off from the base of the carrying capacity of available resources (ie sustained yield utilization).

7. The "freezing" of land with unique features. A legislative mechanism must be found to protect unique scenic, cultural and scientific areas from damage by human ignorance or greed. The quickest method would be to "freeze" such land or coast until a properly founded synoptic ecological landuse survey had been completed (Heydorn and Tinley 1980).

8. Greater self-sufficiency required at coast resorts in water provision, wind and solar energy sources, and of waste disposal with separation of biodegradable and non-degradable rubbish. To conserve water and protect easily polluted dune aquifers, waterless toilets and other conservation approaches are recommended.

9. Confine any further coast resort housing to existing development nodes so as to protect the wilderness quality of the remaining intervening areas.

5.7 SUMMARY OF MAIN POINTS

5.7.1 Administrative requirements

1. There is an urgent need for the establishment of a coastal management advisory body (as recommended for the Cape coast by Heydorn and Tinley (1980)) but with the added suggestion here of local ecological managers to be based in each coast sector.

(a) This would serve as a clearing house of information for coordination, and

(b) provide an on-site advisory service, on the lines of agricultural extension, with guidelines for permissible coast utilization by private or government agencies.

2. A coast buffer zone along the entire coastline should be proclaimed linking with the Littoral Reserve protected by the Sea Shore Act (No 21 of 1935) ie first dune cordon plus beach, or in the absence of this, 100 m landwards from the backbeach.

3. A legislative means be made for the immediate "freezing" of unique areas or sites, until a properly formed on-site land use analysis has been made (Heydorn and Tinley 1980).

4. Forestry and Nature Conservation Departments should not relinquish their control over the dune reserves where resorts and townships develop.

5. Farmers on the coast should form Conservancy Groups as has been done in the Natal Midlands.

6. Involve local people for whom planning and development is being done, ie community participation in the planning programme.

7 One coast ecologist should be based at each coast centre as soon as practicable to (a) monitor coast dynamics, and (b) to deal with on-site ratification and guidance of coast resource use, especially where it intrudes on the coast buffer zone.

5.7.2 Planning and utilization requirements

1. Coastal transport routes must be positioned at a minimal distance of five kilometres inland from the seashore, with tangential access roads to each coast site along watersheds. The distance of a main route from the coast separates out interest groups and thus the degree of impact.

2. Any development envisaged within 100 m landward of the seaward edge of the unbroken vegetation cover on land, should first obtain on-site ratification from the Department of Environment Affairs.

3. Do not allow any development within reach of the active littoral zone.

4. Determine how much the coast or dune cover is receding, and from this a setback line beyond which no development can be allowed.

5. The key to resource protection should be more by selective control of access and the types of facilities provided than by policing.

6. Frontal dunes, beaches, river mouths, estuaries, riverbanks, floodplains, mudflats, vleis and lagoons are all valuable life supporting resources. No development should be permitted on these landforms, except under special circumstances and then with suitable constraints and obligations.

7. Planning and architecture of resorts and other buildings should be in empathy with the surroundings.

8. The processes themselves should be used as key determinants in planning and development.

9. The following five questions should be answered before allowing any development to take place on the coast (i) what is the scenic, cultural, educational or scientific value of the site, (ii) what is the erosional status of the site, (iii) where are the outer limits of the littoral active zone, (iv) where are the nodes of least change, and (v) what parts are most vulnerable to change.

10. Generally in most situations all permanent developements should be confined to the landward base of dunefields (structures such as lighthouses and fire towers are exceptions).

11. Frontal dunes should not be damaged or eliminated.

12. All footpaths, roads and other accesses from dunes onto beaches must be orientated away from the predominant and gale force wind directions.

13. No overgrazing or trampling out of dunes by game or stock.

14. Fire frequency and occurrence in dune areas must be controlled. Protect developments from hazard or run-away fires in dry season and when Berg Winds occur. (NB Judicious use of fire may be required in special sites to maintain certain habitats or dune types).

15. Promote self-sufficiency of each home in lighting, heating and water provision, and rubbish disposal.

16. Only "cottage industries" should be permitted in coast resorts.

17. Where rooikrans and Port Jackson occur in abundance they should form the basis of an economic opportunity for the poorer communities in the production of wood for home heating and cooking especially in the townships, and of braai wood (and charcoal). These people will initially require aid in transport and marketing.

18. Dune mining should be directed first to areas already modified by other uses, eg sugar-cane lands, which can be regrown in a short time, and not towards the remaining pristine forested or heath-covered dunes. Alternative methods to open-cast mining of dune sand should be explored which leaves the indigenous vegetation in situ. Mining activity should not encroach into the coast buffer zone. Where high concentrations of certain thorium-containing heavy minerals, such as monazite, occur in dune sands natural radioactive levels may greatly exceed the safe limits for humans. These localities and the tailings from dune mining will require to be identified and monitored for their potential health hazard.

19. Landuse allocation maps should be completed for each coast sector as soon as possible, identifying, firstly the coast buffer zone and all existing and proposed protection areas, and secondly the other actual and possible uses of the remaining coast areas.

5.7.3 Reclamation requirements

1. Before any dune reclamation programme is begun the following seven features must be identified:

   (i) What is endangered or threatened by sand drift or dune migration. If nothing, leave alone. If something of value, identify the next six points;

   (ii) the landscape and shoreline position and relationship of the mobile sand;

   (iii) the reach of the littoral active zone;

   (iv) the type of dune;

   (v) which processes are active;

   (vi) the trend and direction of change;

   (vii) determine an action priority of highest to lowest.

2. Reclamation of dunes should be directed to two key sites, (a) at the sand source, and (b) along the landward encroaching front. Reclamation must be done in such a way that the natural processes are harnessed into doing most of the dune building and stabilizing work.

3. Dune stabilizing methods must use flexible materials with open sieve-like characteristics such as brushwood or cut reed mats, under- or interplanted with pioneer dune plants indigenous to the area.

4. Invasive alien and other problem plants should be used as the brushwood source for dune stabilization. Any green or ripe pods must be removed before brushwood is laid.

5. If stabilizing materials are in short supply, old fish nets can be used along the leading edge of a migrating dune, while planting up the backbeach with strand plants. Exposure of a high water-table at the sand source will hold the sand in place.

6. Rebuild dune bluffs of half-heart bays.

7. Assist sand mobility in headland bypass dunes to ensure long-term downdrift sand supply to bay beaches.

8. Reinstate parabolic dune systems by leaving uncovered linear gaps of bare sand parallel to the original local dune axis, in preference to total stabilization of bare dune or sand areas.

9. The local people (including those who only use their resort homes in holiday time) should have dune planting outings to establish strand plants along the backbeach.

10. Rooikrans and Port Jackson thickets should be thinned out and utilized (see 5.7.2 (18) above), and planted with clumps of indigenous shrubs and trees.

5.7.4 Values of coastal dunes

1. Coast dune sands form part of the sediment exchange system of the littoral active zone.

2. Dunes support a diverse and specialized plant cover which provides a coactively malleable front to the elements, and takes part in dune formation and stabilization.

3. Dunes display a variety of relief aspects, edaphic and microclimatic features.

4. On coast plains a high dune cordon results in an increased year-round rainfall on the immediate coast, as does a high foreland elsewhere, and the converse where low dunes or gaps occur.

5. Dune aquifers provide a potable water supply (it is not known what effect pumping out this supply will have on forested dune systems).

6. Dunes provide valuable sweetveld pastures where they abut sour oldland pastures.

7. They are a sand and mineral resource.

8. They have afforestation potential.

9. Dunes have strategic use (eg lighthouses).

10. Backdunes can provide development areas.

11. Vegetated dunes are a valuable subsistence resource for rural people.

12. Dunes are part of the coast environment which is the most important free recreation amenity.

13. Dunes are scenically unique, especially where they combine with other coastforms such as points, bays and river mouths.

14. They have high cultural values - prehistorical (archaeological), historic, artistic, unique scenery and wilderness.

15. Dune plants and animals are a valuable genetic resource in terms of ecosystem dynamics, geographical variation, management, medicine, food, agriculture and forestry.

16. Coast dunes provide a vital link and pathway for plant and animal migration between a diversity of geographical regions.

17. Dunes support unique ecosystem and habitat types, and rare or endemic plants and animals. Also species at their beginning or end-points of their geographical distribution.

5.7.5 Education

1. Develop short television guideline programmes of advertisement length on how coast resources should be protected and used.

2. Creative-learning approach to dune management should be applied (changes made as experience is gained).

3. Dunes provide a field laboratory where dynamics, succession and management can easily be taught. Conspicuous and subtle changes occur over a short time - one tide, a gale wind for one day, storm seas or torrential rain. Dunes exhibit both past and present formative features of practical value in determining permissible coast use.

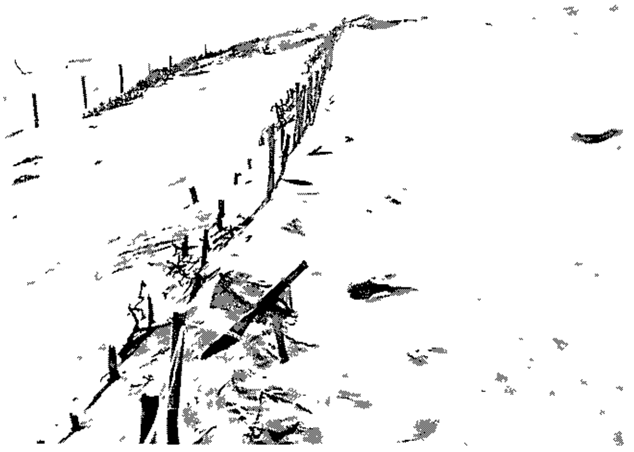


PLATE 127. Establishment of a new littoral dune in the backbeach by erection of slat fences parallel to the shore, and interplanting with beach grasses. Downdrift (east) of Sundays River mouth, Algoa Bay.

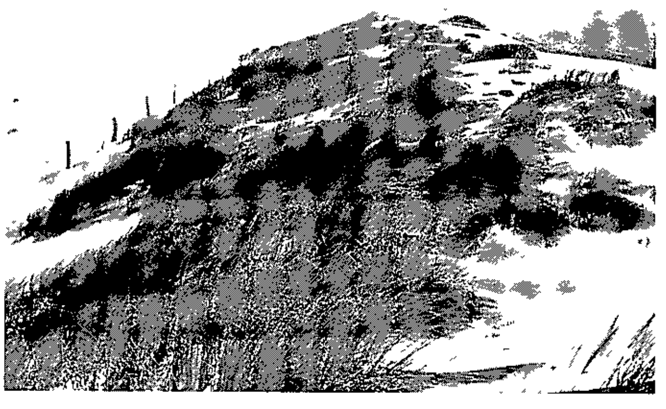


PLATE 128. Successful establishment of new littoral dune; spreading growth of dune grass building the dune upwards and severing the translocation of sand to the Algoa Sand Sea.

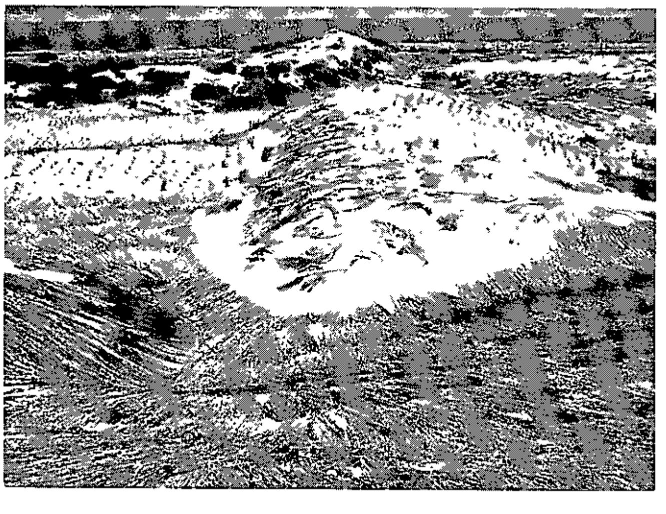


PLATE 129. Efficient stabilization of bare reversing dunes by laying reed mats interplanted with dune pioneer plants. Unprotected plantings mostly unsuccessful. Elands Bay, west coast.

PLATE 130. Method of laying reed mats perpendicular to the slope and meeting along crestlines. Elands Bay.

PLATE 131. Stabilization of bare eroding frontal dunes using a brushwood mat interplanted with strand plants. Note development of a precipitation dune along the seaward edge of the brushwood. Elands Bay, west coast with Bobbiejaansberg in the background.

PLATE 132. Stand of casuarina trees on the foreshore inhibiting strand plant growth and dune development, leaving a trough along which storm seas or equinox tides breach the barrier dune shore protecting estuaries and mangrove swamps. Pomene Bay, south Mocambique Coast.

PLATE 133. Slat-fence erected at Stilbaai to protect beach houses from becoming smothered by drift sand. A new littoral dune has been formed but sand drift continues as there has been no follow-up operation to stabilize the sand. Cape south coast.

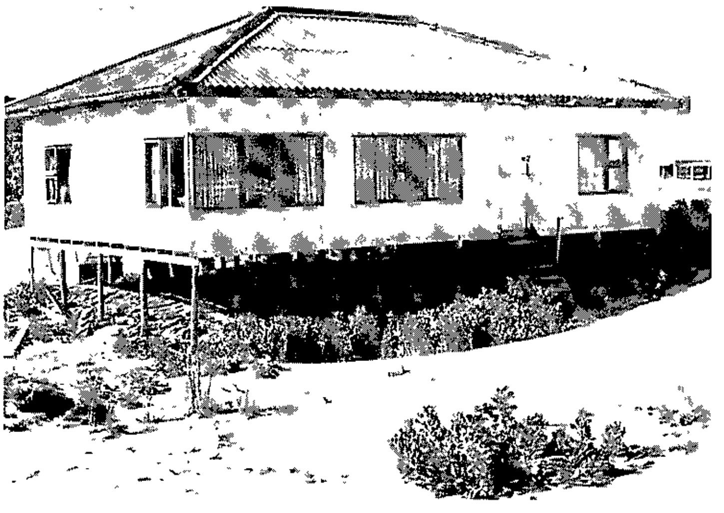


PLATE 134. Beach house supported by stilts as dune sand was scoured out from beneath the foundations to form a typical wind scour hollow associated with solid objects in dunes.

PLATE 135. Beach houses abandoned due to smothering by migrating dunes entrained as part of the sand supply to the climbing-falling dune behind. Silversands, south-west coast.

PLATE 136. Erection of sumptuous holiday houses at the coast in the ephemeral strand plant zone. Albatross area of Jeffreys Bay, St Francis Bay.

PLATE 137. The same house with newly completed, rock-paved, concrete apron already under high tide wave attack (undermining and cracking). Note cliffed duneshore in background.

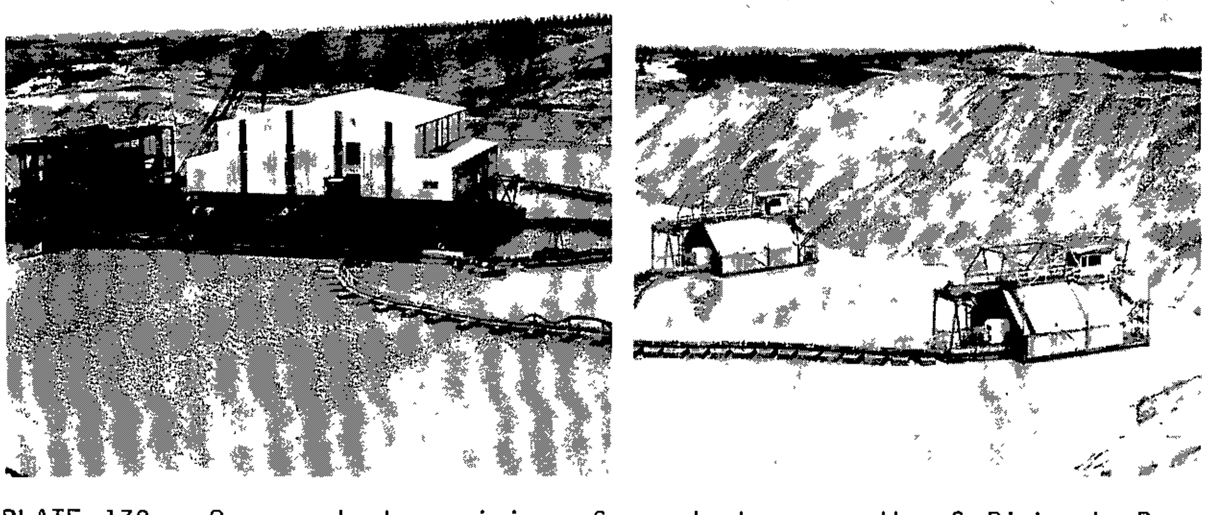


PLATE 138. Open-cast dune mining of coast dunes north of Richards Bay. Paired suction dredgers at work on freshly forming dune slipface of cutting. In the background restabilized worked dune sands.

PLATE 139. Sand tailings left in the wake of the suction dredger is bulldozed in rounded relief and stabilized as in the following plate.

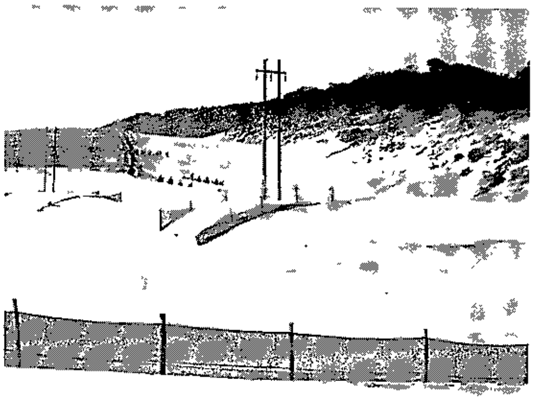


PLATE 140. Stabilization of bare sand left by open-cast mining using parallel series of nets at right angles to the wind to trap the sand, and interplanting with dune flora.

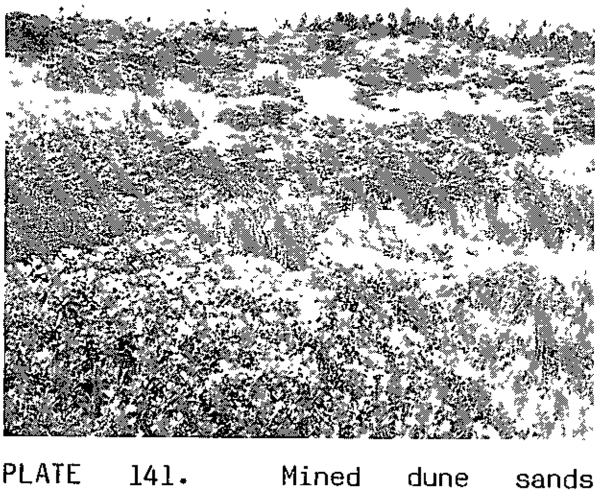


PLATE 141. Mined dune sands completely stabilized by planting of mainly local indigenous grasses, shrubs and trees.

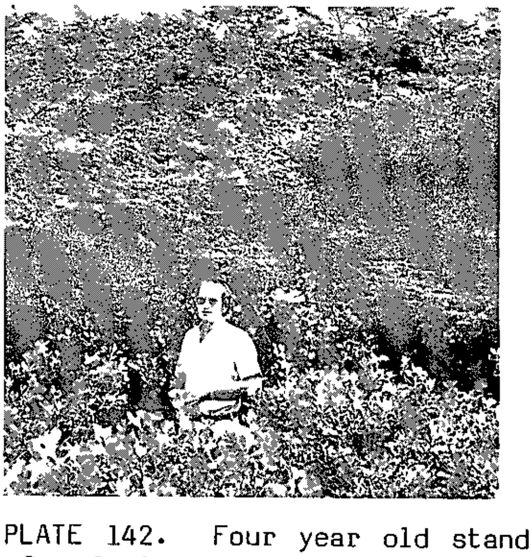


PLATE 142. Four year old stand of planted Acacia karroo in highly successful dune stabilizing programme under the hand of Paul Camp (figured here). Natural woody succession will lead to thicket and eventually forest on the old worked dune sands.

6. ECOSYSTEM PROTECTION STATUS OF COASTAL DUNES

The previous chapter has provided a templet of guiding principles and methods towards the successful conservation of coastal dune areas by any agency or person. The husbanding of resources requires that both utilization and protection measures are applied in tandem. In this way the viability of resource values and products can be more surely retained over the long term. This final chapter appraises the adequacy of present protection of coast dune types and dune biotas in South Africa.

Coastal dunes have a linear pattern of distribution, passing through contrasting geographical regions where a variety of dune forms and combinations have developed. The biotic components, most conspicuously the plant communities, exhibit linear overlapping distribution patterns and gain or lose species from the diverse landward ecosystems which abut the coast.

For these reasons, the array of duneforms, biotic diversity and ecological variability can only be adequately conserved by a system of relatively small reserves located at intervals along the coast (Figure 33). If a coast buffer zone is effected (see Chapter 5) in which development is minimized and controlled, a strip of coast foreland with minimal interference from development will provide an ecological link between reserves of all types along the coast. A representative series of samples of dune ecosystems have been chosen using the following basic criteria (Tinley 1977).

1. concentrations of endemics (modes of endemism),
2. concentrations of biogeographic or ecosystem outliers (end points of distribution),
3. examples of important natural processes (sand dynamics, plant succession),
4. existence of aesthetic landform and ecosystem diversity (including linearly linked habitats such as coast dunes, riverine strips, clifflines, gorges, escarpments and valleys),
5. "ecological quality" of the site (an intact/disturbance rating),
6. danger or threat from human activities (immediate to long term).

Together these provide a templet for identifying priority areas for conservation action. A more detailed means of assessing the conservation potential and ecological value of areas in general is presented by Margules and Usher (1981). More recently a series of papers have examined the subject using different criteria as determinants, depending on the kind of component requiring protection and its particular geographical and ecological setting (Margules et al 1982; Kirkpatrick 1983; McCoy 1983; Reed 1983; Terborgh and Winter 1983).

Due to their dynamic plant-successional relationships the quality of dune systems is not judged on the amount of bare sand or plant cover, but solely on the absence or degree of human interference. The worst disturbance by human activities is of four kinds:

(a) material developments such as wrongly sited buildings, roads, mining etc, (including complete removal of dunes),

(b) degree of invasion by alien plants due to deliberate plantings for stabilization and where disturbance has aided their spread,

(c) damage due to recreational activities (eg unrestricted access of vehicles, pollution),

(d) totally inappropriate planning, zoning and ineffective administrative control (eg pressure from road engineers to push through the construction of a freeway and bridge across the dunes and estuary mouth at Nahoon, East London). What is generally overlooked is that the primary decision may be the wrong one, and no amount of careful post-hoc planning or cosmetic changes can right the initial wrong, and the multiplicity of problems that inevitably follow. The Garden Route is a case in point. It is the original directive that must be questioned, and not the rearrangement of entire ecosystems and human and environmental values in order to mitigate the inadequacies of the initial decision.

Adequately protected whole-dune ecosystems are confined chiefly to the forested dunes of the eastern coasts in Tongaland (KwaZulu Forestry Department and Bureau of Natural Resources), the Lake St Lucia dune range and parts of the east Cape dune cordons which are under the control of the Directorate of Forestry. This department is also responsible for reclamation of bare dune areas on the coast, and thus receive some indirect measure of protection, eg the Algoa Sand Sea is mostly state land under the control of the Directorate of Forestry, except for some small areas on private farmland.

Except for those areas noted above, coast dunes are generally extremely poorly represented in protected areas in Natal, and the whole of the Cape coast west of the Sundays River, despite the existence of protected reserves of six kinds, viz: (1) forestry dune reserves, (2) national parks, (3) provincial reserves, (4) local nature reserves, (5) private nature reserves, and (6) marine reserves (Grindley et al 1976; Cooper 1980; Heydorn and Tinley 1980). In most cases bare dune areas are excluded from these reserves. Exceptional dune systems, such as those west of Cape Agulhas and at the western end of Groenvlei in the Wilderness area, are outside proclaimed reserves.

Both vegetated and bare dune systems are thus recommended for ecological reserve status. Where single dune cordons occur the recommended areas will automatically be afforded protection if the coast buffer zone is implemented. Four dune areas are recommended for protection on the west coast, six on the south-west, 10 on the south coast, one on the east Cape coast, five in the Transkei, 14 sites on the Natal coast and two in Tongaland (KwaZulu) (Figure 33). Ideally these should be incorporated within or linked to, existing coast reserves.

The distribution of forest and thicket in the subcontinent occurs disjunctly along scarps parallel to the coast. These discrete patches are linked at right angles to coastal forest by river valleys. This trellis pattern imposes a major constraint on the possible geometric design for ecological reserves (Diamond 1975). Many relatively small ecological reserves selected in all three topographic units (coastline, river valley and scarp), from the crest of the great escarpment seawards would adequately protect representative samples of the flora along geographical, altitudinal and slope/aspect gradients.

At first glance this may seem an impossible ideal but the following features make such a series of ecological reserves practical:

1. In many instances scarp communities are self-preserving due to their steepness, as are related communities on the steeply incised meander slopes of the river valleys.

2. Protection of the riverine links from catchments to the sea could be enforced by a wider and more assertive application of the soil conservation legislation.

3. The coastline is already protected legally in terms of the Seashore Act (1935) and this can easily be expanded from its intertidal boundary to include the immediate foreland as a national coast buffer zone (ie backbeach plus at least 100 m or the whole first vegetated dune cordon, whichever is the greater).

4. Protection should be promoted by the involvement of a variety of organizations such as, (a) state and provincial conservation authorities, (b) farm conservancies (such as exist in Natal), (c) tribal authority conservancies (Ciskei and Tongaland as recommended by Tinley 1977, 1979; Tinley and van Riet 1981) and, (d) resort township conservancies (eg Betty's Bay and St Francis Bay).

In the final analysis successful conservation of resources lies in the hands of the local people who are in everyday contact with, and dependent to varying degrees on, the resources in their environment.

6.1 UNIQUE COAST DUNE AREAS REQUIRING PROTECTION

Priority dune areas requiring protection status are listed for each coast region. The general location of these areas within which specific reserve boundaries should be demarcated, are indicated in Figure 33.

WEST CAPE COAST

1. Dunes between Holgat and Boegoeberg.
2. Dunes between Bitter and Spoeg Rivers, a 30 km classic example of nearly pristine hairpin deflation parabolics.

3. Elands Bay dunes. These would link the recommended conservation areas at Wadrif, Soutpan and Verlorevlei (Heydorn and Tinley 1980) and must especially give protection to the archaeologically important caves in the Bobiejaansberg.
4. Dwarskersbos prograding parallel dune ridges (south of Rocher Pan Nature Reserve). The adjacent Berg River estuary is a recommended protection area for waders (Grindley et al 1976; Heydorn and Tinley 1980).

SOUTH-WEST CAPE COAST

1. Saldanha dunes immediately east of the iron ore loading berth. Northern limit on west coast of fynbos elements on coast dunes; an ascending parabolic dune type, which should be included in the Langebaan Coast Reserve.

2. Ysterfontein-Langebaan dunefields.

3. False Bay dunes north-west of Macassar Beach.

4. One of the climbing-falling dunes on the Cape Peninsula (the best one if practical is between Hout Bay and Sandy Bay).

5. Littoral dunes at (a) Betty's Bay, including the climbing-falling dune at Silversands) and (b) the Palmiet River mouth at the caravan park.

6. The Agulhas Plain: (a) Renosterkop hummock-blowout dunes between Asfontein and Cape Agulhas. A dune form unique to the subcontinent. (b) Playa lunette dunes occurring nowhere else on the coast in South Africa, and (c) the close proximity to these features of the Soetanysberg with endemic fynbos (the Agulhas Plain area is recommended as a high priority conservation area by Heydorn and Tinley (1980)).

SOUTH CAPE COAST

1. Perched dunes on orange cliffs at Rietvlei east of Stilbaai. Of high geomorphic and scenic importance with karst features and endoreic lake (Heydorn and Tinley 1980).

2. Cape Vacca (Vleesbaai) dunefields including the private Kanonpunt Nature Reserve which has west coast type dwarf dune thicket as found from Rocher Pan northwards to the Olifants River.

3. Groenvlei dunefields east of Swartvlei Mouth. A type locality for classic examples of compound ascending parabolic dunes. Should be added to the existing Goukamma Nature Reserve or given some other protection status (eg Geological Reserve).

4. Buffalo Bay wind-rift dune ridges east of the Goukamma River mouth.

5. Robberg Peninsula, climbing-falling dune (already protected but also requiring national monument status).

6. The Langekloof high wind-rift dune ridges near Slangbaai.

7. The headland bypass dunes across Cape St Francis. A unique suite of parabolic dune types.

8. The barrier dunes and lakelets between Kabeljous and Gamtoos River mouth. An area of extraordinary palaeoecological importance showing traces of the full sequence of Pleistocene sea levels (identified by Butzer and Helgren 1972) and an important dune forest/valley bushveld junction area (Heydorn and Tinley 1980).

9. Dunefields between Gamtoos and van Stadens Rivers.

10. Algoa Sand Sea: dunefield from the Sundays River mouth eastwards to Cape Padrone. The only large bare dunefield system in South Africa, with extremely rich archaeological remains of early man and game. This should include the remnant forested dune sequence at Woody Cape above limestone cliffs which have high interpretive value for elucidating dune dynamics. Several animals are endemic to this area. This is a high priority conservation area recommended by Heydorn and Tinley (1980); McLachlan et al (1982). This dune sea should be linked to the Alexandria Forest area protected by the Directorate of Forestry.

EAST CAPE COAST (including Ciskei)

1. A dune forest reserve is required along this entire sector of coast (Cape Padrone to Kei Mouth) as it is mostly a narrow single cordon and should form part of the coast buffer zone. The bipolar parabolic dunes and landward coast forest immediately south of the Kasuga River mouth should be made a single forest reserve area (see Plate 108A).

TRANSKEI COAST

1. Kobonqaba area.

2. High twin-peaked dune immediately north of Mazeppa Bay.

3. Dune at Nqabara.

4. Mtata River mouth dunes.

5. Dune forest between Mtentwana and Mtamvuna River mouths.

NATAL COAST

As in the Transkei all the modern dunes are small and support thicket or forest, the latter is more typical on the older Berea-type red sands. Fourteen dune areas identified from a March 1982 low-level air survey are recommended (Cooper 1980). They are from south to north:

1. "Red Desert" at Mtamvuna.

2. Zolwane.

3. North Sand Bluff at Port Edward.

4. Between Portobello and Glenmore beaches north of the Tongazi River.

5. Yengele forest on the north side of the Mpenjati River.

6. Mdesingane River mouth area.

7. Durban Bluff.

8. Hawaan forest (at Mhlanga Lagoon) including forested foredunes.

9. Seteni: Strip of dune forest south of Casuarina.

10. Deep forested ravines cut in Berea-type red sands south of Mvoti River mouth.

11. Dune forest between Blythdale Beach and Mdlotane River.

12. Deep forested ravine cut in Berea red sands, south of Nonoti River mouth.

13. Hlogwane forest south of the Tugela Mouth.

14. The entire prograding coast between the Tugela and Mlalazi Rivers at Mtunzini - the best example of a growing coastline in South Africa. This area should also include the Matigula and Nyoni estuaries and the Hwangu forest which are all under KwaZulu jurisdiction. This protection zone should be continued unbroken northwards to Richards Bay in the next coast sector.

KWAZULU/TONGALAND SECTOR OF EAST COAST

1. Mlalazi to Nhlabane Mouth and Cape St Lucia. The only large exposure of the Port Durnford fossiliferous beds. Slump-scar shoreline of erosion cirques developed in red sands overlying clays. A unique coast landform found nowhere else in South Africa.

2. The entire coast dune range from Cape St Lucia north to the Mocambique border. With special emphasis on the high forested dunes of Mapelane, Cape Vidal to St Mary's Hill, Lake Sibayi and the cycad-dominated dunes six kilometres south of Banga Neck.

Glossary of terms

There are five frequently used terms which require specific definition if the reader is to avoid possible confusion.

Estuary - a tidally influenced river mouth including all regions of the physical and biological transition from freshwater to saltwater

River mouth - all non-estuarine river mouths (usually the smaller ones) where tidal mixing of fresh- and saltwater does not take place to any appreciable extent

Coastal lagoon - a more or less confined body of predominantly saltwater, connected to the sea either directly or by one or more tidally influenced channels

Marine wetland - all shallow tidally influenced water bodies, together with their fringing marshes and mud flats; often associated with estuaries and lagoons, characterized by communities of rooted tidal (halophytic) plants

Vlei - area of low marshy ground with a high, often seasonal water-table (vernacular use and proper names such as Verloerevlei, Swartvlei often refer to coastal lagoons)

---

aeolian deposits - rocks or sediments which have accumulated in a non-marine environment (typically on a desert surface) consisting of essentially windblown sand or dust particles

areic - without surface drainage

arenosols - sandy soils of a variety of origins, usually of low nutient and mineral status and low silt/clay ratio

bathymetry - measurement of depth of a water body

berm - a narrow terrace, shelf or ledge of sediment thrown up on the beach by spring tides or storm waves

catena - a sequence of soils (and associated vegetation) of similar derivation and age, having different characteristics due to relief and drainage, typically occurring from hill top to valley bottom

colluvium - a deposit of soil and/or rock fragments accumulated at the base of slopes as a result of gravitational action

cotidal lines - lines on a tidal chart joining points at which high water occurs simultaneously

crenate (crenulate) - having a toothed or notched margin, finely scalloped, with rounded teeth (minutely crenate)

dystrophic - of soil; leached, low in nutrients and minerals, of low inherent productivity, of water bodies; low in nutrient salts but often acidic, humic, with organic matter and tannins, also of low productivity (eg podsols, blackwaters)

ecotone - a boundary zone between two plant communities containing elements of both and often its own characteristic components, consequently an area of high biotic diversity (the edge effect), the zone may be sharp (narrow) or gently intergraded (wide)

edaphic - of the soil, particularly those physical and chemical properties of the soil that influence the plant and other organisms associated with it at a particular site

endemic - confined to and evolved under the unique conditions of a particular region or site

endoreic - drainage inward to an enclosed basin or depression without any link to the sea

eustatic - a widescale change of sea level, probably due to changes in the polar ice caps or to crustal movements in ocean basins

eutrophic - of soil; not leached, relatively high nutrient and mineral status and consequently high inherent productivity, of water bodies; similarly high in nutrient salts and productivity, often used to describe artificially enriched (polluted) waters

ferrallitic - highly weathered, porous lateritic red or yellow soils with little or no reserves of weatherable minerals. Formed in areas where mean annual rainfall is greater than 800 mm. Gibbsite usually present mixed with significant amounts of fine iron oxide

ferruginization - the process of iron oxide deposition on soil particles from weathering of the ferro-magnesium minerals

fersiallitic	-	less weathered red and yellow lateritic soils with higher clay fraction and appreciable reserves of weatherable minerals. Formed in areas where mean annual rainfall is beween 400 and 800 mm
geophytes	-	dry land plants with underground storage organs and perennating buds, from which annual aerial growth is produced
guttation	-	exudation by plants of dilute salt solution through specialized pores - hydathodes. Occurs when conditions favour rapid moisture uptake but low transpiration rates eg humid, windless and cool; often mistaken for dew
fynbos	-	literally, fine-leaved shrub. Local term for the sclerophyllous heathland vegetation of the Mediterranean climate regions of the Cape. Otherwise known as the Cape Floristic Kingdom, smallest of the world's six; stretches from van Rhynsdorp south to the Cape Peninsula and east to scattered patches near Grahamstown, from the coast, upto and including the coastal mountain ranges
halomorphic soils	-	soils having properties determined wholly or in part by the occurrence of neutral or alkaline salts, or both. These are classified as saline, saline-sodic or sodic
halophytes	-	plants which tolerate very salty soils
heterotrophic	-	of consumer and decomposer organisms (usually fauna and microbiota) which depend for their nourishment on organic material (cf autotrophic - of producer organisms, nourished via inorganic material)
horst (and graben)	-	an upthrown block of the earth's crust between two parallel faults. A downthrown block between two parallel faults is a graben
interfluve	-	the area of land between two rivers
isobath	-	line on a map joining points on the seabed at equal depths
isohyets	-	lines on a map connecting points having equal amounts of rainfall
isolines	-	enclosed lines on a map connecting points of equal or relative value

isostasy (isostatic)	-	a condition of presumed equilibrium in the earth's crust whereby equal earth masses underlie equal areas, resulting in movement of and within the earth's crust in response to changes in distribution of surface material
isotherm	-	line on a map joining places having the same temperature at a particular time, or the same average, extremes or ranges of temperatures over a certain period
katabatic (wind)	-	convective descent of cold air. Typically occurs at night in valleys, caused by the gravitational flow of dense chilled air
lateritic weathering	-	the process of soil formation which, in freely drained conditions results in a loss of bases (ca, Mg, K, Na) and silica and relative accumulation of sesquioxides of aluminium and iron. It leads to the formation of fersiallitic and ferallitic soils and residual clays collectively termed laterites. A lateritic hard pan is formed under conditions of fluctuating water-table
lithosols	-	shallow or skeletal soils less than 25 cm deep, often containing rock fragments with exposed bed-rock or gravel
littoral	-	of or pertaining to the seashore. Used more specifically as the zone between high- and low-water
marls	-	crumbly mixture of clay, sand and limestone, usually with shell fragments
montmorillonitic	-	dark, expanding and self-churning clays, typically with high base saturation of water soluble salts (mainly calcium and sodium). Impervious, sticky and plastic when wet; shrinking, cracking and hard when dry, eg black turf soils
palaeoecology	-	the ecology of past geological times, particularly in relation to the associated changing climates
parabolic dune	-	steeply ascending, parabolic shaped, bare, mobile dunes on vegetated sand coast
pediment	-	an inclined planation surface sloping gently away from the foot of mountains or hills. Whilst present in most regions, they are most conspicuous in arid areas
phyllite	-	a cleaved metamorphic rock having affinities with both slates and schists. Formed by low-temperature metamorphism

physiography	-	the science of the surface of the earth and the interrelations of air, water and land
planation surface	-	a plane formed by down-wearing of convex surfaces and the filling in of concave surfaces, which may or may not be covered by a veneer of alluvium. Result of the long-term action of rain, sheetwash, rivers, wind or marine erosion
playa	-	endoreic flat-floored basins in arid areas flooded temporarily, or containing a shallow fluctuating lake usually of saline water. Evaporation results in salts being left behind to form saline and alkaline soils and salt crusts
podzols	-	acid dystrophic soils which develop under moist climatic conditions on quartz-rich parent material. They are intensely leached of bases and iron/aluminium compounds. Podzols support conifers and heaths in the temperate zone, fynbos in the Cape.
rhizomatous	-	producing underground horizontal stems
schist	-	a group of metamorphic rocks with a closely spaced parallel foliation, so that almost any part can be split into flaky sheets
solonetzic soils	-	duplex soils (porous top soil overlying a hard clay sub-soil) with columnar structure which are typically alkaline due to high sodium content
splay deposit	-	a small scale alluvial fan
stoloniferous	-	having stems which grow horizontally along the surface of the ground
swashbank	-	a small sandbank formed in shelving shallows by the upper limit of wave action
sympodial growth	-	a branching system in which the main axis ceases to elongate after a time and one or more lateral branches grow on; these cease to grow and produce laterals which repeat the process
syncline	-	a flexure found in sedimentary rocks, the form of which is concave upwards with the beds rising outwards in opposite directions
talus	-	scree, unconsolidated rubble slopes at the foot of hills, escarpments or cliffs
tectonic	-	of rock structures which are directly attributable to earth movements involved in folding and faulting

BIBLIOGRAPHY

ACOCKS J P H 1975. Veld types of South Africa. Mem Bot Surv S Afr 40, 1-128 pp vegetation map 1,5 million (2 sheets).

ACOCKS J P H 1979. The flora that matched the fauna. Bothalia 12, 673-709.

AFRICA PILOT III 1954. South and east coast of Africa. Admiralty Hydrographic Dept, London.

AFRICA PILOT II 1963. The west coast of Africa. Admiralty Hydrographic Dept, London.

*AIRY-SHAW H K 1947. The vegetation of Angola. J Ecology 35, 23-48.

ANDERSON W 1906. On the geology of the Bluff bare, Durban, Natal. Trans Geol Soc A Afr 9, 111-116.

*ANDERSON W 1907. On the discovery in Zululand of marine fossiliferous rocks of Tertiary Age, containing mammalian remains. 3rd Report Geol Surv Natal & Zululand pp 121-130.

*ATLAS OF AFRICA 1965. Oxford regional economic atlas of Africa. Clarendon Press, Oxford.

AVERY G 1975. Discussion on the age and use of tidal fish traps (visvywers). S Afr Archaeol Bull 30, 105-113.

*AVEYARD J M 1971. Studies on the germination of bitou bush Chrysanthemoides monolifera. J Soil Conserv Serv New South Wales 27, 82-91.

*AXELROD & RAVEN 1978. Extract from Vol 1 of Biogeography & Ecology of southern Africa edited by Werger M J A.

BAGNOLD R A 1941. The physics of blown sand and desert dunes. Morrow W, New York.

*BARBOUR M G, CRAIG R B, DRYSDALE F R and GHISELIN M T 1973. Coastal Ecology. University of California Press, Berkeley.

BARNARD W S 1973. Duinformasies in die sentrale Namib. Tegnikon, 2-13 pp.

BARRADAS L A 1955. Flutuacoes climates e eustaticas no Sul de Mocambique o Quaternario. Bol So de Estudos de Mocambique 90, 69-79.

BARRADAS L A 1962. Esboco Agrologico do Sul de Mocambique. Vol 1. Lourenco Marques. Serv de Agri e Florest e Inst Invest Cient Mocamb. (11 Plano de Fomento) 152 pp.

BARRADAS L A 1965a. Cronologia da beira-mar do Sul de Mocambique. Mem Inst Invest Cient Mocamb 7, Serie B, 23-35 pp.

BARRADAS L A 1965b. Rochas do Quaternario da beira-mar (Sul de Mocambique). Mem Inst Invest cient Mocamb 7, Serie B, 37-84 pp.

*BARRADAS L A 1966/67. Esboco Agrologico do Sul de Mocambique. Mem Inst Invest Mocamb, (2) 8, Serie B, 325-374 pp.

BASCOM W 1964. Waves and beaches. Anchor Books, Garden City, New York.

BASCOM W 1964. Waves and beaches. Anchor Books, Garden City, New York.

BAYER A W 1938. An account of the plant ecology of the coastbelt and midlands of Zululand. Ann Natal Mus 8, 371-455.

BAYER A W 1952. Notes on the vegetation of Natal. I. Natal Wild Life Magazine 1(6).

*BAYER A W & TINLEY K L 1966. The vegetation of the St Lucia Lake Area. In: St Lucia Commission Report 1964-1966, 344-352 pp plus vegetation map.

BAYLEY M G 1960. Review of the Australian beach mining industry. Qd Govt Min J 61, 629-642.

BEATER B E 1970. Soil series of the Natal Sugar Belt. S Afr Sugar Assoc, Durban. Hayne and Gibson Printers.

BEWS J W 1917. The plant succession in the thornveld. S Afr J Sci 14, 153-172.

BEWS J W 1920. The plant ecology of the coastbelt of Natal. Ann Natal Mus 4(2).

BEWS J W 1925. Plant forms and their evolution in South Africa. Longmans, Green & Co, London.

*BICKERTON I B 1981a. Estuaries of the Cape. Part 2. Synopses of available information on individual systems: Spoeg. CSIR Research Report No 400.

BICKERTON I B 1981b. Estuaries of the Cape, Part 2. Synopses of available information on individual systems: Groen. CSIR Research Report No 402.

*BICKERTON I B 1981c. Estuaries of the Cape. Part 2. Synopses of available information on individual systems: Holgat. CSIR Research Report No 404.

*BICKERTON I B 1981d. Estuaries of the Cape. Part 2. Synopses of available information on individual systems: Bitter. CSIR Research Report No 405.

BIGALKE E H 1973. The exploitation of shellfish by coastal tribesman of the Transkei. Ann Cape Prov Mus (Nat Hist) 9, 159-175.

BIRCH G F (In press a). Quaternary sedimentation off the east coast of South Africa (Cape Padrone to Cape Vidal). Geol Surv Bull.

BIRCH G F (In press b). A submerged coastal line ridge on the eastern margin of South Africa. Geo-Marine Letters.

BIRCH G F 1980. Nearshore Quaternary sedimentation off the south coast of South Africa. (Cape Town to Port Elizabeth). Geological Survey of S Afr Bull 67.

BIRCH G F 1981. Bathymetry and geomorphology of the Cape Seas to Cape Recife shelf. Trans Geol Soc S Afr 84(3), 233-237.

BIRCH G F, DU PLESSIS A & WILLIS J P 1978. Offshore and onland geological and geophysical investigations in the Wilderness Lake Region. Trans Geol Soc S Afr 81, 339-352.

*BIRD E C F 1964. Coastal landforms. Canberra, A N U Press Austr.

BIRD E C F 1969. Coasts. M I T Press, Cambridge, Massachusetts, London, 246 pp.

BISH R, WARREN R, WESCHLER L F, CRUTCHFIELD J A & HARRISON P 1975. Coastal Resource Use. University of Washington Press, Seattle.

BOARD C 1962. The border region: Natural environment and land use in the eastern Cape. 2 Vols. Oxford University Press, London.

*are not cited in the text but provide additional reading information

BOND G 1963. Pleistocene environments in southern Africa. In: Howell F C & Bourliere (eds) African Ecology and Human Evolution. Methuen, London, pp 308-334.
*BOND W J 1980. Periodicity in fynbos of the non-seasonal rainfall belt. J S Afr Bot 46(4), 343-354.
*BOORMAN L A 1977. Sand-dunes. In: Barnes R S K (ed) The coastline. Wiley, London, pp 161-197.
BOSAZZA V L 1956. The geology and development of the bays and coastline of the Sul Do Save of Mocambique. Bol Soc Est Mocambique 98, 19-28.
BOSAZZA V L 1957. The Kalahari system in southern Africa and its importance in relationship to the evolution of Man. In: Clark J D & Cole S (eds) Third Pan-African Congress in Pre-history, Livingston 1955. Chatto and Windus, London, pp 127-132.
BOUCHER C 1974. Dune vegetation in the south-western Cape. Veld and Flora 4(4), 67-69.
BOUCHER C 1978. Cape Hangklip area. II. The vegetation. Bothalia 12(3), 455-497.
BOUCHER C 1981. Dune plumes in the western Cape. Veld and Flora 67(1), 11-13.
*BOUCHER C & JARMAN M L 1977. The vegetation of the Langebaan area. Trans roy Soc S Afr 42, 241-272.
BOUCHER C & LE ROUX A (In press). South African west coast strand vegetation: A regional survey. In: Ecosystems of the World series. Springer-Verlag.
BOUCHER K 1975. Global climate. The English University Press.
*BOUGHEY A S 1957. Ecological studies of tropical coastlines. I. The Gold Coast, West Africa. J Ecology 45(3), 665-687.
BOWLER J M 1971. Pleistocene salinities and climatic change. Evidence from lakes and lunettes in south-eastern Australia. In: Mulvaney D J & Golston J (eds) Aboriginal man and environment in Australia. Canberra.
BOWLER J M 1973. Clay dunes: their occurrence, formation and environmental significance. Earth Sci Rev 9, 315-338.
*BOYCE S G 1954. The saltspray community. Ecol Monogr 24, 29-67.
BRADY N C 1974. The nature and properties of soils. (8th ed). MacMillan Publ Co New York and London.
BREEN C M 1971. An account of the plant ecology of the dune forest at Lake Sibayi. Trans roy Soc S Afr 39, 223-234.
BREMNER J M 1977. Sediments on the continental margin off South West Africa between latitudes 17° and 25° S. PhD thesis, University of Cape Town.
*BREMNER J M (In press). Namibia. In: Schwartz M & Bird C (eds) The World's shorelines.
BROWN J C 1958. Soil fungi of some British sand dunes in relation to soil type and succession. J Ecol 46, 641-664.
*BRUTON M N & COOPER K H (eds) 1980. Studies on the ecology of Maputaland. Rhodes University and Natal Branch of the Wildlife Society of Southern Africa. Cape and Transvaal Printers, CT, 560 pp.
BUCKLE C 1978. Landforms in Africa. Longman, London, 249 pp.
BURGES A & DROVER D P 1953. The rate of podsol development in the sands of the Woy Woy district, New South Wales. Aust J Bot 1, 83-94.
BUTZER K W 1972. Geology of Nelson Bay Cave, Robberg, South Africa. S Afr Archaeol Bull 27.
BUTZER K W & HELGREN D M 1972. Late Cenozoic evolution of the Cape coast between Knysna and Cape St Francis, South Africa. Quaternary Research 2(2), 143-169.
CALDWELL L K 1972. The ecosystem as a criterion for public land policy. In: Smith R L (ed) The ecology of Man: An ecosystem approach. Harper & Row, New York & London. pp 410-419.
CALLAN E McC 1964. Ecology of sand dunes with special reference to the insect communities. In: Davis D H S, De Meillon B & Harington J S (eds) Ecological studies in southern Africa. Junk Publishers, The Hague.
CAMPBELL E M 1968. Lunettes in southern South Australia. Trans R Soc S Austr 92, 85-109.
*CAPE PROVINCIAL ROADS DEPT 1981. Circular policy statement on environmental evaluation and assessment of roads. (Circular 29/1981).
*CARTER R W G 1980. Vegetation stabilization and slope failure of eroding sand dunes. Biol Cons 18, 117-122.
CHAPMAN V J 1964. Coastal vegetation. Pergamon Press, Oxford, London. MacMillan Co, New York, 245 pp.
*CHRISTENSEN M S 1980. Sea surface temperature charts for southern Africa. S Afr J Sci 76(12), 541-546.
*CITY OF PORT ELIZABETH METROPOLITAN PLANNING UNIT 1978. Coastal study: A structure plan for the metropolitan coastline. Report No MP 2/78, 1-84 pp.
CLARK J R 1977. Coastal ecosystem management. A technical manual for the conservation of coastal zone resources. John Wiley & Sons, New York, 829 pp.
CLAYTON J L 1972. Salt spray and mineral cycling in two California coastal ecosystems. Ecology 53, 74-81.
*CLOS-ARCEDUC A 1969. Essai d'explication formes dunaires sahariennes. Etudes de photo-interpretation No 4. Inst Geog Nat Paris.
*COALDRAKE J E & BEATTIE K J 1974. Annotated bibliography on the ecology and stabilization of coastal sand dunes, mining spoils and other disturbed areas. Supplement No 1. CSIRO, Canberra, Australia, 103 pp.
*COALDRAKE J E, McKAY M & ROE P A 1973. Annotated bibliography on the ecology and stabilization of coastal sand dunes, mining spoils and other disturbed areas. CSIRO, Canberra, Australia, 158 pp.
COETZEE F 1975a. Coastal aeolianites at Black Rock, northern Zululand. Trans Geol Soc S Afr 78, 313-322.
COETZEE F 1975b. Solution pipes in coastal aeolianites of Zululand and Mocambique. Trans Geol Soc S Afr 78, 323-333.
COMINS D M 1962. The vegetation of the districts of East London and King Williams Town, Cape Province. Mem Bot Surv S Afr 33.
CONSERVATION FOUNDATION, WASHINGTON, USA 1980. Coastal environmental management: Guidelines for conservation of resources and protection against storm hazards. Contract No EQ7AC004.

COOKE H B S 1964. The Pleistocene environment in southern Africa. In: Davis D H S, De Meillon B & Harington J S (ed Ecological studies in southern Africa. Junk Publ, The Hague.

COOKE R U & DOORNKAMP J C 1974. Geomorphology in environmental management. Clarendon Press, Oxford, 413 pp.

COOKE R U & WARREN A 1973. Geomorphology in deserts. California University Press, Los Angeles, 374 pp.

COOPER K H 1980. Preliminary inventory of important areas for conservation in Natal. Conservation Division of the Wildlife Society of S Africa, Durban. Plus map.

*COOPER K H (ed) 1977. A preliminary survey of the Transkei coast. Report of Wildlife Soc S Afr. Linden, Natal, 48 pp.

COOPER K H & MOLL E J 1966. Hlogwene forest. Natal Fieldwork Section Report No 5, 8 pp. Wildlife Society of Southern Africa.

COOPER W S 1967. Coastal dunes of California. Mem Geol Soc Amer 104, 1-124.

CORREIA M M 1969. O regime dos ventos na Beira. Serv Meteor de Mocambique SMM 47, MEM 45.

COWLING R M 1980. The coastal dune ecosystems of the Humansdorp District - A plea for their conservation. The Eastern Cape Naturalist 70, 2 pp.

COWLING R M 1982. Vegetation studies in the Humansdorp Region of the Fynbos Biome. 2 Vols. PhD thesis, University of Cape Town.

CROWE P R 1971. Concepts in climatology. Longmans, London.

CURTIS J T & COTTAM G 1962. Plant ecology workbook. Burgess Publication Co, Minnesota, USA.

D'HOORE J L 1964. Soil map of Africa 1:5 million: Explanatory Monograph. CTCA Publ No 93, Lagos.

*DA MATA L A 1965. Elementos actinometricos de base relativos a Mocambique, de interesse para a engenharia. Serv Meteor da Mocambique SMM16, MEM 14.

*DA MATA L A 1966. Caracteristicas da incidencia da radiacao solar em Mocambique. Serv Meteor de Mocambique SMM23, MEM 21.

*DA ROCHA FARIA J M 1965. Condicoes climaticas de Mocambique. Serv Meteor da Mocambique SMM15, MEM 13.

DA ROCHA FARIA J M & DA MATA L A 1965. Algumas notas sobre a clima de Mocambique. Serv Meteor de Mocambique SMM22, MEM 20.

*DA ROSA J M 1969. Ciclones e depressoes tropicais do Canal de Mocambique. Serv Meteor de Mocambique SMM54, MEM 52.

*DALE I R & GREENWAY P J 1961. Kenya trees and shrubs. Buchanan's Kenya Estates, Nairobi, 654 pp.

DART R A 1955. Three strandlopers from the Kaokoveld coast. S Afr J Sci 51(6), 175-179.

DAVIDSE G & MORTON E 1973. Bird-mediated fruit dispersal in the tropical grass genus Lasiacis (Gramineae: Paniceae). Biotropica 5(3), 162-167.

DAVIES O 1970. Pleistocene beaches of Natal. Ann Natal Mus 20(2), 403-442.

DAVIES O 1971a. Pleistocene shorelines in the southern and south-eastern Cape Province (Part 1). Ann Natal Mus 21(2), 183-223.

DAVIES O 1971b. Pleistocene shorelines in the southern and south-eastern Cape Province (Part 2). Ann Natal Mus 21(2), 225-279.

DAVIES O 1973. Pleistocene shorelines in the western Cape and South West Africa. Ann Natal Mus 21(3), 719-765.

DAVIES K & JARVIS J U M 1982. A preliminary investigation of the ecological role of mole-rats in the Fynbos of the western Cape. Progress Report. Cooperative Scientific Programmes, CSIR, Pretoria, 24 pp.

DAVIES D E 1945. The annual cycle of plants, mosquitoes, birds and mammals in the Brazilian forests. Ecological Monographs 15, 243-295.

DAVIES J L 1964. Morphogenic approach to world shorelines. Ann Geomorph. Vol 8, 127-142.

DAVIES J L 1980. Geographical variation in coastal development (2nd edn). Longman, London and New York, 212 pp.

*DAVIS R A & ETHINGTON R L 1976. Beach and nearshore sedimentation. Soc Econ Palaeontologists and Mineralogists. Special Publication No 24. Tulsa, Oklahoma, USA, 187 pp.

DAY J H 1981. Estuarine ecology: With particular reference to southern Africa. Balkema, Cape Town, 411 pp.

*DAY J, SIEGFRIED W R, LOUW G N & JARMAN M L (eds) 1979. Fynbos ecology: a preliminary synthesis. S Afr Natal Sci Programmes Report 40, 163 pp.

DE CARVALHO M 1969. A agriculture tradicional de Mocambique. Missao de Inquerito Agricola de Mocambique, Lourenco Marques.

DE FIGUEIRIDO NUNES A 1961. Notas sobre os gres costeins do Sul do Save Boletim da Sociedade Geologica de Portugal 14, 47-56.

DE FREITAS A J & BEGG G W 1981. Proposed Mvumase Project, Lower Tugela River. Report of Oceanographic Research Institute Durban, 6 pp.

*DEACON H J 1972. A view of the Post-Pleistocene in South Africa. S Afr Archaeol Soc. Goodwin Series 1, 26-45.

DEACON H J 1974. Patterning in the Radiocarbon Dates for the Wilton/Smithfield Complex in southern Africa. S Afr Archaeol Bull 29(113+114), 3-18.

*DEACON H J 1976. Where hunters gathered: A study of Holocene Stone Age people in the eastern Cape. S Afr Archaeol Soc Monograph No 1, 232 pp.

*DEACON H J 1979. Excavations at Boomplaas Cave - a sequence through the Upper Pleistocene and Holocene in South Africa. World Archaeology 10(3), 242-257.

DEACON H J 1982. The comparative evolution of Mediterranean-type ecosystems: A southern perspective. In: Evolution of Mediterranean-type ecosystems. Springer-Verlag.

*DEACON H J & BROOKER M 1976. The Holocene and Upper Pleistocene sequence in the southern Cape. Ann S Afr Mus 71, 203-214.

DEACON H J, HENDEY Q B & LAMBRECHTS J J N 1983. Fynbos palaeoecology: A preliminary synthesis. S Afr NaH Sci Progr Report No 75.

DEBANO L F 1969. Water repellent soils: A worldwide concern in management of soil and vegetation. Agric Sci Rev US Dept Agric 7, 11-18.

DERRICOURT R M 1977. Prehistoric Man in the Ciskei and Transkei. Struik, Cape Town.
DIAMOND J M 1975. The Island dilemma: Lessons of modern biogeographic studies for the design of natural reserves. Biol Cons 7, 129-146.
DINGLE R V 1971. Tertiary sedimentary history of the continental shelf off southern Cape Province, South Africa. Trans Geol Soc S Afr 74, 173-186.
DINGLE R V & ROGERS J 1972. Pleistocene palaeogeography of the Agulhas Bank. Trans roy Soc S Afr 40(3), 155-165.
DINGLE R V & SCRUTTON R A 1974. Continental break-up and the development of post-Palaeozoic sedimentary basins around southern Africa. Bull Geol Soc Amer 85, 1467-1474.
DU TOIT A L 1922. The evolution of the South African shoreline. S Afri Geog J 4, 1-9.
DYER R A 1937. The vegetation of the divisions of Albany and Bathurst. Mem Bot Surv S Afr No 17.
DYKSTERHUIS E V 1958. Ecological principles in range evaluation. Bot Rev 24, 253-272.
EDWARDS D 1967. A plant ecological survey of the Tugela River Basin. Town & Regional Planning Commission, Pietermaritzburg, Natal.
*EDWARDS D 1974. Survey to determine the adequacy of existing conserved areas in relation to vegetation types. Koedoe 17, 2-37.
ENDRÖDY-YOUNGA S 1982. Dispersion and translocation of dune specialist Tenebrionids in the Namib area. Cimbebasia (A)5, 257-271.
ETHERINGTON J R 1967. Studies of nutrient cycling and productivity in oligotrophic ecosystems. 1. Soil potassium and wind-blown sea-spray in a south Wales dune grassland. J Ecology 55, 743-752.
EVANS G 1979. Quaternary transgressions and regressions. J Geol Soc Lond Vol 136, 125-132.
*EVANS J R 1962. Falling and climbing sand dunes in the Cronese (Cat) Mountain area, San Vernadino County, California. J Geol 70, 107-113
FAIR T J D 1943. Pleistocene and Recent strand movements in Natal. Trans Geol SocS Afr 46, 13-22
FETHERSTON R 1982. Texel's devotion to nature. Geog Mag 54(6), 332-337.
FINKEL H J 1959. The barchans of southern Peru. J Geol 67, 614-647.
FLEMMING B W 1982. Geological and sedimentary processes. In: Heydorn A E F (ed) Ecology of the Agulhas Current Region. Trans roy Soc S Afr 43(2), 162-167.
*FLINT R F & BOND G 1968. Pleistocene sand ridges and pans in western Rhodesia. Bull Geol Soc Amer 79, 299-314.
*FRIEDMAN G M 1961. Distinction between dune, beach and river sands from their textural characteristics. J Sedim Petrol 31, 514-529.
*FROMME G A W 1976. Evaluation of beaches along the Natal south coast. CSIR Report (C/SEA 7604), 16 pp.
FROMME G A W 1980. Determination of the direction of longshore sediment transport by natural tracer tests: A feasibility study. CSIR Report (T/SEA 8011).
FUGGLE R F & ASHTON E R 1979. Climate. In: Day J, Siegfried W R, Louw G N and Jarman M L (eds) Fynbos ecology: A preliminary synthesis. S Afr Natal Sci Progr Report 40, 1-164 pp.
*GALIL J 1967. On the dispersal of the bulbs of Oxalis cernua Thunb by mole-rats (Spalax ehrenbergi Nehring). J Ecology 55(3), 787-792.
*GEIGER R 1965. The climate near the ground. Harvard University Press, Massachusetts, 611 pp.
GIBBS D G & LESTON D 1970. Insect phenology in a forest farm locality in West Africa. J Applied Ecology 7, 519-548.
GIBBS RUSSELL G E & ROBINSON E R 1981. Phytogeography and speciation in the vegetation of the eastern Cape. Bothalia 13(3 & 4), 467-472.
*GIESS W 1968. A short report on the vegetation of the Namib coastal area from Swakopmund to Cape Frio. Dinteria 1, 13-29.
GIESS W 1971. A preliminary vegetation map of South West Africa. Dinteria 4, 114 pp and Map 1:3 million.
*GILLHAM M E 1967. Coastal vegetation of Mull and Iona in relation to salinity and soil reaction. J Ecology 45, 757-778.
*GILLILAND H B 1952. The vegetation of Eastern British Somaliland. J Ecology 40, 91-124.
GILMOUR D A 1968. Water repellence of soils related to surface dryness. Australian Forestry 32(3), 143-148.
GLOVER P E, GLOVER J & GWYNNE M D 1962. Light rainfall and plant survival in East Africa. J Ecology 50, 199-206.
*GODBOLD M 1974. An explanation of the Natal river mouth patterns in terms of coastal and fluvial processes. 3rd Year thesis, unpubl, University of Natal, 58 pp.
GODFREY P J 1978. Management guidelines for parks on barrier beaches. Parks 5(2), 5-10.
*GOHL C R 1944. Drift sand reclamation and coast stabilization in the south western districts of the Cape Province. J S Afr For Ass 12, 14-18.
GOLDBLATT P 1978. An analysis of the flora of southern Africa: its characteristics, relationships and origins. Ann Missouri Bot Gardens 65, 369-436.
GOLDSMITH V 1971. Formation and internal geometry of coastal sand dunes: An aid to palaeographic reconstruction. Abstr Geol Soc Ann 3, 582-583.
GOLDSMITH V 1973. Internal geometry and origin of vegetated coastal sand dunes. J Sedim Petrol 43, 1128-1142.
*GOLDSMITH V (ed) 1977. Coastal process and resulting forms of sediment accumulations. (Currituck Spit, Virginia - North Carolina field guide book). Special report in marine science and ocean engineering. No 143.
GOMES E SOUSA A 1966. Dendrologia de Mocambique 2 Vols. Instituto de investigacao Agronomica de Mocambique. Serie: Memorias No 1.

GOMES E SOUSA A 1968. Breves consideracoes sobre a flora de dispersao maritima de Mocambique. Agron Mocambique 2(3), 127-137. Lourenco Marques.

GOOD R 1964. The geography of the flowering plants. (3rd ed). Longmans, London, 518 pp.

*GOUDIE A 1970. Notes on some major dune types in southern Africa. S Afr Geog J 52, 93-101.

*GOUDIE A S 1977. Environmental change. Contemporary problems in geography series. Clarendon Press, Oxford.

*GRANDVAUX BARBOSA L A 1970. Carta fitogeographica de Angola. Inst Invest Dient de Angola. Luanda.

GRIFFITHS J F (ed) 1972. Climates of Africa. World survey of climatology. Volume 10, Elsevier Publication Co.

GRIME J P & HUTCHINSON T C 1967. The incidence of lime-chlorosis in the natural vegetation of England. J Ecology 55(2), 557-566.

GRINDLEY J R, COOPER K H & HALL A V 1976. Proposals for Marine Nature Reserves for South Africa. Wildlife Soc S Afr & Council for the Habitat.

GROVE A T 1969. Landforms and climatic change in the Kalahari and Ngamiland. Geogri J 134, 194-208.

GROVE A T & PULLAN R A 1963. Some aspects of the Pleistocene palaeogeography of the Chad Basin. In: Howell F C and Bourliere F (eds) African ecology and human evolution. Methuen, London, pp 230-245.

GRUBB P J, GREEN H E & MERRIFIELD R C J 1969. The ecology of chalk heath: Its relevance to the calcicole - calcifuge and soil acidification problems. J Ecology 57(1), 175-212.

GUY P R & JARMAN N G 1969. Preliminary qualitative and quantitative account of the vegetation of Umdoni Park, Natal south coast. Botany Dept, University of Natal. BSc (Hons) dissertation.

HACK J T 1941. Dunes of the Western Navajo County. Geog Rev 31, 240-263.

HALL M 1980. Enkwazini, an Iron Age site on the Zululand coast. Ann Natal Mus 24(1), 97-110.

HALL M 1981. Settlement patterns in the Iron Age of Zululand: An ecological interpretation. Cambridge Monographs in African Archaeology No 5, Oxford, England.

HARMSE H J von M 1978. Schematic soil map of South Africa south of latitude 16° 31'S. In: Werger, M J A (ed) Biogeography and ecology of southern Africa. Volume 1. pp 71-75. Monographiae Biologicae No 31. Junk Publ, The Hague.

HARMSE J T 1982. Geomorphologically effective winds in the northern part of the Namib Sand Desert. S Afr Geo 10(1), 43-52.

*HARRIS T F W 1978. Review of coastal currents in southern African waters. S Afr Natal Sci Programmes Report 30, 103 pp.

HASTENRATH S 1967. The barchans of the Arequipa region, southern Peru. Z Geomorph 11, 300-331.

HAYS J D & PITMAN W C III 1973. Lithospheric plate motion, sea level changes land climatic and ecological consequences. Nature, Lond, 246, 18-22.

*HEDBERG I & HEDBERG O (eds) 1968. Conservation of vegetation in Africa south of the Sahara. Acta Phytogeographica Suecica 54, Uppsala, 320 pp.

*HEINENCKEN T J E 1970. Brief historical background of the Goukamma Nature Reserve (1907 to 1961). Dept Nature Conservation Investigational Report No 15, 14 p.

*HEINENCKEN T J E 1981a. Estuaries of the Cape. Part 2 Synopses of available information on individual systems: Buffels. CSIR Research Report No 401.

*HEINENCKEN T J E 1981b. Estuaries of the Cape. Part 2 Synopses of available information on individual systems: Swartlintjies. CSIR Research Report No 403.

*HEINENCKEN T J E 1981c. Estuaries of the Cape. Part 3 Synopses of available information on individual systems: Gamtoos. CSIR Research Report No 406.

HENKEL J S, BALLENDEN St C & BAYER A W 1936. An account of the plant ecology of the Dukuduku Forest Reserve and adjoining areas of the Zululand Coast Belt. Ann Natal Mus 8(1), 95-125.

*HENNESSY E P 1974. Dune vegetation in Natal. Veld and Flora 4(3).

HEYDORN A E F 1978. Coastal zone management and conservation. Ocean Management 4, 303-317.

HEYDORN A E F & TINLEY K L 1980. Synopsis of the Cape coast - Natural features, dynamics and utilization. Part 1. Estuaries of the Cape series. CSIR Research Report No 380, 97 pp.

HEYDORN A F P J 1975. Plant succession on the sea dunes of Betty's Bay. Veld and Flora 61(2), 26-29.

*HILL B J 1975. The origin of southern African coastal lakes. Trans roy Soc S Afr 41(3), 225-239.

HILLARY O M 1947. An account of the plant ecology of the coastal dunes at Tongaat Beach, Natal, South Africa. MSc thesis. Unpubl. University of Natal.

HOBDAY D K 1976. Quaternary sedimentation and development of the lagoonal complex, Lake St Lucia, Zululand. Ann S Afr Mus 71, 93-113.

*HOBDAY D K & JACKSON M P A 1979. Transgressive shore zone sedimentation and syndepositional deformation in the Pleistocene of Zululand, South Africa. J Sedim Petrol 49(1), 145-158.

*HOBDAY D K & ORME A R 1974. The Port Durnford Formation: A major Pleistocene barrier - lagoon complex along the Zululand Coast. Trans Geol Soc S Afr 77, 141-149.

HOLMES A 1965. Principles of physical geology. Nelson, London. 1288 pp.

*HOYT J H 1966. Air and sand movements in the lee of dunes. Sedimentology 7, 137-144.

*HUNTER I T 1981. On the land breeze circulation of the Natal Coast. S Afr J Sci 77(8), 376-378.

HUNTLEY B J 1965. A preliminary account of the Ngoya Forest Reserve, Zululand. J S Afr Bot 31(3), 177-205.

*HUNTLEY B J 1977a. Terrestrial ecology in South Africa. S Afr J Sci 73, 366-370.

*HUNTLEY B J 1977b. Ecosystem conservation in southern Africa. In: Werger M J A (ed) Biogeography and ecology of southern Africa. Vol 2. pp 1333-1384. Monographiae Biologicae 31, Junk Publ, The Hague.

HURRY L & VAN HEERDEN J 1981. Southern Africa's weather patterns. Via Afrika, Goodwood, CT, 80 pp.

*HUTSON W H 1980. The Agulhas Current during the Late Pleistocene: Analysis of modern faunal analogs. Science 207, 64-66.

HYDRAULICS RESEARCH UNIT, CSIR 1970. Algoa Bay Coastal Erosion Investigation. Parts 1 & 2. National Mechanical Engineering Research Inst. CSIR Report MEG 913.

*INMAN D L & NORDSTROM C E 1971. On the tectonic and morphologic classification of coasts. J Geology 79(1), 1-21.

INSKEEP R R 1978. The peopling of Southern Africa. David Philip, Cape Town and London, 160 pp.

JACKS G V & WHYTE R O 1939. The rape of the Earth. Faber & Faber, London.

JACKSON S P & TYSON P D 1971. Aspects of the weather and climate over southern Africa. Environmental Studies Occasional Paper No 6. Dept Geog and Environ Studies, University of the Witwatersrand, Jhb, 13 pp.

*JAGSCHITZ J S & WAKEFIELD R C 1971. How to build and save beaches and dunes: Preserving the shoreline with fencing and beach grass. University of Rhode Island, College of Resource Development, Kingston R.I.

JEFFRIES R L & DAVY A J (eds) 1979. Ecological processes in coastal environments. Blackwells, Oxford.

JEHNE W & THOMPSON C H 1981. Endomycorrhizae in plant colonization on coastal sand-dunes at Cooloola, Queensland. Austr J Ecology 6, 221-230.

*JENNINGS J N 1965. The influence of wave action on coastal outline in plan. Austr Geogr 6, 36-44.

JONES R 1972. Comparative studies of plant growth and distribution in relation to water logging. V: The uptake of iron and manganese by dune and dune slack plants. J Ecology 50(1), 131-139.

*KEET J D M 1936. Report on drift sands in South Africa. For Ser Un S Afr No 9.

*KILLIGREW L P & GIKES R J 1974. Development of playa lakes in South Western Australia. Nature London 247, 454-455.

*KIMBER M L 1969. Plant succession on sand-dunes of the Oregon Coast. Ecology 50, 695-704.

KING C A M 1962. Beaches and Coasts. (2nd ed). Edward Arnold, London, 570 pp.

KING L C 1962. Morphology of the Earth. Oliver & Boyd, Edinburgh, London.

KING L C 1967. South African scenery. (3rd ed revised). Oliver & Boyd, London, 308 pp.

*KING L C 1972a. The Natal monocline. University of Natal, Durban, 113 pp.

KING L C 1972b. The coastal plain of South East Africa: Its form, deposits and development. Zeit fur Geomorph 16, 239-251.

*KING N L 1939. Reclamation of the Port Elizabeth drift sands. J S Afr For Ass 2, 5-10.

KIRKPATRICK J B 1983. An iterative method for establishing priorities for the selection of Nature Reserves: An example from Tasmania. Biol Conserv 25(1), 127-134.

KLEIN R G 1972. The Late Quaternary mammalian fauna of Nelson Bay Cave (Cape Province, South Africa): Its implications for megafauna extinctions and environmental and cultural change. Quaternary Res 2(2), 135-142.

KLEIN R G 1980. Environmental and ecological implications of large mammals from Upper Pleistocene to Holocene sites in southern Africa. Ann S Afr Mus 81(7), 223-283.

KLINGE H 1969. Climatic conditions in lowland tropical podzol areas. Trop Ecol 10, 222-239.

KOCH C 1961. Some aspects of abundant life in the vegetationless sand of the Namib Desert dunes. Scient Pap Namib Desert Res Stn No 1, 8-92.

KREFT J 1973. The occurrence of Guti in Rhodesia. Met Notes, series A No 40. Meteorological Services of Rhodesia, Salisbury, 12 pp.

*KRUGER F J 1977. Ecological reserves in the Cape Fynbos: Towards a strategy for conservation. S Afr J Sci 73, 81-85.

KRUGER F J 1979a. Fire. In: Day J, Siegfried W R, Louw G N & Jarman M L (eds) Fynbos Ecology: A preliminary synthesis. S Afr Natal Sci Progr Report 40, 1-166 pp.

KRUGER F J 1979b. South African heathlands. In: Specht R L (ed) Heathlands and related shrublands of the world. Elsevier, Amsterdam.

*LANCASTER N 1981. Aspects of the morphometry of linear dunes of the Namib Desert. S Afr J Sci 77, 366-368.

*LANDSBERG S Y 1956. The orientation of dunes in Britain and Denmark with respect to the wind. Geog J 122, 176-189.

LANGDALE-BROWN L, OSMASTON H A & WILSON J G 1964. The vegetation of Uganda and its bearing on land-use. Govt Printer, Entebbe, Uganda.

*LAVER C G 1936. Reclamation of drift sands. Farming S Afr 11, 53-57.

*LAWRENCE R F 1953. The biology of the cryptic fauna of forests. (With special reference to the indigenous forests of South Africa). A A Balkema, Cape Town, Amsterdam, 408 pp.

*LE ROUX P J 1976. Stabilization of dune sand at Borgo Bonsignore in Italy. Suid-Afrikaanse Bosboutydskrif 97, 44-46.

LEATHERMAN S P (ed) 1979. Barrier islands. Academic Press, New York.

LEATHERMAN S P & GODFREY P J 1979. The impact of off-road vehicles on coastal ecosystems in Cape Cod National Seashore: An overview. University of Massachusetts NPSCRU Report No 34.

LEOPOLD A 1949. A Sand County Almanac.

LIDDLE M J 1975. A selective review of the ecological effects of human trampling on natural ecosystems. Biol Cons 7, 17-36.

LIVERSIDGE R 1972. A preliminary study of fruit production in certain plants. Ann Cape Prov Mus (Nat Hist) 9(3), 51-63.

LLOYD P S & PIGGOTT C D 1967. The influence of soil conditions on the course of succession on the chalk of southern England. J Ecology 55(1), 137-146.

*LOCK B E 1973. Tertiary limestones at Needs Camp, near East London. Trans Geol Soc S Afr 76, 1-5.

LOGAN R F 1960. The central Namib Desert, South West Africa. Publ Nat Acad Sci 758, 1-141.

LONGMAN K A & JANIK J 1974. Tropical forest and its environment. Longman, Tropical Ecology Series, London.
LOUW G N 1972. The role of advective fog in the water economy of certain Namib Desert animals. Symp 2001 Soc Land 31, 297-314.
LOUW G N & SEELY M K 1980. Exploitation of fog water by a perennial Namib dune grass Stipagrostis subulicola. S Afr J Sci 76(1), 38-39.
*LOUW W J 1976. Mesoclimate of the Port Elizabeth-Uitenhage metropolitan area. Weather Bureau of South Africa, Technical Paper No 4.
*LOUW W J 1980. Aspekte van die reënvalgeskiedenis van Suid-Afrika. S Afr Weather Bureau Newsletter 373, 119-124.
*LOUW W J 1981. Ariditeit in suidelike Afrika. S Afr Weather Bureau Newsletter, 386, 85-88.
LOUW W J 1982. Rawson se Siklus. S Afr Weather Bureau Newsletter 400, 103-105.
LOXTON, HUNTING & ASSOCIATES 1969. Survey of the natural resources of Maputuland. (mapped survey).
MABBUTT J A 1977. Desert landforms. The MIT Press, Cambridge, Massachusetts, 340 pp.
MACNAE W & KALK M (eds) 1958. A natural history of Inhaca Island, Moçambique. Witwatersrand University Press, Jhb, 163 pp.
MACVICAR C N, DE VILLIERS J M, LOXTON R F, VERSTER E, LAMBRECHTS J J N, MERRYWEATHER F R, LE ROUX J, VAN ROOYEN T H and HARMSE H J VON M 1977. Soil classification: A binomial system for South Africa. Dept Agric Techn Services, Pretoria.
*MACVICAR, C N (ed) 1973. Soil Map Republic of South Africa: Interim Compilation (Map 1:2,5 million). Soil & Irrigation Dept Res Inst. Dept Agric & Techn Services, Pretoria.
MAGGS T 1980. The Iron Age sequence south of the Vaal and Pongola Rivers: Some historical implications. J Afr Hist 21(1), 1-15.
*MAGGS T M O'C 1971. Some observations on the size of human groups during the Late Stone Age. S Afr J Sci supplement, Special Issue No 2.
MAINGARD L F 1931. The lost tribes of the Cape. S Afr J Sci 28, 487-504.
MALHERBE I DE V 1962. Soil Fertility. (4th English ed). Oxford University Press, Cape Town, London, New York.
MARGULES C & USHER M B 1981. Criteria used in assessing wildlife conservation potential: A review. Biological Conservation 21, 79-109.
MARGULES C, HIGGS A J & RAFE R W 1982. Modern biogeographic theory: Are there any lessons for nature reserve design? Biol Conserv 24(2), 113-128.
MARKER M E 1976. Aeolianite: Australian and South African deposits compared. Ann S Afr Mus 71, 115-124.
MARKHAM C G & McLAIN D R 1977. Sea surface temperature related to rain in Ceara, north-eastern Brazil. Nature 265, 320-323.
*MARTIN A K 1981. Evolution of the Agulhas Current and its palaeo-ecological implications. S Afr J Sci 77, 547-554.
*MARTIN A R H 1960. The ecology of Groenvlei, a South African fen. Part 1. Secondary communities. J Ecology 48, 55-71. Part II. The secondary communities. J Ecology 48, 307-329.
MARTIN A R H 1962. Evidence relating to the Quaternary history of the Wilderness Lakes. Trans Geol Soc S Afr 65(1), 19-42.
*MAUD R R 1961. A preliminary review of the structure of coastal Natal. Trans Geol Soc S Afr 64, 247-256.
MAUD R R 1965. Laterite and lateritic soil in coastal Natal, South Africa. J Soil Sci 16, 60-72.
MAUD R R 1968. Quaternary geomorphology and soil formation along the Natal coast. Zeit Geomorph Suppl 7, 155-199.
MAUD R R 1982. Geomorphic genesis of the east and south-east coasts of Africa in the Quaternary. Unpubl man.
McCARTHY M J 1967. Stratigraphical and sedimentological evidence from the Durban region of major sea-level movements since the Late Tertiary. Trans Geol Soc S Afr 70, 135-165.
McCARTHY M J 1969. The origin of the Durban Bluff and Aliwal Shoal. Petros 1, 39-45.
McLACHLAN A 1980a. The definition of sandy beaches in relation to exposure: A simple rating system. S Afr J Sci 76, 137-138.
McLACHLAN A 1980b. Exposed sandy beaches as semi-closed ecosystems. Marine Environment Research 4, 59-63.
McLACHLAN A, ERASMUS T, DYE A H, WOOLRIDGE T, VAN DER HORST G, LASIAK T A & McGWYNNE L 1981. Sand beach energetics: An ecosystem approach towards a high energy interface. Estuarine, Coastal & Shelf Science 13, 11-25.
McLACHLAN A, SIEBEN P R & ASCARAY C 1982. Survey of a major coastal dunefield in the eastern Cape. University of Port Elizabeth, Zoology Department Report Series No 10, 48 pp.
McLACHLAN A, WOOLRIDGE T & DYE A H 1981. The ecology of sandy beaches in southern Africa. S Afr J Zool 16(4), 219-231.
McCOY E D 1983. The application of Island-Biogeographic Theory to patches of habitat: How much land is enough. Biol Conserv 25(1), 53-61.
McHARG I L 1969. Design with nature. The Natural History Press, New York.
McKEE E D 1979. A study of global sand seas. Geological Survey. Professional Paper No 1052, USA, Govt Printer, Washington, 429 pp.
McKEE E D 1982. Sedimentary structures in dunes of the Namib Desert, South West Africa. Geol Soc Amer. Special Paper No 188, 64 pp.
MEIDNER H 1963. Sea, sand, salt and sap. S Afr J Sci 9(11), 532-535
MEIGS P 1966. Geography of coastal deserts. UNESCO Arid Zone Research 28, 1-140.
*MERCER J H 1973. Cainozoic temperature trends in the southern hemisphere: Antarctic and Andean glacial evidence. Palaeoecol Afr 8, 85-114.
*MIDDLEMISS E 1963. The distribution of Acacia cyclops in the Cape Peninsula area by birds and other animals. S Afr J Sci 59(9), 419-420.

*MIDGELEY D C & PITMAN W V 1969. Surface water resources of South Africa. University Witwatersrand Report 2/69, 127 pp.

MILLER A A 1959. Climatology. Methuen, London, Dutton, New York, 318 pp.

MOCAMBIQUE METEOROLOGICAL SERVICES 1968. Tabua de apuramento anual do vento a superficie por classes e rumos, em percentagem - Lourenco Marques 1951-1960. Serv Meteor de Mocambique SMM 45, MEM 43.

*MOLL E J 1968. An account of the plant ecology of the Hawaan Forest, Natal. J S Afr Bot 34(2), 61-89.

MOLL E J 1972. A preliminary account of the dune communities at Pennington Park, Mtunzini, Natal. Bothalia 10, 615-626.

*MOLL E J 1974. A preliminary report on the Dwesa Forest Reserve, Transkei. Combined Wildlife Society of S Afr and University of Cape Town Wildlife Society Report.

MOLL E J 1981. Trees of Natal. University of Cape Town, Eco-lab Trust Fund. ABC Press, Cape Town, 567 pp.

*MOLL E J & WHITE F 1977. The Indian Ocean coastal belt. In: Werger M J A (ed) Biogeography and ecology of southern Africa. Vol 1, pp 561-598. Monographiae Biologicae 31, Junk Publ, The Hague.

MONKHOUSE F J 1976. A Dictionary of Geography. Arnold, London.

MONOD T 1963. The Late Tertiary and Pleistocene in the Sahara and adjacent southerly regions. In: Howell F C and Bourlier F (eds) African ecology and human evolution. Methuen, London, pp 117-229.

MONOD T 1973. Les deserts. Horizons de France.

MOORE W G 1959. A Dictionary of Geography. Penguin Books, Great Britain.

*MORTON J K 1957. Sand dune formation on a tropical shore. J Ecology 45(2), 495-497.

MOUNTAIN E D 1966. Footprints in calcareous sandstone at Nahoon Point. S Afr J Sci 62(4), 103-111.

MOURA A R 1969. Contribuicao para o conhecimento dos gres costeiros do Sul do Save (Mocambique). Bol Serv Geol Minas, Mocambique No 35, 5-59.

*MUIR J 1929. The vegetation of the Riversdale Area, Cape Province. Mem Bot Surv S Afr 13.

MUIR J 1937. The seed-drift of South Africa and some influences of ocean currents on the strand vegetation. Bot Surv Mem No 16, 124 pp. Govt Printer, Pretoria.

MURGATROYD A L 1979. Geologically normal and accelerated rates of erosion in Natal. S Afr J Sci 75, 395-396.

MYRE M 1971. As pastagens da regiao do Maputo. Inst Invest Agronomica de Mocambique. Serie Memorias No 3.

NAGEL J F 1962. Fog precipitation measurements on Africa's southwest coast. Notos 11, 51-60.

*NAGTEGAAL P J C 1973. Adhesion-ripple and barchan-dune sands of the recent Namib (South West Africa) and Permian Rotliegend (North West Europe) deserts. Madoqua series II vol 2, Nos 63-68, 5-19.

*NATIONAL SCIENCE FOUNDATION 1973. Managing Coastal Lands. Mosaic 4(3).

*NETTERBERG F 1969. The interpretation of some basic calcrete types. S Afr Archaeol Bull 24, 117-122.

*NETTERBERG F 1971. Calcrete in road construction. CSIR Research Report 286, NIRR Bulletin No 10, 73 pp.

NEWALL N D 1961. Recent terraces of tropical limestone shores. Zeits Geomorph Suppl 3, 87-106.

NICHOLSON S E & FLOHN H 1980. African environmental and climatic changes and the general atmospheric circulation in Late Pleistocene and Holocene. Climatic Change 2, 313-348.

NICHOLSON T H 1960. Mycorrhiza in the Gramineae: II Development in different habitats, articularly sand dunes. Trans Brit Mycol Soc 43(1), 132-145.

NOBLE R G & HEMENS J 1978. Inland water ecosystems in South Africa - a review of research needs. S Afr Nat Sci Prog Report 34, 1-150 pp.

NORRIS R M 1969. Dune reddening and time. J Sedim Petrol 39, 7-11.

OATLEY T B 1959. Report on sock-stripping along the coastline between St Lucia Estuary and St Mary's Hill (Leven Point) in January 1959. Natal Parks Board internal report, 7 pp.

ODUM W E 1976. Ecological guidelines for tropical coastal ecosystems. IUCN Publ New Series No 42, Morges, Switzerland, 60 pp.

*OLSON J S 1958. Lake Michigan dune development. 2. Plants as agents and tools in geomorphology. J Geology 66, 345-351.

OLSON-SEFFER P 1909. Relation of soil and vegetation on sandy sea shores. Bot Ga 67, 85-126.

OOSTING H J 1954. The ecological processes and vegetation of the maritime strand in the south-eastern United States. Bot Rev 20, 226-262.

OOSTING H J & BILLINGS W D 1942. Factors effecting vegetational zonation on coastal dunes. Ecology 23, 131-142.

*ORME A R 1973. Barrier and lagoon systems along the Zululand coast, South Africa. In: Coates D R (ed) Coastal geomorphology. Binghampton State University of New York, pp 181-187, Techn Rep Office of Naval Res (1).

*ORME A R 1975. Late Pleistocene channels and Flandrian sediments beneath Natal estuaries: A synthesis. Ann S Afr Mus 71, 77-85.

*ORME A R & LOEHER L L 1974. Remote sensing of subtropical coastal environments, Natal, South Africa. Office of Naval Research Techn Rep No 5, 89 pp.

OSBORN J F, PELISHEK R E, KRAMMES J S & LETEY J 1964. Soil wettability as a factor in erodibility. Proc Soil Sci Soc Amer 29, 294-295.

PALGRAVE K C 1977. Trees of southern Africa. C Struik, CT and Jhb, 959 pp.

*PARKIN D W & SHACKLETON N J 1973. Trade Winds and temperature correlations down a deep-sea core off the Sahara Coast. Nature 245, 455-457.

*PHILLIPS J F V 1926. General biology of the flowers, fruits and young regeneration of the more important species of the Knysna forests. S Afr J Sci 23, 366-417.

PHILLIPS J F V 1931. Forest-succession and ecology in the Knysna region. Mem Bot Surv S Afr 14, 327 pp.

PLAYER I C 1972. Big Game. Caltex Series No 5, National Commercial Printers, Cape Town.

POLHILL R M 1968. Tanzania. In: Hedberg, Inga and Olov (eds) Conservation of vegetation in Africa south of the Sahara, pp 166-178. Acta Phytogeographica Suecica 54, Uppsala, 320 pp.

POOLEY A C 1968. A short note on the diet of the vervet monkey Cercopithecus aethiops in Zululand. The Lammergeyer 9, 29-31.
POYNTON R J 1971. A silvicultural map of southern Africa. S Afr J Sci 67(2), 58-60 with maps of thermal and moisture regions.
PRELL W L & HUTSON W H 1979. Zone temperature-anomaly maps of Indian Ocean surface waters: Modern and Ice-Age patterns. Science 206, 454-456.
PRESTON-WHYTE R A 1970. Land breezes and rainfall on the Natal Coast. S Afr Geog J 52, 38-43.
*PRESTON-WHYTE R A 1975. A note on some bioclimatic consequences of coastal lows. S Afr Geog J 57(1), 17-35.
PRICE W A 1962. Stages of oxidation coloration in dune and barrier sands with age. Bull Geol Soc Amer 73, 1281-1283.
PROCTOR M & YEO P 1973. The pollination of flowers. The New Naturalist Series, Collins, London.
PYE K 1981. Rate of dune reddening in a humid tropical climate. Nature 290, 582-584.
*RANWELL D S 1958. Movement of vegetated sand dunes at Newborough Warren, Anglesey. J Ecology 46, 83-100.
*RANWELL D S 1959. Newborough Warren, Anglesey. I. The dune system and dune slack habitat. J Ecology 47, 571-601.
*RANWELL D S 1960. Newborough Warren, Anglesey. II. Plant associes and succession cycles of the sand dune and dune slack vegetation. J Ecology 48, 117-141.
*RANWELL D S 1979. Strategies for the management of coastal systems. In: Jeffries R L & Davy A J (eds) Ecological processes in coastal environments. Blackwell, Oxford, pp 515-542.
RAUNKIAER C 1934. The life forms of plants and statistical geography. Oxford University Press, London.
REED T M 1983. The role of species-area relationships in reserve choice: A British example. Biol Conserv 25(1), 263-271.
REEDER C J & JURGENSEN M F 1979. Fire induced water repellency in forest soils of Upper Michigan. Can J For Res 9, 369-373.
REEVES C C (ed) 1972. Playa Lake Symposium. ICASALS Publ No 4, Lubbock, Texas, USA.
*REINECK H E & SINGH I B 1973. Deposition sedimentary environments. Springer-Verlag, Berlin.
RHODES R C 1968. Some aspects of the post-depositional history of the red sands in coastal Natal. S Afr J Sci 64(3), 145-149.
RICHARDS P W 1957. The Tropical Rain Forest. Cambridge University Press, London.
RIDLEY H 1930. The dispersal of plants throughout the world. Reeve Co, Ashford, England.
RITCHIE W 1980. On the waterfront. Geog Mag 52(12), 810-816.
RN AND SAAF 1941/1944. Weather on the coasts of southern Africa. Vol 2, Parts 1 to 5a. Meteorological services of the Royal Navy and South African Air Force.
ROBERTSON T C 1968. Soil is Life. Caltex Series, Cape and Transvaal Printers, Cape Town.
*ROBINSON E R & GIESS W 1974. Report on the plants noted in the course of a trip from Luderitz Bay to Spencer Bay, January 10-21. Dinteria 10, 13-17.
ROGERS J 1971b. Sedimentology of Quaternary deposits on the Agulhas Bank. S Afr Natal Committee for Oceanographic Research, Marine Geology Programme Bulletin No 1.
ROGERS J 1977. Sedimentation on the continental margin off the Orange River and the Namib Desert. PhD thesis, University of Cape Town.
ROOSEBOOM A 1978. Sedementavoer in Suider-Afrikaanse riviere. Water S Afr 4(1), 14-17.
ROUX E R & MARAIS C C G 1964. Rhizobial nitrogen fixation in some South African acacias. S Afr J Sci 60(7), 203-204.
ROUX E R & WARREN J L 1963. Symbiotic nitrogen fixation in Acacia cyclops. A Cunn S Afr J Sci 59, 294.
RUDDOCK A 1968. Cainozoic sea-levels and diastrophism in a region bordering Algoa Bay. Trans Geol Soc Afr 71, 209-233.
RUDNER J 1968. Strandloper pottery from South and South West Africa. Ann S Afr Mus 49(2), 441-663.
*SA MOREIRA LOPES M E 1973. Algumas notas sobre o clima da Inhaca. Mem Insti Invest Cient Mocambique 9(B), 17-52.
SALISBURY E J 1921. The significance of the calcicolous habit. J Ecology 8, 202-215.
SALISBURY E J 1925. Note on the edaphic succession in some sand dunes with special reference to the time factor. J Ecology 13, 322-328.
SALISBURY E J 1952. Downs and Dunes: Their Plant Life and its Environment. Bell, London.
SARNTHEIN M 1978. Sand deserts during glacial maximum and climatic optimum. Nature 272, 43-46.
SAUER J D 1965a. Geographic reconnaissance of Western Australia seashore vegetation. Aust J Bot 13, 39-69.
SAUER J D 1965b. Notes on the seashore vegetation of Kenya. Ann Missouri Bot Ard 52, 438-443.
SAUER J D 1967. Plants and Man on the Seychelles Coast. University of Wisconsin Press, Madison, Milwaukee and London, 132 pp.
SCHALKE H J W G 1973. The upper Quaternary of the Cape Flats area. Scripta Geol 15, 1-55.
SCHULZE B R 1965. Climate of South Africa. Part 8. General Survey. Weather Bureau of S Afr Publ No 28, 330 pp. Pretoria.
*SCHULZE B R 1969. The climate of Gobabeb. Scient Pap Namib Desert Res Stn No 38, 5-12.
SCHULZE G C 1983. 'n Moontlike verband tussen die Suidelike Ossilasie/El Nino - verskynsels en droogtes oor die Somerreënvalstreke van Suid-Afrika: 'n voorlopige studie. Afr Weather Bureau Newsletter No 410, 79-84.
SCHULZE R E & McGEE O S 1978. Climatic indices and classification in relation to the biogeography of Southern Africa. In: Werger M J A (ed) Biogeography and ecology of southern Africa. Vol 1, pp 19-52. Monographiae Biologicae 31, Junk Publ, The Hague.
SCHWARTZ M L & BIRD E C F (1984). The World's shorelines.
*SCHWEITZER F R 1979. Excavations at Die Kelders, Cape Province, South Africa. Ann S Afr Mus 78(10), 101-233.
SEELY M K 1974/75. Namib Dune Coast reconnaissance, 1973. Namib und Meer 5/6, 15-26.
SEELY M K 1979. Irregular fog as a water source for desert dune beetles. Oecologia 42, 213-227.

SEELY M K & HAMILTON W J III 1976. Fog catchment sand trenches constructed by tenebriod beetles, Lepidochora, from the Namib Desert. Science 193, 484-486.
SENANAYAKE F R, SOULE M & SENNER J W 1977. Habitat values and endemicity in the vanishing rain forests of Sri Lanka. Nature 265, 351-354.
SHEPARD F P & WANLESS H R 1971. Our changing coastlines. McGraw-Hill, New York 577 pp.
SHEPARD FP & YOUNG R 1961. Distinguishing between beach and dune sands. J Sedim Petrol 31, 196-214.
*SIDDLE D J 1975. Rural plans most likely to succeed. Geog J 67(2), 681-684.
SIESSER W G 1972a. Petrology of the Cainozoic coastal limestones of the Cape Province, South Africa. Trans Geol Soc S Afr 75, 117-185.
*SIESSER W G 1972b. Abundance and distribution of carbonate constituents in some African coastal and offshore sediments. Trans roy Soc S Afr 40(4), 261-277.
*SIESSER W G 1972c. Limestone lithofacies from the South African continental margin. Sedimentary Geology 5(8), 83-112.
SIESSER W G 1974. Relict and recent beachrock from southern Africa. Bull Geol Soc Amer 85, 1849-1854.
SIESSER W G & DINGLE R V 1981. Tertiary sea-level movements around southern Africa. J Geology 89, 83-96.
SILVESTER R 1960. Stabilization of sedimentary coastlines. Nature 188 (4749), 467-469.
SIMBERLOFF D S & ABELE L G 1976. Island biogeography theory and conservation practise. Science 191, 285-286.
*SIMS T R 1906. The forests and forest flora of the Colony of the Cape of Good Hope.
*SKEAD C J 1967. Ecology of birds in the eastern Cape. Ostrich, Suppl 7, 1-103.
SLINGSBY P & BOND W 1981. Ants - friends of the fynbos. Veld and Flora 67(2), 39-45.
*SNOW D W 1971. Evolutionary aspects of fruit-eating by birds. Ibis 113, 194-202.
SOARES DE CARVALHO G 1961. Geologia do Deserto de Mocâmedes (Angola). Mem Junta Invest Ultram. 2nd Ser. No 26, 277 pp.
*SOARES DE CARVALHO G 1974. Notice on sedimentological, chronostratigraphic and geomorphological problems of Inhaca Island. Mem Inst Invest Cien Mocambique 10, Serie B pp 51-71.
SOUTH AFRICA YEARBOOK 1977. Official Yearbook of the Republic of South Africa. 4th edn S Afr Dept Information. Perskor, Johannesburg.
SOUTH AFRICAN WEATHER BUREAU 1952. Climate of South Africa: Part 1 - Climate statistics. WB 19, Pretoria.
SOUTH AFRICAN WEATHER BUREAU 1960. Climate of South Africa: Part 6 - Surface Winds. WB 26, Pretoria.
SOUTH AFRICAN WEATHER BUREAU 1975. Climate of South Africa: Part 12 - Surface Winds. WB 38, Pretoria.
SPEED E 1969. Prehistoric shell collectors. S Afr Aracheol Bull 24(3 & 4).
*ST LUCIA LAKE 1964/66. Report of the Commission of Enquiry into the alleged threat to animal and plant life in St Lucia Lake. Commission of the State President of the Republic of South Africa. 371 pp.
STAFFORD D B & LANGFELDER J 1971. Air photo survey of coastal erosion. Photogramm Engng 37, 565-575.
STEERS J A 1966. Coastal Changes. In: Darling F F & Milton J P (eds) Future environments of North America. The National History Press, New York, pp 539-551.
STEERS J P (ed) 1971. Introduction to coastline development. London, MacMillan.
STEHLE T C 1980a. Waaisandbestuurplan vir die Alexandriakusstaatbos 1981/2 tot 1990/1. Dept of Forestry Report.
STEHLE T C 1980b. Aantekeninge oor die gebruik van inheemse plantegroei vir die herrinnering van waaisande in die bosstreek: Oos-Kaap. Dept of Forestry Report.
STIRTON C H (ed) 1978. Plant Invaders. ABC Press, Cape Town. Cape Dept of Nature Conservation.
STREET F A & GROVE A T 1976. Environmental and climatic implications of Late Quaternary lake-level fluctuations in Africa. Nature 261, 385-390.
SWART H 1981. An ode to the tube factory. Zigzag 5(2), 10-11.
*SWIFT D J P 1968. Coastal erosion and transgressive stratigraphy. Journal of Geology 76, 444-456.
*TAKEHARA M O H 1967. Revised Standard Soil Colour Charts. Japan.
TALJAARD J J 1982. March maximum of the rainfall over the western plateau of southern Africa. S Afr Weather Newsletter No 397, 51-53.
*TANKARD A J 1975. Pleistocene history and coastal morphology of the Ysterfontein-Elands Bay area, Cape Province. Ann S Afr Mus 69(5), 73-119.
TANKARD A J 1976a. Cenozoic sea-level changes: A discussion. Ann S Afr Mus 71, 1-17.
*TANKARD A J 1976b. Stratigraphy of a coastal cave and its palaeoclimatic significance. Palaeoecology of Africa 9, 151-159.
TANKARD A J & ROGERS J 1978. Late Cenozoic palaeoenvironments on the west coast of southern Africa. Journal Biogeography 5, 319-337.
*TAYLOR H C 1972. Notes on the vegetation of the Cape Flats. Bothalia 10(4), 637-646.
TAYLOR H C 1978. Capensis. In: Werger M J A (ed) Biogeography and ecology of southern Africa. Junk, The Hague. 2 Vols. pp 171-229.
*TAYLOR H C & MORRIS J W 1981. A brief account of coast vegetation near Port Elizabeth. Bothalia 13(3 & 4), 519-525.
TERAMURA A H 1980. Relationships between stand age and water repellency of chaparral soils. Bull Torrey Bot Club 107(1), 42-46.
*TERBORGH J 1975. Faunal equilibria and design of wildlife preserves. In: Golley F B & Medina E (ed) Tropical ecological systems: Trends in terrestrial and aquatic research. Springer-Verlag, Berlin.
TERBORGH J & WINTER B 1983. A method for siting parks and reserves with special reference to Colombia and Equador. Biol Conserv 27(1), 45-58.
*THOM B G, McLEAN R F, LANGFORD-SMITH T & ELIOT I 1973. Seasonal beach change, Central and South Coast, New South Wales. In: Engineering Dynamics of the coastal Zone. Sydney, Institution of Engineers Australia. Nat Conf Publ No 73/1, pp 131-134.
THOMPSON B W 1965. The climate of Africa. Oxford University Press, Oxford.
TINLEY K L 1958a. A preliminary report on the ecology of Lake Sibayi, Tongaland. Natal Parks Board Report. 44 pp and vegetation map 1:36 000 (traced from airphotos of 1942).

TINLEY K L 1958b. A preliminary report on the ecology of the Kosi Lake System, Tongaland. Natal Parks Board Report. 90 pp and vegetation map 1:36 000 (traced from airphotos of 1942).

TINLEY K L 1966. An ecological reconnaissance of the Moremi Wildlife Reserve, Botswana. Okavango Wildlife Soc. Gothic Printers, Cape Town.

TINLEY K L 1967. The moist evergreen forest - tropical dry semideciduous forest tension zone in north-eastern Zululand and hypotheses on past temperate/montane rain forest connections. In: van Zinderen Bakker E M (ed) Palaeoecology of Africa 2, 82-85. Balkema, Cape Town.

TINLEY K L 1970. Proposed maritime national parks and a dugong and sea turtle sanctuary in the Bazaruto Island region of the Mocambique Coast. Report to the Mocambique Govt. Conservation Section of Veterinary Dept. 12 pp. 6 figs.

*TINLEY K L 1971a. Lake St Lucia and its peripheral sand catchment. Wildlife Society of South Africa. 62 pp. 7 figs.

TINLEY K L 1971b. Determinants of coastal conservation: Dynamics and diversity of the environment as exemplified by the Mocambique Coast. In: Nature Conservation as a form of land use. Proceedings SARCCUS Symposium. Govt Printer, Pretoria. pp 125-153.

TINLEY K L 1975a. Habitat physiognomy, structure and relationships. In: Die Soogdiernavorsingsinstituut 1966-1975, Symposium proceedings. University of Pretoria Publ. New Series No. 97, 69-77.

*TINLEY K L 1975b. Salient features of the Dwessa Forest reserve and its place in the regional economy. In: Planning and management proposals for the Dwessa Forest Reserve, Transkei. By Farrel & Van Riet Landscape Planners, Pretoria. pp 67-88.

*TINLEY K L 1976. The ecology of Tongaland. The Natal Branch of the Wildlife Society. 140 pp.

TINLEY K L 1977. Framework of the Gorongose ecosystem, Mocambique. DSc thesis, University of Pretoria.

TINLEY K L 1979. The maintenance of wilderness diversity in Africa. In: Player, Ian (ed) Voices of the Wilderness. Jonathan Ball Publ Johannesburg. pp 29-42.

TINLEY K L 1981. A double take at Durban's waves. Zigzag 5(3), 10-11.

TINLEY K L 1982. The influence of soil moisture balance on ecosystem patterns in southern Africa. In: Huntley B J & Walker B H (eds) Ecology of Tropical Savannas. Ecological Studies Vol 42. pp 175-192. Springer-Verlag, Berlin.

TINLEY K L & DE SOUSA DIAS A H 1970. Wildlife reconnaissance of the Mid Zambeze Valley in Mocambique before completion of the Caborabassa Dam. Veterinaria Mocambicana.

*TINLEY K L & DE SOUSA DIAS A H 1973. Wildlife reconnaissance of the Mid-Zambezi Valley in Mocambique before formation of the Caborrabassa Dam. Veterinaria Mocambicana 6(2), 103-131.

TINLEY K L & VAN RIET W F 1981. Tongaland: Zonal ecology and rural land use proposals. Dept of Cooperation and Development contracted study for the KwaZulu Govt. 186 pp. 33 figs. 96 plates.

TORQUATO J R 1970. Origin and evolution of the Mocamedes Desert. In: Dessauvagie T F J & Whiteman A J (eds) African Geology. Ibadan, Nigeria.

TRUDGILL S T 1977. Soil and vegetation systems. Contemporary problems in Geography Series. Clarendon Press, Oxford.

TRUSWELL J F 1977. The Geological Evolution of South Africa. Purnell, Cape Town & London.

*TURNER J S, CARR S G M & BIRD E C F 1962. The dune succession at Corner Inlet, Victoria. Proc Roy Soc Victoria, (Australia). 75(1), 17-33.

*TWIDALE C R 1972. Evolution of sand dunes in the Simpson Desert, central Australia. Trans Inst Br Geog 56, 77-109.

TYSON P D 1964. Berg Winds of South Africa. Weather 19(1), 7-11.

TYSON P D 1969. Atmospheric circulation and precipitation over South Africa. Environmental Studies Occasional Paper No 2. Dept Geog and Environ Studies, University of the Witwatersrand, Jhb. 21 pp.

TYSON P D 1977. The enigma of changing world climates. S Afr Geog J 59(2), 77-116.

TYSON P D 1978. Rainfall changes over South Africa during the period of meteorological record. In: Werger M J A (ed) Biogeography and ecology of southern Africa. Vol 1. pp 53-69. Monographiae Biologicae 31. Junk Publ, The Hague.

TYSON P D (ed) 1971. Outeniqualand: The George-Knysna area. The South African Landscape No 2. S Afr Geog Soc. 23 pp.

USHER M B 1977. Coastline management: Some general comments on management plans and visitor surveys. In: Barnes R S K (ed) The Coastline. Wiley, London. pp 291-311.

VAN DER ELST R & TREGONING C 1984. The harvesting of intertidal fauna by subsistence gatherers and visiting fishermen on the Maputuland Coast. Oceanographic Res Inst Invest Report. Durban (in press).

VAN DER EYK J J, MacVICAR C N & DE VILLIERS J M 1969. Soils of the Tugela Basin. Town and Regional Planning Commission, Natal. Vol 15.

VAN DER MAAREL E 1979. Environmental management of coastal dunes in the Netherlands. In: Jeffries R L & Davy A J (eds) Ecological processes in coastal environments. Blackwell, Oxford, pp 543-570.

VAN DER MERWE C R 1962. Soil groups and subgroups of South Africa. (2nd ed revised). Govt Printer, Pretoria.

VAN DER PIJL 1972. Principles of dispersal in higher plants. (2nd ed). Springer-Verlag, Berlin.

*VAN HELDIN P D 1981. The contribution of small areas to conservation. Veld and Flora 67(1), 25-27.

VAN WYK A E 1981. Die botaniese waarde van die Umtamvuna-Natuurreservaat en die moontlike inlywing van aangrensende gebiede. Verslag van die Departement Plantkunde, Universiteit van Pretoria. 6 pp. 1 map (to appear in Dendrologiese Tydskrif).

*VAN ZINDEREN BAKKER E M 1975. The origin and palaeoenvironment of the Namib Desert biome. J Biogeography 2, 65-73.

*VAN ZINDEREN BAKKER E M 1976a. The evolution of Late-Cenozoic palaeoclimates of southern Africa. Palaeoecology of Africa 9, 160-202.

VAN ZINDEREN BAKKER E M 1976b. Late Quaternary environmental changes in southern Africa. Ann S Afr Mus 71, 141-152.

VAN ZINDEREN BAKKER E M 1978. Quaternary vegetation changes in southern Africa. In: Werger M J A (ed) Biogeography and Ecology of southern Africa. Vol 1. pp 132-143. Junk Publ, The Hague.

VAN ZINDEREN BAKKER E M & BUTZER K W 1973. Quaternary environmental changes in southern Africa. Soil Science 116(2), 236-248.

VENTER H J T 1972. Die plantekologie van Richardsbaai, Natal. DSc thesis. University of Pretoria.

VENTER H J T 1974. 'n Plantekologiesie studie van die duinwoud by Sibayimeer, noordoos-Zoeloeland. Universiteit van die OVS, Unpubl MSc thesis.

VENTER H J T 1976. An ecological study of the dune forest at Mapelane, Cape St Lucia, Zululand. J S Afr Bot 42(2), 211-230.

*VERSTAPPEN H Th 1972. On dune types, families and sequences in areas of unidirectional winds. Gott Geogr Abh 60, 341-354.

*VESEY-FITZGERALD D F 1940. On the vegetation of Seychelles. J Ecology 28, 465-483.

VESEY-FITZGERALD D F 1942. Further studies of the vegetation on islands in the Indian Ocean. J Ecology 30, 1-16.

*VESEY-FITZGERALD D F 1955. The vegetation of the Red Sea coast south of Jedda, Saudi Arabia. J Ecology 43, 477-489.

*VESEY-FITZGERALD D F 1957a. The vegetation of the Red Sea coast north of Jedda, Saudi Arabia. J Ecology 43, 547-562.

*VESEY-FITZGERALD D F 1957b. Coastal desert sand associations, Central Arabia. J Ecology 45, 793-795.

*VINES R G 1980. Analyses of South African rainfall. S Afr J Sci 76(9), 404-409.

VOGT G 1979. Adverse effects of recreation on sand dunes: A problem for coastal zone management. Coastal Zone Management Journal 6(1), 37-68.

*VON BREITENBACH F 1972. Indigenous forests of the southern Cape. J Bot Soc S Afr 58, 18-47.

VON WILLERT D J, BRINCKMANN E & SCHULZE E D 1979. Ecophysiological investigations of plants in the coastal desert of southern Africa: Ion content and Crassulacean acid metabolism. In: Jeffries, RL & Davy A J (eds) Ecological processes in coastal environments. pp 321-331. Blackwell, London.

WAGAR J A 1972. Growth versus the quality of life. In: Smith R L (ed) The Ecology of Man: An ecosystem Approach. Harper and Row, New York & London. pp 400-408.

WALSH B N 1968. Some notes on the incidence and control of drift sands along the Caledon, Bredasdorp and Riversdale coastline of South Africa. Dept Forestry Bulletin No 44, 79 pp. Govt Printer, Pretoria.

WALTER H 1971. Ecology of tropical and subtropical vegetation. Oliver & Boyd, London.

WALTER H 1976. Gibt es in der Namib Nebelpflanzen? Namib und Meer 7, 5-13.

WARD C J 1980. The plant ecology of the Isipingo Beach area, Natal, South Africa. Mem Bot Surv S Afr 45, 147 pp.

WARREN A & MAINGUET M 1982. Defences against the aeolian threat. Geog Mag 54(3), 165-167.

*WASSON R J & HYDE R 1983. Factors determining desert dune type. Nature 304, 337-339.

WEBLEY D M, EASTWOOD D J & GIMINGHAM C H 1952. Development of a soil microflora in relation to plant succession on sand-dunes, including the "rhizosphere" flora associated with colonizing species. J Ecology 40, 168-178.

*WEINERT H H 1976. Past climate derived from calcrete and N-value. Ann S Afr Mus 71, 133-140.

WEISSER P J 1978a. Changes in area of grasslands on the dunes between Richards Bay and the Mfolozi River 1937 to 1974. Proc Grassld Soc S Afr 13, 95-97.

WEISSER P J 1978b. A vegetation study of the Zululand dune areas. Natal Town & Regional Planning Report. No 38, 64 pp.

*WEISSER P J 1979. Suitability of air-photo interpretation for monitoring coastal dune vegetation on the Zululand dunes, South Africa. In: The use of ecological variables in environmental monitoring. The National Swedish Environmental Protection Board, Report PM 1151, pp 62-72.

*WEISSER P J 1980. The dune forest of Maputaland. In: Bruton M N & Cooper K H (eds) Studies on the ecology of Maputaland. 560 pp. Rhodes University & Natal Branch of the Wildlife Society of southern Africa. pp 78-90.

WEISSER P J 1982. Vegetation and conservation priorities in the dune area between Richards Bay and Mlalazi estuary. Report of Botanical Research Institute, Pretoria, 111 pp.

WEISSER P J & COOPER K H (in press). The dry coastal ecosystems of the South African east coast. In: Van der Maarel E (ed) Dry coastal ecosystems. Ecosystems of the world series. Elsevier Publ Co.

WEISSER P J & DREWS B K 1980. List of vascular plants of the forested dunes of Maputaland. In: Bruton M N & Cooper K H (eds) Studies on the ecology of Maputaland. 560 pp. Rhodes University & Natal Branch of the Wildlife Society of southern Africa. pp 91-101.

*WILSON I G 1972. Sand waves. New Scient 53, 634-637.

WEISSER P J & HOWARD-WILLIAMS C 1982. The vegetation of the Wilderness Lakes system and the macrophyte encroachment problem. Bontebok 2, 19-40.

WEISSER P J & MARQUES F 1979. Gross vegetation changes in the dune area between Richards Bay and the Mfolozi River, 1937-1974. Bothalia 12(4), 711-721.

WEISSER P J & MULLER R 1983. Dune vegetation dynamics from 1937 to 1976 in the Mlalazi-Richards Bay area of Natal, South Africa. Bothalia 14(3 & 4).

WEISSER P J, GARLAND I F & DREWS B K 1982. Dune advancement 1937-1977 and a preliminary vegetation succession chronology at Mlalazi Nature Reserve, Mtunzini, Natal, South Africa. Bothalia 14.

WELLINGTON J H 1955. Southern Africa: A geographical study. Vol 1. Physical geography. Cambridge University Press.
*WERGER M J A (ed) 1978. Biogeography and ecology of southern Africa. 2 Vols. Junk Publ, The Hague. Monographiae Biologicae Vol 31, 1439 pp.
WHITE F 1977. The underground forests of Africa: A preliminary review. Gardens' Bulletin, Singapore 29, 57-71.
*WHITMORE J S 1971. South Africa's water budget. S Afr J Sci 67, 166-176.
*WILD H & GRANDVAUX BARBOSA 1967. Vegetation of the Flora Zambeziaca area. Map 1:25 million with Supplement edited by Wild H & Fernandes A. Sailisbury, Rhodesia.
WILD H 1964. The endemic species of the Chimanimani Mountains and their significance. Kirkia 4, 125-157.
*WILD H 1968. Phytogeography of South Central Africa. Kirkia 6, 197-222.
*WILLIS A J & YEMM E W 1961. Braunton burrows: Mineral nutrient status of the dune soils. J Ecology 69, 377-390.
WILSON K 1960. The time factor in the development of dune soils at South Haven Peninsula, Dorset. J Ecology 48, 341-359.
*WILSON I G 1971. Desert sandflow basin and a model for the development of ergs. Geog J 137, 180-199.
*WOODS HOLE OCEANOGRAPHIC INSTITUTION 1980. The Coast. Oceanus 23(4).
*WRIGHT L D 1977. Sediment transport and deposition at river mouths: A synthesis. Geol Soc Amer Bull 88, 857-868.
WRIGHT T W 1955a. Profile development in the sand dunes of Culbin Forest, Morayshire. I Physical properties. Soil Sci 7, 33-42.
WRIGHT T W 1955b. Profile development in the sand dunes of Culbin Forest, Morayshire. II Chemical properties. Soil Sci 7, 33-42.
YAALON D H & LOMAS J 1976. Factors controlling the supply and chemical composition of aerosols in a near shore and coastal environment. Agric Meteor 7, 370-381.
ZENKOVITCH V P 1967. Processes of coastal development. Oliver & Boyd, Edinburgh, 738 pp.
ZWAMBORN J A 1969. Coastal erosion and beach restoration measure. CSIR Report MEG 859.

RECENT TITLES IN THIS SERIES

75. *Fynbos palaeoecology: a preliminary synthesis. H J Deacon, Q B Hendey and J J N Lambrechts (editors). December 1983. 216 pp.

76. *A South African perspective on conservation behaviour - a programme description. Compiled by A A Ferrar. December 1983. 34 pp.

77. Limnology and fisheries potential of Lake Le Roux. B R Allanson and P B N Jackson (editors). December 1983. 182 pp.

78. Limnology of Lake Midmar. C M Breen (editor). December 1983. 140 pp.

79. The limnology of the Touw River floodplain. B R Allanson and A K Whitfield. December 1983. 35 pp.

80. *SANCOR: Summary report on marine research 1983. SANCOR. February 1984. 52 pp.

81. South African Antarctic Earth Science Research Programme. SASCAR. February 1984. 53 pp.

82. *The SANCOR marine sedimentology programme January 1984-December 1988. I C Rust (editor). March 1984. 15 pp.

83. *A description of major vegetation categories in and adjacent to the Fynbos biome. E J Moll, B M Campbell, R M Cowling, L Bossi, M L Jarman, C Boucher. March 1984. 29 pp.

84. Environmental research perspectives in South Africa. February 1984. 77 pp.

85. Invasive alien organisms in the terrestrial ecosystems of the Fynbos Biome, South Africa. I A W Macdonald and M L Jarman (editors). April 1984. 72 pp.

86. Terrestrial ecology in South Africa - project abstracts for 1982-1983. May 1984. 198 pp.

87. Conservation priorities in lowland fynbos. M L Jarman. May 1984.

88. A synthesis of plant phenology in the Fynbos Biome. Shirley M Pierce. December 1984. 57 pp.

89. Aquaculture in South Africa: A cooperative research programme. O Safriel and M N Bruton. June 1984. 79 pp.

90. Pipeline discharges of effluents to sea. D A Lord, F P Anderson and J K Basson (editors). October 1984. 108 pp.

91. Monitoring in South African Grasslands. M T Mentis. September 1984. 55 pp.

92. *Conservation of threatened natural habitats. Anthony V Hall (editor). November 1984. 185 pp.

93. Limnological criteria for management of water quality in the Southern Hemisphere. R C Hart and B R Allanson (editors). December 1984. 181 pp.

94. Water quality criteria for the South African coastal zone. J A Luscher (editor). December 1984. 42 pp.

95. National Programme for Weather, Climate and Atmosphere Research Annual Report 1984/85. C W Louw (compiler). December 1984. 28 pp.

96. A guide to the literature on research in the grassland biome of South Africa. N M Tainton. December 1984. 77 pp.

97. South African Red Data Book - Birds. R K Brooke. December 1984. 213 pp.

98. Directory of southern African conservation areas. T Greyling and B J Huntley (editors). December 1984. 311 pp.

99. *The effects of crude oil pollution on marine organisms. A C Brown. February 1985. 33 pp.

100. *SANKON : Opsommingsverslag oor mariene navorsing 1984. SANKON. Februarie 1985. 53 pp.

101A Verslag van die Hoofprogram vir Navorsingsondersteuning. Februarie 1985. 30 pp.

101E Report of the Main Research Support Programme. February 1985. 30 pp.

102. National programme for remote sensing. Report: 1984. P J van der Westhuizen. February 1985. 50 pp.

103. Bibliography of marine biology in South Africa. A supplement to the 1980 edition. A C Brown. March 1985. 83 pp.

104. The plant communities of Swartboschkloof, Jonkershoek. D J McDonald. March 1985. 54 pp.

105. Simulation modelling of fynbos ecosystems: systems analysis and conceptual models. F J Kruger, P M Miller, J Miller and W C Oechel (editors) March 1985. 101 pp.

106. The Kuiseb environment: the development of a monitoring base line. B J Huntley (editor). March 1985. 138 pp.

107. Annotated bibliography of South African indigenous evergreen forest ecology. C J Geldenhuys. May 1985. 125 pp.

108. Review of metal concentrations in Southern African coastal waters, sediments and organisms. August 1985. 140 pp.