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Floristic composition and vegetation ecology of the Malindi Bay coastal dune field, Kenya

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Abstract. A short outline is given of the floristic composition, structure and distribution of coastal dune vegetation found at Malindi Bay, Kenya. The area was studied by air photo interpretation and field sampling to determine the relationship of plants to aeolian features. TWINSPAN classification was used to distinguish geomorphological units on the basis of their species composition.

In this paper, an inventory and first quantitative analysis of vegetation distribution is presented. We identified 174 plant species from 62 families in the sand dunes and several plant communities are distinguished based on the species content and the connection with morphological units. *Papilionaceae* with 18 species and *Poaceae* with 17 species were the most represented families. A distinct zonal distribution of the plant communities was found.

The most important plant species are the pioneer vegetation consisting of *Halopyrum mucronatum, Ipomoea pes-caprae* and *Scaevola plumieri*. The woody shrub species which have colonized the established primary dunes and hummock dunes are *Cordia somaliensis*, *Pluchea discoridis*, *Tephrosia purpurea (dunensis)*. Succulent herbs were identified in the dune slacks and salt marsh that are moist and damp environments.

Keywords: Classification; Coastal dune; Ecosystem; Geomorphological unit; Geomorphology; Monsoon; Structure; Tropical.

Introduction

Interest in the factors that control the stability and instability of the natural dune ecosystem has grown as the demands for their recreational and industrial usage have increased and as the value of dunes as natural coastal defence has been recognized. The dynamic dune management procedure requires that as much as possible of their natural aesthetics are retained during coastal development and management. However, when coastal infrastructure is threatened by transgressive sand sheets, the most effective method of arresting such dune mobility is the use of sand binding vegetation because littoral vegetation is capable of trapping sand close to the beach.

Exceptions occur where the rate of aeolian sand transport from the beach is so high that vertical growth of vegetation is unable to keep pace, or where vegetation vigour is inhibited for other biological or environmental reasons. This is normally the case where vegetation is disturbed or destroyed through human settlement, trampling, farming, overgrazing, collection of fuelwood or construction of tourist amenities as is happening in the study area. Disturbance of vegetation cover caused the reactivation of previously stabilized dunes.

The area under investigation is a distinct morphodynamic system with well defined boundaries, representing the littoral sediment cell extending from Malindi to Mambrui. It gets more distinct from the extremities in north and south, towards the Sabaki river in the middle of the stretch.

The aeolian sediments forming the current foredune system and drifting sands are derived from the beach, which is supplied by the Sabaki river. However, the mobile sand climbing over the dune ridges is a combination of beach sand and sand resulting from erosion of older stabilized dunes (Abuodha 2000).

The literature on coastal dune vegetation in the tropics is rather scanty and it is therefore envisaged that the present data set will instigate more investigations into the ecological status of the present dunes. In addition, this investigation will assist in the evaluation of a suitable vegetation community which may be used in future coastal dune management and conservation in the Malindi Bay area.

Several studies on the coastal vegetation in East Africa have appeared (Dale 1939; Moomaw 1960; Birch 1963; Frazier 1974). These reports describe only the nature of the coastal vegetation, but specifically, little or no detailed information on Kenya's dune vegetation and ecology exists. Studies of the relationship between vegetation and dune formation along the coast of East Africa are few. Barker et al. (1989) investigated vegetation dynamics in coastal Somalia and concluded that sand dune encroachment directly influences vegetation structure and composition due to saltation and deposition. About 75% of plant species in the dune field have therapeutic or medicinal properties when the present taxonomic list is cross-checked against the catalogue by Kokwaro (1993) of medicinal plants in East Africa.

In South Africa's south coast more recent accounts have centred on the use of both indigenous and alien vegetation in dune stabilization and coastal management (Stehle 1988; Avis 1989). Castillo et al. (1991) studied the sand dune vegetation along the tropical coast of the Mexican states of Tabasco and Campeche. These studies show that coastal dunes form a complex system of habitats for plants due to the combined effect of steep environmental gradients which are related to the distance from the shoreline and to elevation. Plants that are suited to the dune habitat are highly specialized; the ecosystem is characterized by water limitations for plant growth and also limited soil fertility. In fact, the main problem with dune stabilization using plants in many dunes exist in part, because the terrain is too dry to support vegetation. Even in a tropical humid climate such as that pertaining in coastal Kenya dry conditions are experienced due to high evaporations rates that are almost double the annual precipitation (Anon. 1996). Aside from any water limitations, juveniles may find it difficult to establish in shifting dune sands because their tiny roots may not be able to hold. Coastal dune vegetation also have to contend with the salt spray and nutrient limitation in dune soils.

In this prograding shoreline, a temporal and spatial dune succession is found. The ecological aspects of dune succession have been discussed by Willis et al. (1959), Ranwell (1972) and van der Maarel et al. (1985) albeit for climatic conditions different from Kenya.

Work by Melton (1940), Cooper (1958), Ash & Wasson (1983), Sarre (1989), Carter & Wilson (1990), Thomas & Tsoar (1990) and Wolfe & Nickling (1993) has clearly demonstrated that vegetation has an important control on dune morphology as it impedes sand movement in several ways: 1. Aerial roots and plant form increase the effective roughness of the sand surface. 2. Roots also have a direct binding effect on the surface sand layers. 3. Humus derived from dead vegetation increases the cohesive and water retentive properties of the surface sand. 4. Vegetation extracts momentum from the air flow. 5. Vegetation elements present an obstacle for incoming saltation. 6. The part of the surface that is covered by vegetation is withdrawn from the sediment supply system (Wolfe & Nickling, 1993)

Objectives

This research was conducted in order to compile an inventory of the dune floristic composition and relate the structure and distribution of plant species to the main aeolian features. In addition, the research aims to determine whether geomorphological units can be distinguished on the basis of their species composition.

Study area

The study area is a 10-km coastal strip between Malindi and Mambrui (Fig. 1). It is situated within the latitudes 3°06' S and 3°12' S, and bounded westward by the transition zone from active to stabilized dune forms. The area is geographically set within a wide open bay near the mouth of the Sabaki river. The bay is bordered mainly by long and wide (300-400 m), low-gradient beaches and high (5-45 m) mobile dune complexes. Reef patches and sheltered lagoons occur in the northern and southern extremities where narrow beaches (100-150 m) are found.

Behind the active dune field, are complex fossil dune ridge systems together with former shorelines associated with raised coral reef platforms (terraces). Therefore the area could geomorphologically be classified as a prograding dune ridge coast which emphasizes the predominantly advancing character of the coast- a shoreline of progradation or emergence.

Climate and soils

The coastal belt of Kenya experiences an equatorial monsoon climate with southeast trades prevailing from April to October and northeast monsoon from November to March (Anon. 1996). Abuodha (2000) showed that the southerly winds were stronger, and the duration of these higher wind speeds was longer. Northeasterly winds were usually of low velocities and prevailed for a duration of less than three months. The coastal wind system is locally influenced by a land breeze which develops at night and a moderate sea breeze towards midday, reaching its maximum during the afternoon.

Sand dynamics was measured by Abuodha (2000).

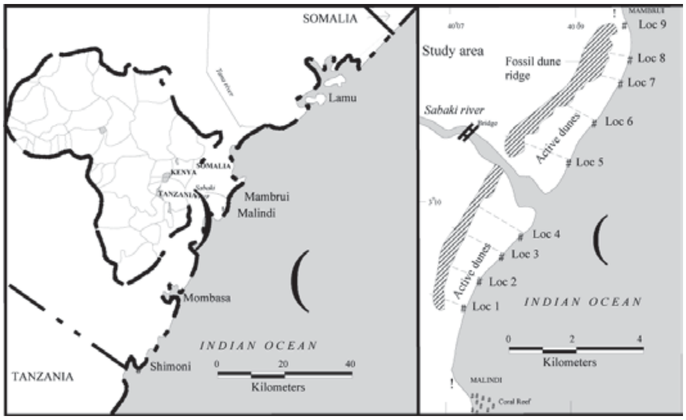

Fig. 1. Map of the Kenyan coastline indicating the location of the dune field, including transects where plots were made and plants collected for identification.

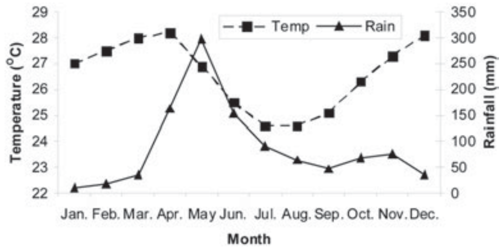

Fig. 2. Climatographs for the Malindi area. **a.** Mean monthly rainfall; **b.** Mean monthly temperature.

The potential long-term aeolian sand transport into the dune field was estimated at 200 000 m^3/year with a directional variability of 87%. The study suggested that the winds from a southerly direction dominated sand transport processes at Malindi Bay, whereas winds from the northeast were less important in the annual shifting of sand.

The climatographs (Figs. 2 and 3) depict the conditions found at Malindi. The temperature, rainfall and wind regimes of the study area combine to give the dunes a hot, arid and semi-arid climate and these affect the ecology of the dunes.

A soil survey for the Malindi area was carried out by Oosterom (1988) and Musila (1998). The soils of the stable dunes are typically grey in the area of investigation forming a thin layer of water-repellent topsoil; water repellency in recent dunes has been attributed to organic matter content (Jungerius & de Jong 1989). The soil consists of quartz sand; the dark colour appears to be caused by a combination of heavy minerals and organic matter. In the tropical environment experienced here, silicate minerals in quartz-rich dune sands break down gradually to form authigenic clay minerals and iron oxides. These silicate minerals may eventually be almost completely destroyed leaving a residual product rich in quartz and residual heavy minerals such as zircon, rutile and tourmaline (Pye 1982). Subsurface horizons of such sands are often cemented by humate (Pye 1982). Soils of the Pleistocene dunes in Malindi are developed further and have acquired a reddish colour. The origin of the red coloration have been widely discussed in terms of its origin, palaeo-environmental significance and use as a means of dating sand dunes (Pye 1981). (For further information on climate and soils see also Abuodha 2000 and the references quoted here.)

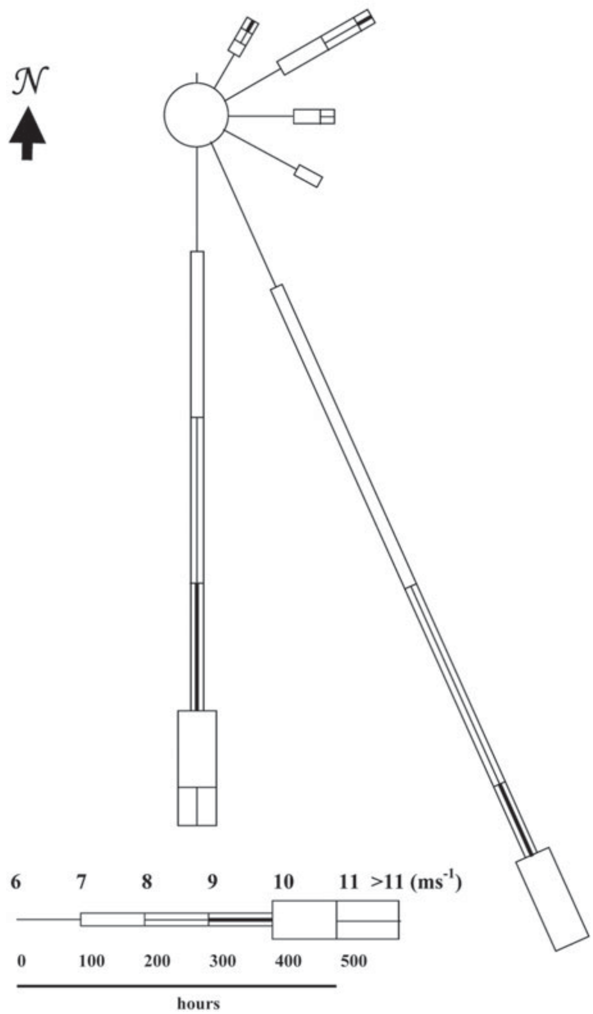

Fig. 3. Annual wind rose for magnitudes above 6 m.s^{-1} (threshold velocity of sand movement), recorded at Mambrui during 1993 (after Abuodha 2000).

Material and Methods

Geomorphological mapping

Aerial photography of the coastline between Malindi and Mambrui was taken on 15 January 1994 at 12.00 hr on a scale of 1 : 5000. The photographs were interpreted through analysis of stereoscopic pairs, mosaic and ground truthing to produce a map of the geomorphological units. In order to determine the dune profiles, heights were recorded from the Low Water Mark using an Abney level, a makeshift cross-like staff and a tape measure.

Vegetation survey

Along nine arbitrarily chosen transects (Fig. 1), a preliminary vegetation typology was drawn-up, in effect a list of vegetation types encountered from the shoreline through the mobile sand dunes to the fossil dune ridge complex.

On 12 August 1993 plant samples were collected along the nine transects which were established in the study area in order to make a taxonomic list which would facilitate subsequent inventory of the dune field ecology. The pressed specimens were taken to the Department of Resource Surveys and Remote Sensing (DRSRS) and the East African Herbarium laboratories for identification.

A second taxonomic inventory of plants seen on or near the transects on sand dunes north of the Sabaki river, up to Mambrui was carried out on 2 September 1993 and south of the river mouth on 10 March 1994. One specimen of each species was collected, identified and pressed as basic reference collection by Mrs Ann Robertson of the National Museums of Kenya.

A final and more detailed vegetation data was collected between October 1995 and March 1996 from the entire dune complex lying between Malindi and Mambrui. The first two surveys revealed the complexity of vegetation identification and mapping over such a vast dune field. As a consequence, the established transects were used as a baseline upon which smaller sampling plots were located- much of the quantitative work involving records of the cover and density of the plant species was done during this period.

Vegetation analysis

Vegetation structure and distribution in relation to geomorphology were described by the vegetation classification methods adapted from Mueller-Dombois & Ellenberg (1974) and Kent & Coker (1992). Species richness was taken as the total of different plant species. This was used to express species diversity. Margalef's (1958) diversity index was computed from plant species in each geomorphological unit using the following formula:

$$\partial = \frac{(\kappa - 1)}{\log_{10} N} \quad (1)$$

where δ = diversity index of a geomorphological unit ;
κ = species richness of the unit;
N = total number of species.

TWINSPAN (Hill 1979) was used to identify synecological relationships between species and to judge whether the geomorphological classification used was distinct enough to be separated on the basis of their floristic composition.

Results

Dune morphology

From the air photographs, different geomorphological units may be distinguished in the Malindi Bay dune field (Fig. 4). These are the beach unit, berm zone, deflation plain, primary dunes, barchan dunes, transverse dunes, compound crescentic dunes, sand sheets, precipitation ridge, hummock dunes, dune ridges, inter-dune valley and salt marsh. The foredunes, slacks and blowouts were also recognized in the field but they cannot be presented on a map of this scale due to their sporadic occurrence.

Fig. 5a, b shows profiles across the transects which were surveyed. The dune belt reaches a width of about 4 km (including fossil dunes) although profiles through the active transgressive dune field stretch approximately 1 km inland. The profiles measured encompass dunes of variable geometry and show different degrees of mobility and stabilization by vegetation.

Floristic composition, structure and distribution

App. 1 gives the complete taxonomic list of all vascular plants collected from the sand dunes by genus and family. A total of 174 plant species was recorded belonging to 62 families. The largest family was that of the *Papilionaceae* followed by *Poaceae* with 18 and 17 different species respectively.

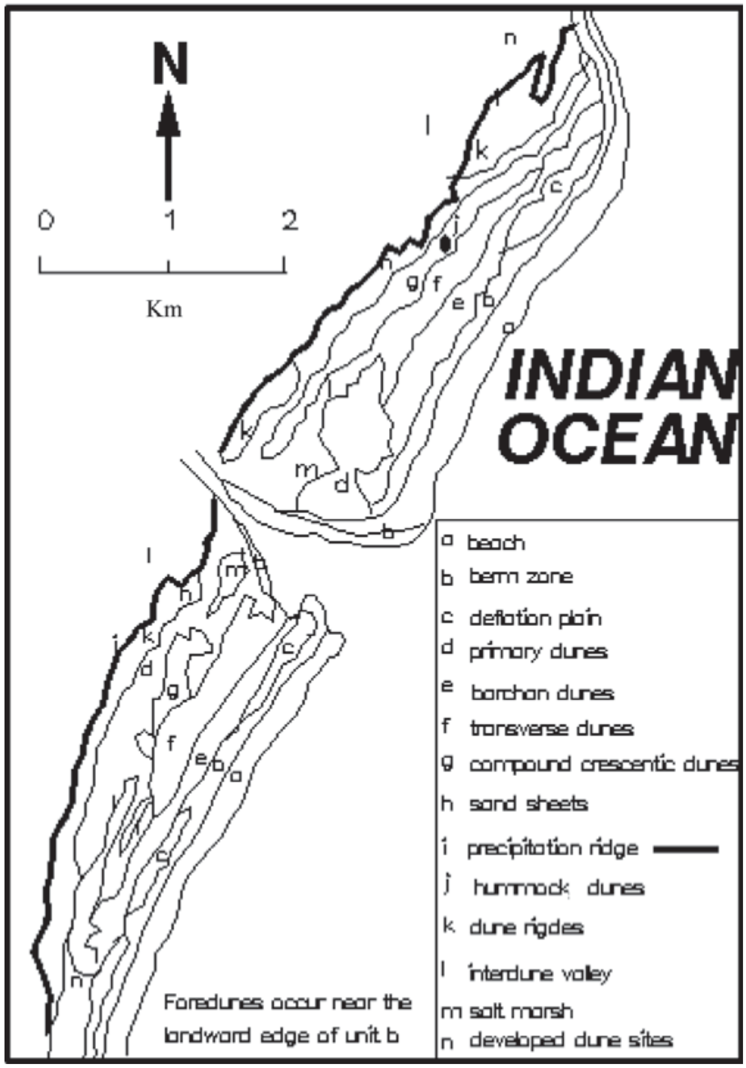

Fig. 4. Map showing major geomorphological units of the Malindi Bay area. Foredunes and dune slacks are not indicated due to their sporadic appearance.

A summary of vegetation classification at different geomorphological units is presented in Table 1. The results show that species richness is highest in the dune ridges and lowest in the transverse dunes. As expected the species diversity apparently increases with distance from the shoreline; the older and more landward dunes are stabilized beneath increasingly complex communities, which have progressively better developed soils, and the influx of wind-blown sand is either minimal or non-existent.

In App. 2 vegetation structure for each geomorphological unit are given showing calculated values of relative cover, relative frequency, relative density and importance value indices for each species. The objective here was to show the relative contribution of each species to the entire geomorphological unit. In addition, names of plant communities were derived from the plants with the highest Importance Value Index in each geomorphological unit.

Ecological units

The vegetation communities show a close association with the main geomorphological units (App. 2). The letters placed after each unit (in brackets) are the mapping codes (Fig. 4).

Foredunes (berm zone, b)

The formation and development of the foredunes, which are a distinctive feature of the berm zone is associated with pioneer plant communities such as:

a. *Halopyrum mucronatum*, in the north and

b. *Ipomoea pes-caprae* in the south of the Sabaki river- in this community *Scaevola plumieri* and *Hermbstaedtia gregoryi* occur as companion species.

These species are remarkable for their ability to exist on highly siliceous and excessively well-drained soils and to withstand long periods of drought.

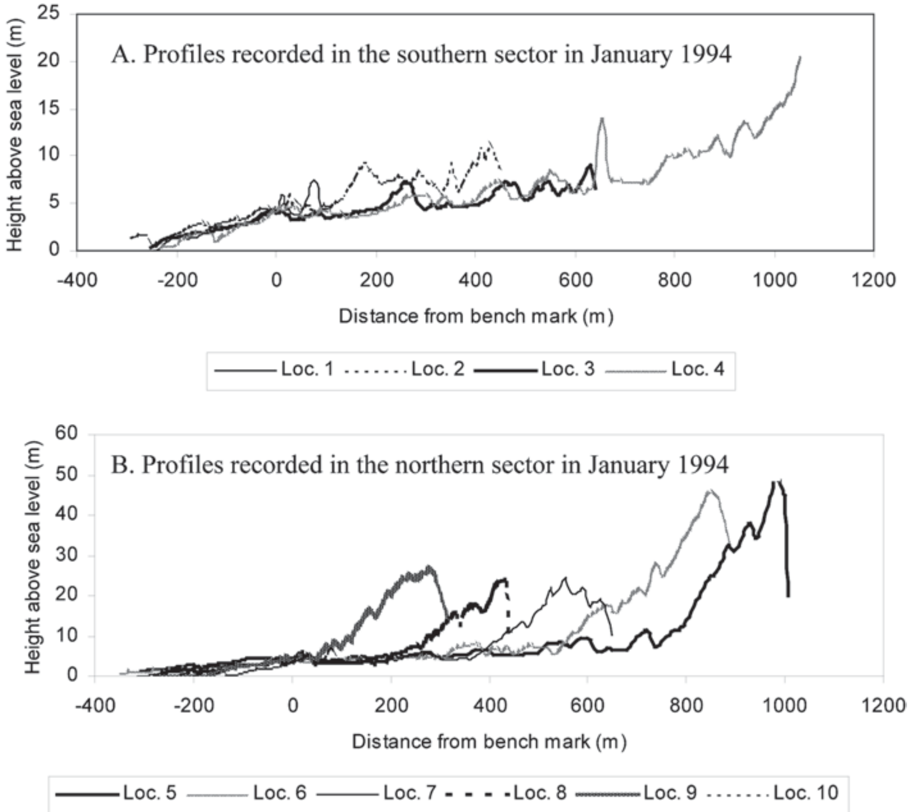

Fig. 5. Shore profile diagrams of beach-dune sections, **(A)** south; **(B)** north of Malindi Bay.

Deflation plain (c)

Within the deflation plains of the northern sites, where scattered features of embryo and shadow dunes are present, poorly developed communities of succulent plants occur such as:

a. *Halopyrum mucronatum*;
b. *Ipomoea pes-caprae*

In addition, dead woody plant relicts were observed to occur *in situ*. *H. gregoryi* and *S. plumieri* are associated with the *I. pes-caprae* community. The former is a fleshy creeping herb and forms carpet-like mart on the embryo dunes. The habit of this plant enables it to bind sand.

Primary dunes (d)

Incipient foredunes **(b)** are transformed into established primary dunes colonized mainly by woody shrub species such as:

a. *Tephrosia purpurea*;
b. *Cordia somaliensis*

In the *Tephrosia purpurea* community other herbs present include *Macrotyloma uniflora* and *I. pes-caprae*. Grasses are also present in this community and include *Digitaria argyrotricha* and *Eragrostis ciliaris*.

Associated shrubs found in the *Cordia somaliensis* community include *Pluchea discoridis*, *Maytenus senegalensis*, *Calotropis procera* and *Cadaba farinosa*. Frequently, the shrubs form a single dense layer ranging from about 1 to 5m tall. Often, this layer is infested by a parasitic plant species *Cassytha filiformis* which forms a mat on the canopy of the shrubs and this helps to counteract wind speed. Underneath this thicket of shrubs are a few dicotyledonous herbs and grasses poorly distributed. These include *Justicia flava*, *D. nuda*, *D. gazensis* and *D. argyrotricha*. *Sideroxylon inerme* tree species and climbers such as *Rhynchosia velutina*, *J. flumenence*, *Cyphostemma dysocarpus* and *Pergularia daemia* are also frequent in this community.

Barchan and transverse dunes (e, f)

The barchan and transverse dune fields have very scanty vegetation on the windward slopes, where sand ripples and high dune migration rates imply active aeolian sand transport. The main vegetation type is either grass or dicotyledonous herbs in nature. Two plant communities were identified:

a. *H. mucronatum*;
b. *Ipomoea pes-caprae*

H. mucronatum grows vigorously especially when covered by sand, enabling it to survive in this unstable and mobile region. As this grass grows, it forms low shadow dunes. Some strands of *I. pes-caprae* and *H. gregoryi*

Table 1. Vegetation classification in different geomorphological units.

Geomorphological unit	Species richness	Species diversity □	Growth forms				
			Grass	Herbs	Shrubs	Trees	Climbers
Foredune	5	4.4	1	3	1	-	-
Deflation plain	4	4.3	1	2	1	-	-
Barchan dunes	3	2.2	1	2	-	-	-
Transverse dunes	2	2.1	1	1	-	-	-
Compound dunes	23	13.2	5	10	4	1	3
Primary dunes	27	16.6	6	6	9	2	4
Dune slacks	29	16.3	7	17	3	1	1
Salt marsh	39	21.3	7	19	8	2	3
Dune ridges	59	28.9	5	17	19	11	7

were also present in this community.

Ipomoea pes-caprae is a herb community which occurs south of the Sabaki river in the barchan dunes. *Ipomoea pes-caprae* is the dominant plant and *H. gregoryi* is the other associate plant. Plants in this community are scantily distributed (App. 2). This is an active and mobile zone and plants mostly occur on the deflation surfaces between the barchan dunes.

Compound crescentic dunes and sand sheets (hummock dunes in g, h)

On the hummock dunes that are present as discrete bodies within the zone of compound crescentic dunes and sand sheets (Fig. 4), species assemblages of diverse affinities flourish; vegetation is mostly herbaceous or short shrub species. It is in this zone that trees and climbers first appear indicating that it may be more stable than the other transgressive dunes. The main component of the dune vegetation in this zone is *Cordia somaliensis*. The hummock dunes are also thickly vegetated by woody shrubs such as *Azima tetracantha*, *Phyllanthus reticulatus* and *Pluchea discoridis*. A herbaceous layer occurs beneath the thickets of shrubs with *Asystasia gangetica* being the most dominant. The other shrubs present include *Justicia flava*, *Commelina latifolia* and *Achyranthes aspera*. There are also grasses and sedges such as *D. argyrotricha*, *D. ciliaris*, *D. nuda* *Eragrostis ciliaris* and *Cenchrus biflorus* as well as climbers that include *Cissus rotundifolia*, *Jasminium fluminence* and *Momordica rostrata*. Shrubs in this zone nearly always have a wind-swept appearance on the seaward side.

Dune slacks (sporadic in h)

Slacks occur in sheltered low-lying depressions within the field of sand sheets, hence they are damp stable sand surfaces which provide an ideal habitat for the rapid development of plant communities. Moreover, the water table is close to the surface, and the groundwater is not saline but fresh. This zone has a species richness of 29 with most of the plant species being herbs and grasses (Table 1). Succulent dicotyledonous herbs, grasses and some foredune species make up the characteristic flora of this zone. Two plant communities were identified in this zone namely:

a. *T. purpurea-H. mucronatum* community
b. *Pluchea discoridis-Portulaca parensis* community

Species composition of the slack vegetation closely reflects the characteristics of the ground water table, especially its water depth. Plants in the first community were found to be xeromorphic in nature; they occur in slack areas where the water table is more than 0.5 m. *T. purpurea* is especially common in the slacks south of the Sabaki river. It is associated with some grasses such as *E. ciliaris* and *D. nuda*. A few trees of *Casuarina equisetifolia* were also present in this community. *H. mucronatum* occurs in the slacks north of the Sabaki river.

Pluchea discoridis-Portulaca parensis community occur in slack areas where the water table is less than 0.5 m. The main component of slack vegetation in this case is *Pluchea discoridis* in the south and *Portulaca parensis* in the north of the Sabaki river. The former plant is a shrub which has long roots while the latter is a succulent herb. Other associated dicotyledonous herbs include *Stylosanthes fruticosa*, *Desmodium triflorum*, *Alysicarpus glumaceus*, *H. gregoryi*, *Polygala sphenoptera* and *Enicostema axillare*. Sedges were also frequent in this community and include *Cyperus articulatus*, *Fimbristylis cymosa*, *Typha domigensis*, *Pycreus polystachyos* and *Cyperus rotundus*. This is a pointer to the shallow water table since these plants are aquatic in nature. Grasses are also present in this community and include *D. nuda* and *Sporobolus virginicus*.

Dune ridges (k)

These are more stabilized dunes and support a rich variety of plant species (Table 1; App. 2). In some sections of this zone, vegetation has been cleared to pave way for human settlement. Where the sand dunes have been little disturbed, the vegetation is rich in species with *C. somaliensis* shrub being the most dominant. The soils in this zone appears to be more developed and grey in colour, indicating that it contains more humus.

Two plant communities were identified in this zone and these include:

a. *C. somaliensis-P. discoridis* community
b. *Achyranthes aspera-Justicia flava* community

In the first community, *C. somaliensis* is more dominant. This community includes medium to tall shrubs interspersed with trees. *P. discoridis* is also a common shrub, especially to the south of the river. Other shrubs present include *A. tetracantha*, *Phyllanthus reticulatus*, *Deinbollia borbonica*, *Maytenus senegalensis*, *Tricalysia ovalifolia* and *Dichrostachys cinerea*. Trees especially occur on the more sheltered zone of hummock dunes and include *Afzelia cuanzensis*, *Garcinia livingstonei*, *S. inerme* and *Drypetes natalensis*.

The second community forms a herb layer beneath the *C. somaliensis-P. discoridis* community. Other companion herbs include *C. crassipes*, *A. gangetica*, *Boerhavia diffusa*, *T. purpurea* and *C. latifolia*. A few grasses are also present such as *E. ciliaris*, *D. argyrotricha* and *D. ciliaris*.

Salt marshes (m)

The salt marsh zone occurs near the river mouth (Fig. 4), both to the north and south. It has a complex vegetation structure comprising of the following plant communities:

a. *Fimbristylis cymosa-Sporobolus virginicus*
b. *T. purpurea-Phyla nodiflora*

The first community comprises low tussocks of *F. cymosa* intermingled with species of *S. virginicus*. These plants form a dense mat of vegetation and are heavily grazed by goats, sheep and cattle. Other species in this community include *Macrotyloma uniflorum*, *Dactyloctenium geminatum* and *E. axillare*.

T. purpurea is dominant in the second community intermingled with *Phyla nodiflora*. These plants include dicotyledonous herbs like *E. axillare*, shrubs like *Lawsonia inermis*, *P. discoridis*, *M. senegalensis* and trees like *C. equisetifolia* and *Azardichta indica*.

Relation between morphology and vegetation

The results of the TWINSPAN classification of vegetation in the main geomorphological units are presented in Fig. 6. The first division separated the foredune and deflation plain from barchan dunes and transverse dunes. A second division separated the dune slacks and salt marsh from the compound crescentic dunes (hummock dunes), primary dunes and dune ridges. Thus, most of the groups defined by TWINSPAN consist of geomorphological units sharing common plant species and having almost similar characteristics. For instance, the foredune, deflation plain, barchan dunes and transverse dunes were grouped together. These four geomorphological units occur near the sea and have a low species richness and diversity due to the instability of the sand. As sand accumulation and shift decrease, the landscape is more or less fixed, the number of species increases and gradually enriched with herbs. It therefore appears that similar geomorphological units have distinct vegetation types.

Discussion

Ecological classification of geomorphological units

The TWINSPAN analysis separated geomorphological units on the basis of their floristic composition (Fig. 6). The groups defined by this analysis indicated that geomorphological units having almost similar characteristics had common vegetation structure and composition. For instance, the foredune, deflation plain, barchan and transverse dunes had low species richness and diversity indices, and *H. mucronatum* and *I. pes-caprae* plant communities were common in all of them. The hummock dunes (in the compound crescentic dunes and sand sheets landscapes), primary dunes and dune ridges had high species richness and diversity indices and *C. somaliensis* community was found to be common in these geomorphological units. *P. nodiflora*, *F. cymosa* and *T. purpurea* were common in the slacks and salt marsh zones.

The first four geomorphological units are sparsely vegetated, reflecting very high rates of sand movement. Similar observations were made by Barker et al. (1989) in the coastal dunes of Somalia. They found that the different sub-environments of a dune field were characterized by unique floristic composition, and the species diversity was higher in areas with least sand movement.

The physical forms of vegetation inhabiting the foredunes ensure that they are efficient sand catchers. Their leaf structure and a rhizomatous rooting system safeguard their development under considerable amounts of deposited sand. In addition, the plants must be able to withstand saline conditions emanating either through sea-spay, flooding or salt water intrusion. These attributes make particular monospecific plant species to be the primary colonizers of the foredunes.

Herbaceous plants mostly appear further away from the sea where the sand begins to be more or less stabilized. Dune slacks and salt marshes which are characteristically moist because the groundwater table is at depths of less than 1 m; this actually governs the deflation level and are therefore also regarded as stable environments.

The dune species distribution reveals that a distinct

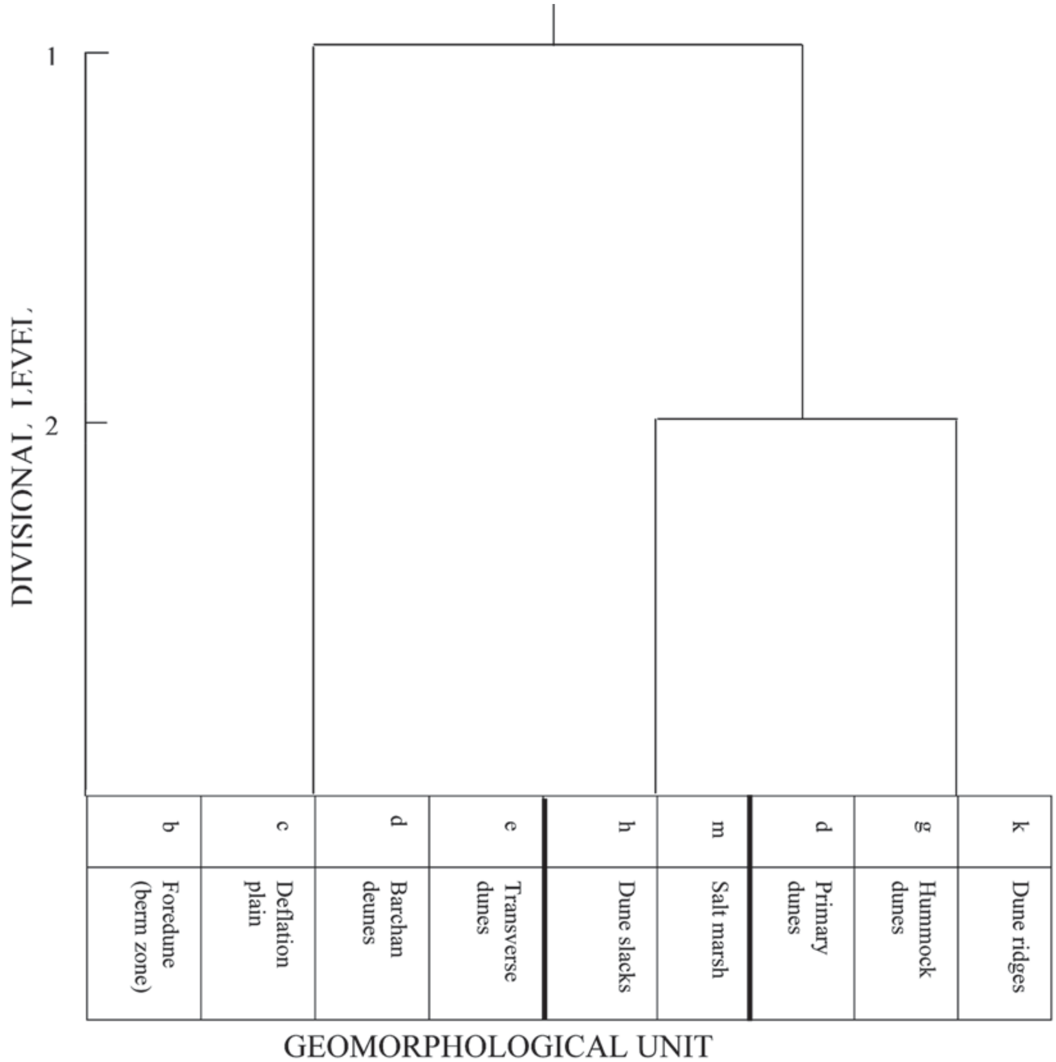

Fig. 6. Dendrogram showing the ecological classification of the nine geomorphological units, based on floristic composition (after TWINSPAN).

successional zonation occurs in this dune system which follows the same trend as in other coastal dunes (Kumler 1968; Olson 1958). The zonation of plants reflects the fact that physico-chemical properties of the sand surface, soil development and local wind processes vary across the dune field. Musila (1998) found significant variations in the soil parameters in different geomorphological units. She concluded that sand dynamics and mean particle size of the sand are the most important factors influencing the vegetation composition, structure and distribution. As a consequence, such vegetation communities impose varying stability degrees along the points of the dune profile as reported by Thomas & Tsoar (1990).

Effect of shoreline progradation on succession

Following the foredune classification procedure (where distinction is based on 'development types') proposed by Arens & Wiersma (1994), the southern foredunes can be designated progressive foredunes whereas their northern counterparts are regressive foredunes. In the first case, deposition takes place in front of the foredunes, which in addition to the fast prograding nature of the coast, results in a series of low established primary dunes. A series of established primary dunes, according to similar observations by Hesp & Nordstrom (1990) in North Ireland, were therefore formed under conditions of rapid coastal progradation. A typical situation of vegetation community succession takes place here with the immediate colonization of the preceding foredune by *Tephrosia purpurea*. In the second case, sand deposition takes place in the back of foredunes and is eventually lost to the sand sheet zone via the deflation plain. During shoreline progradation the foredune feature is usually obliterated but in some instances survive as primary dunes inhabited by *Cordia somaliensis* and *Tephrosia purpurea*. In fact, the primary dunes are largely established due to the trapping effect of these plant communities which have the ability to utilize deep water using long roots.

Ecological succession is evident on the deflation plain where *Cordia somaliensis* has been replaced by *Halopyrum mucronatum* and *Ipomoea pes-caprae*. It can be suggested from this observation that *Cordia somaliensis* is less tolerant to the wash-over effect which occasionally causes seawater flooding of the deflation plain than *Halopyrum mucronatum* and *Ipomoea pes-caprae*. Leatherman (1979) referred to an ecological succession in barrier dune systems from a study conducted at Assateague Island, Maryland, USA, where on one hand, woody vegetation cannot withstand frequent severe seawater flooding and/or burial and on the other hand, grass ecosystems are well adapted to the wash-over stresses and can therefore survive in a flexible, changing environment.

Conclusions

1. The Malindi Bay dune field is very rich in geomorphological units with an enormous diversity of vegetation communities of contrasting structure, floristic composition and ecological strategy.

2. The plant density and diversity gradually increases with distance from the shoreline until a dune ridge vegetation complex has evolved, virtually halting any further inland movement of sediment and resulting in the formation of a large precipitation ridge.

3. The results indicate that geomorphological units having almost similar characteristics had common vegetation structure and composition:

a. foredunes, deflation plain, barchan and transverse dunes;

b. compound crescentic dunes, sand sheets, primary dunes and dune ridges;

c. dune slacks and salt marshes.

4. A distinct successional zonation is evident in the present dune system.

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App. 1. Vegetation samples collected from coastal sand dunes at Malindi Bay.

ACANTHACEAE
Asystasia ansellioides (L) T. Anders.
Asystasia gangetica (L) T. Anders.
Blepharis maderaspatensis (L) Roth
Justicia flava Vahl

AIZOACEAE
Glinus setiflorus Forsk.
Sesuvium portulacastrum L.
Trianthema ceratosepala Volk. & Irmsch

AMARANTHACEAE
Achyranthes aspera L.
Allmaniopsis fruticulosa L.
Hermbstaedtia gregoryi C.B. Cl.
Psilotrichum sericeum L.

ANACARDIACEAE
Lannea schweinfurthii (Engl.) Engl. var. *stuhlmannii* (Engl.) Kokwaro

APOCYNACEAE
Dictyophleba lucida (K. Schum.) Pierre
Hunteria zeylanica (Retz.) Gardn. var. *africana*

ASCLEPIADACEAE
Calotropis procera (Ait.) (Ait.) f.
Pergularia daemia (Forsk.) Chiov.

ASPARAGACEAE (*Liliaceae*)
Asparagus africanus Lam.
Asparagus racemosus Willd (A. buchanii Bak)

BORAGINACEAE
Bourreria nemoralis (Gurke) Thulin.
Bourreria petiolaris (Lam.) Thulin.
Cordia somaliensis Bak.
Heliotropium gorinii Chiov.

BURSERACEAE
Commiphora sp.

CACTACEAE
Opuntia vulgaris L.

CAESALPINIACEAE
Afzelia cuanzensis Welw.
Caesalpinia bonduc (L.) Roxb.
Senna occidentalis (L.) Linl
Prosopis chilensis (Molina) Stuntz
Tamarindus indica L.

CAMPANULACEAE
Lobelia fervens Thunb. ssp. *fervens*

CAPPARACEAE
Boscia coriacea Pax
Cadaba farinosa Forssk. ssp. *farinosa*
Capparis sepiaria L.
Cleome strigosa (Boj.) Oliv.
Maerua triphylla A. Rich.
Thylacium thomasii

CASUARINACEAE
Casuarina equisetifolia L.

CELASTRACEAE
Elaeodendron schweinfurthianum (Loes.) Loes.
Maytenus senegalensis (Lam.) Exell

CHENOPODIACEAE
Suaeda monoica J.F. Gmel.

COMBRETACEAE
Combretum paniculatum Vent.

COMMELINACEAE
Commelina latifolia A. Rich.

COMPOSITAE (*Asteraceae*)
Eclipta prostrata (L.) L.
Launaea cornuta (Oliv. & Hiern) C. Jeffrey
Launaea intybacea (Jacq.) Beauv.
Pluchea dioscoridis DC
Solanecio angulatus (Vahl) C. Jeffrey
Tridax procumbens L.
Vernonia hildebrandtii Vatke
Vernonia homilantha S. Moore

CONVOLVULACEAE
Ipomoea pes-caprae (L.) R. Br.

CUCURBITACEAE
Coccinea grandis (L.) Voigt
Coccinea trilobata (Cogn.) C. Jeffrey
Corallocarpus ellipticus L.
Kedrostis gijef J.F. Gmel.) C. Jeffrey
Momordica littorea Thulin
Momordica rostrata A. Zimm.
Momordica trifoliate Hook. f.

CYPERACEAE
Cyperus articulatus L.
Cyperus crassipes Vahl
Cyperus rotundus L.
Fimbristylis cymosa (Lam.) R.Br.
Fimbristylis complanata L.
Pycreus polystachyos (Rottb.) P. Beauv.
Schoenoplectus junceus L.
Scirpus sp.

DRACAENACEAE
Sansevieria arborescens Cornn.
Sansevieria raffillii N.E. Br.
Sansevieria suffruticosa N.E. Br.

EUPHORBIACEAE
Dalechampia scandens (Lam.) auct. non L.
Drypetes natalensis (Harv.) Hutch
Erythrococca sp.
Euphorbia tirucalli L.
Jatropha stuhlmannii Pax
Phyllanthus reticulatus Poir.

FLACOURTIACEAE
Flacourtia indica (Burm.F.) Merril

FLAGELLARICEAE
Flagellaria guineensis Schumach.

GENTINIACEAE
Enicostema axillare (Lam.) A. Raynal

GOODENIACEAE
Scaevola plumieri (L.) Vahl

GUTTIFERAE
Calophyllum inophyllum L.
Garcinia livingstonei T. Anders

LABIATAE (*Lamiaceae*)
Hoslundia opposita Vahl.
Ocimum basilicum L.
Plectranthus sp.

LAURACEAE
Cassytha filiformis L.

LOGANIACEAE
Strychnos madagascariensis Poir.

LORANTHACEAE
Helixanthera kirkii (Oliv.) Danser

LYTHRACEAE
Lawsonia inermis L.

MALPHIGIACEAE
Acridocarpus zanzibaricus A. Juss.

MALVACEAE
Abutilon zanzibaricum Mast.
Hibiscus tiliaceus L.

MELIACEAE
Azardirachta indica A. Juss.

MENISPERMACEAE
Tinospora caffra (Miers) Troupin

MIMOSACEAE
Acacia nilotica (L.) Del.
Dichrostachys cinerea (L.) Wight & Arn.

NYCTAGINACEAE
Boerhavia coccinea Mill.
Boerhavia diffusa L.
Boerhavia erecta L.

OLACACEAE
Ximenia americana L. var. *americana*

OLEACEAE
Jasminum fluminense Vell.

PALMAE
Hyphaene compressa H. Wendl.
Hyphaene coriacea Gaertn.

PAPILIONACEAE
Abrus precatorius L.
Aeschynomene uniflora E. Mey.
Alysicarpus glumaceusi (Vahl) DC.
Alysicarpus ovalifolius (Vahl) DC.
Clitoria ternatea L.
Crotalaria granta Polhill
Crotalaria retusa L.
Desmodium triflorum (L.) DC.
Indigofera hirsute L.
Indigofera tanganyikensis Bak. f.
Indigofera vohemarensis Baill.
Macrotyloma uniflora (Lam.) Verdc.
Rhynchosia velutina Wight & Arn.
Stylosanthes erecta P. Beauv.
Stylosanthes fruticosa (Retz) Alston
Tephrosia purpurea (L.) Pers. ssp. *dunensis*
Tephrosia subtrifola Bak.
Zornia apiculata Milne-Redh

PEDALIACEAE
Pedalium murex L.

POACEAE
Cenchrus biflorus Roxb.
Cynodon nlemfuensis Vanderyst
Dactyloctenium ctenioides (Steud.) Bosser
Dactyloctenium geminatum Hack.
Digitaria argyrotricha (Anderss.) Chiov.
Digitaria ciliaris (Retz.) Koel
Digitaria gazensis Rendle
Digitaria macrocephara (Hack.) Stapf
Digitaria milanjiana (Randle) Stapf
Digitaria nuda Schumach.
Eragrostis ciliaris (L.) R.Br.
Halopyrum mucronatum (L.) Stapf
Lepturus repens (G. Forst.) R.Br.
Panicum maximum Jacq.
Paspalum vaginatum Sw.
Phragmites mauritianus Kunth
Sporobolus virginicus (L.) Kunth

POLYGALACEAE
Polygala sphenoptera Fres.

POLYGONACEAE
Oxygonum atriplicifolium (Meisn.) Mart

PORTULACACEAE
Portulaca parensis van Poelln.
Portulaca petersii van Poelln.
Talinum portulacifolium (Forsk.) Schweinf.

RHAMNACEAE
Colubrina asiatica (L.) Brongn.

RUBIACEAE
Diodia aulacosperma K. Schum.
Feretia apodanthera Del.
Kohautia caespitosae Schnizl.
Oldenlandia affinis (Roem. & Schlt.) DC
Psychotria punctata Vatke
Tricalysia ovalifolia Hiern

RUTACEAE
Zanthoxylum chalybeum Engl. var. *chalybeum*

SALVADORACEAE
Azima tetracantha Lam.
Dobera glabra (Forssk.) Poir.
Salvadora persica L.

SAPINDACEAE
Deinbollia borbonica Scheff.
Dodonaea viscosa Jacq.
Haplocoelum inoploeum Radlk.

SAPOTACEAE
Sideroxylon inerme L. subsp. *diospyroides* (Bak.) J.H. Hemsl

SOLANACEAE
Datura *metel* L.
Solanum incanum L.

SONNERATIACEAE
Sonneratia alba Sm.

STERCULIACEAE
Waltheria indica L.

TILIACEAE
Grewia glandulosa Vahl.
Grewia plagiophylla K. Schum.
Grewia vaughaniae Exell

TYPHACEAE
Typha domigensis Pers.

VERBENACEAE
Avicennia marina (Forssk.) Vierh.
Clerodendrum glabrum L.
Lantana camara L.
Phyla nodiflora (L.) Greene
Premna chrysoclada (Boj.) Guerke

VITACEAE
Cissus rotundifolia (Forsk..) Vahl
Cyphostemma dysocarpum (Gilg. & Brandt.) Descoigns

App. 2. Vegetation structure associated with aeolian geomorphological units. D = Density; C = Cover; F = Frequency; RD = Relative density; RC = Relative cover; RF = Relative frequency; IVI = Importance value index.

Plant species	D	C	F	RD	RC	RF	IVI
Foredunes							
Halopyrum mucronatum	11.5	43.5	22	19.3	48.8	25.6	93.7
Ipomoea pes-caprae	19	18.1	16	31.9	20.3	18.6	71.0
Hermbstaedtia gregoryi	13	15	20	21.9	16.8	23.3	61.9
Scaevola plumieri	10	8.5	24	16.8	9.5	27.9	54.3
Cyperus crassipes	6.0	4.0	4	10.1	4.5	4.7	19.2
Deflation plain							
Halopyrum mucronatum	90.5	71	56	72.7	70.1	60.2	203.0
Ipomoea pes-caprae	18	18.2	9	14.5	18.0	9.7	42.2
Hermbstaedtia gregoryi	12	5.8	24	9.6	5.7	25.8	41.1
Scaevola plumieri	4	6.3	4	3.2	6.2	4.3	13.76
Barchan dunes							
Halopyrum mucronatum	37.8	59.3	36.0	69.4	83.8	54.0	207.1
Ipomoea pes-caprae	11.7	9.5	14.7	21.4	13.4	22.0	56.9
Hermbstaedtia gregoryi	5.0	2.0	16.0	9.2	2.8	24.0	36.0
Transverse dunes							
Halopyrum mucronatum	14.5	32.1	14	42.0	68.2	41.2	151.4
Ipomoea pes-caprae	20.0	15.0	20	58.0	31.8	58.8	148.6
Compound crescentic dunes							
Cordia somaliensis	3.0	75.0	32.0	1.2	21.9	13.3	36.2
Asystasia gangetica	50.0	15.0	20.0	19.3	4.4	8.2	31.9
Dobera glabra	0.4	75.0	20.0	0.2	21.9	8.2	30.2
Justicia flava	36.0	15.5	20.0	13.9	4.5	8.2	26.0
Digitaria argyrotricha	28.5	16.3	15.0	11.0	4.7	6.2	21.9
Cissus rotundifolia	14.0	15.5	20.0	5.4	4.5	8.2	18.1
Commelina latifolia	16.0	18.8	8.0	6.2	5.5	3.3	14.9
Digitaria ciliaris	21.0	11.3	8.0	8.1	3.3	3.3	14.7
Ipomoea pes-caprae	14.0	6.0	16.0	5.4	1.8	6.6	13.7
Digitaria nuda	19.0	7.5	8.0	7.3	2.2	3.3	12.8
Portulaca parensis	23.0	2.5	4.0	8.9	0.7	1.7	11.2
Azima tetracantha	0.4	25.0	8.0	0.1	7.3	3.3	10.7
Phyllanthus reticulatus	0.2	22.0	8.0	0.1	6.4	3.3	9.8
Stylisanthus erectus	4.0	3.5	12.0	1.5	1.0	4.9	7.5
Achyranthes aspera	10.0	6.3	4.0	3.9	1.8	1.7	7.3
Jasminium fluminense	4.0	6.8	8.0	1.5	2.0	3.3	6.8
Eragrostis ciliaris	8.0	6.3	4.0	3.1	1.8	1.7	6.6
Pluchea dioscoridis	0.3	10.0	8.0	0.1	2.9	3.3	6.3
Momordica rostrata	3.0	2.5	4.0	1.2	0.7	1.7	3.5
Cenchrus biflorus	2.0	1.3	4.0	0.8	0.4	1.7	2.8
Fimbristylis cymosa	1.0	0.5	4.0	0.4	0.2	1.7	2.2
Hermbstaedtia gregoryi	1.0	0.5	4.0	0.4	0.2	1.7	2.2
Launaea cornuta	1.0	0.5	4.0	0.4	0.2	1.7	2.2
Primary dunes							
Tephrosia purpurea	86.5	41.6	44.0	45.7	15.2	19.6	80.5
Digitaria argyrotricha	23.0	9.8	16.0	12.2	3.6	7.1	22.8
Cordia somaliensis	0.6	39.4	16.0	0.3	14.4	7.1	21.8
Phyllanthus reticulatus	0.9	37.5	14.7	0.5	13.7	6.5	20.7
Rynchosia velutina	14.0	5.3	16.0	7.4	1.9	7.1	16.4
Eragrostis ciliaris	18.0	2.6	10.0	9.5	1.0	4.5	14.9
Asystasia gangetica	11.0	15.0	4.0	5.8	5.5	1.8	13.1
Grewia glandulosa	2.7	22.0	8.0	1.5	8.1	3.6	13.1
Cyperus rotundus	0.5	20.0	8.0	0.3	7.3	3.6	11.2
Pluchea dioscoridis	2.8	15.9	5.3	1.5	5.8	2.4	9.7
Feretia apondanthera	0.6	7.0	12.0	0.3	2.6	5.3	8.2
Jasminium fluminense	3.0	5.3	8.0	1.6	1.9	3.6	7.1
Maytenus senegalensis	3.0	10.0	4.0	1.6	3.7	1.8	7.0
Sideroxylon inerme	0.1	12.5	4.0	0.1	4.6	1.8	6.4
Flacourtia indica	0.1	7.0	8.0	0.1	2.6	3.6	6.2
Digitaria nuda	7.0	0.5	4.0	3.7	0.2	1.8	5.7
Calotropis procera	0.5	4.5	8.0	0.3	1.7	3.6	5.5
Sporobolus virginicus	1.0	5.0	4.0	0.5	1.8	1.8	4.1
Macrotyloma uniflora	3.0	1.0	4.0	1.6	0.4	1.8	3.7

App. 2, cont.

Plant species	D	C	F	RD	RC	RF	IVI
Digitaria gazensis	2.0	1.3	4.0	1.1	0.5	1.8	3.3
Pergularia daemia	2.0	1.3	4.0	1.1	0.5	1.8	3.3
Eclipta prostrata	2.0	1.3	4.0	1.1	0.5	1.8	3.3
Cadaba farinosa	0.1	3.8	4.0	0.1	1.4	1.8	3.2
Digitaria macrocephara	1.0	2.0	4.0	0.5	0.7	1.8	3.0
Cyphostemma dysocarpus	2.0	0.5	4.0	1.1	0.2	1.8	3.0
Ipomoea pes-caprae	1.0	0.9	4.0	0.5	0.3	1.8	2.6
Launaea intyacea	1.0	0.5	4.0	0.5	0.2	1.8	2.5
Dune slacks							
Tephrosia purpurea	121.5	70.5	46.0	32.7	22.9	14.8	70.5
Halopyrum mucronatum	31.5	28.1	40.0	8.5	9.1	12.9	30.5
Pluchea dioscoridis	1.8	48.7	20.0	0.5	15.8	6.5	22.7
Portulaca parensis	40.0	7.0	16.0	10.8	2.3	5.2	18.2
Casuarina equisetifolia	0.3	45.0	8.0	0.1	14.6	2.6	17.3
Eragrostis ciliaris	21.0	6.8	24.0	5.7	2.2	7.7	15.6
Fimbristylis cymosa	25.7	10.2	13.3	6.9	3.3	4.3	14.5
Cyperus articulatus	20.0	12.3	12.0	5.4	4.0	3.9	13.2
Phyla nodiflora	22.2	8.2	10.4	6.0	2.7	3.4	12.0
Dactyloctenium geminatum	17.0	6.8	16.0	4.6	2.2	5.2	11.9
Maytenus senegalensis	0.1	25.0	4.0	0.1	8.1	1.3	9.4
Sporobolus virginicus	15.0	4.8	7.2	4.0	1.6	2.3	7.9
Digitaria nuda	8.0	5.3	12.0	2.2	1.7	3.9	7.7
Ipomoea pes-caprae	9.7	3.7	9.3	2.6	1.2	3.0	6.8
Cyperus rutundus	5.5	10.5	4.0	1.5	3.4	1.3	6.2
Stylosanthus fruticosa	4.0	1.5	12.0	1.1	0.5	3.9	5.4
Alyscarpus glumaceus	3.0	1.0	8.0	0.8	0.3	2.6	3.7
Typha domigensis	5.0	1.5	4.0	1.4	0.5	1.3	3.1
Pycreus polystachys	4.0	1.3	4.0	1.1	0.4	1.3	2.8
Desmodium triflorum	3.0	1.5	4.0	0.8	0.5	1.3	2.6
Hermbstaedtia gregoryi	2.0	2.3	4.0	0.5	0.7	1.3	2.6
Polygala sphenoptera	3.0	0.5	4.0	0.8	0.2	1.3	2.3
Digitaria macrocephara	2.0	0.5	4.0	0.5	0.2	1.3	2.0
Enicostema axillare	2.0	0.5	4.0	0.5	0.2	1.3	2.0
Heliotropium gorinii	1.0	1.3	4.0	0.3	0.4	1.3	2.0
Calotropis procera	0.1	2.0	4.0	0.1	0.65	1.3	1.9
Cynodon nlemfuensis	1.0	0.5	4.0	0.3	0.2	1.3	1.7
Indigofera vohemarensis	1.0	0.5	4.0	0.3	0.2	1.3	1.7
Pergularia daemia	1.0	0.5	4.0	0.3	0.2	1.3	1.7
Salt marsh							
Fimbristylis cymosa	401.3	70.3	44.8	31.7	14.9	7.9	54.5
Sporobolus virginicus	290.2	58.7	46.4	23.0	12.5	8.2	43.6
Tephrosia purpurea	82.3	64.0	54.0	6.5	13.6	9.5	29.6
Phyla nodiflora	145.0	38.4	56.0	11.5	8.2	9.9	29.5
Pluchea dioscoridis	10.3	60.8	44.0	0.8	12.9	7.8	21.5
Enicostema axillare	61.0	15.5	40.0	4.8	3.3	7.1	15.2
Casuarina equisetifolia	0.1	40.0	20.0	0.1	8.5	3.5	12.0
Dactyloctenium geminatum	59.0	13.2	24.0	4.7	2.8	4.2	11.7
Cynodon nlemfuensis	42.0	12.3	20.0	3.3	2.6	3.5	9.5
Eragrostis ciliaris	41.0	9.3	21.3	3.2	2.0	3.8	9.0
Cyperus articulatus	41.5	12.5	12.0	3.3	2.7	2.1	8.1
Phyllanthus reticulatus	0.7	9.0	20.0	0.1	1.9	3.5	5.5
Azardichta indica	0.1	15.0	8.0	0.1	3.2	1.4	4.6
Alyscarpus glumaceus	12.7	5.2	12.0	1.0	1.1	2.1	4.2
Pycreus polystachys	14.0	3.5	12.0	1.1	0.7	2.1	4.0
Lantana camara	0.2	6.5	12.0	0.1	1.4	2.1	3.5
Paspalum vaginatum	18.0	3.0	8.0	1.4	0.6	1.4	3.5
Cyperus rotundus	8.0	3.3	12.0	0.6	0.7	2.1	3.4
Pergularia daemia	4.0	1.5	12.0	0.3	0.3	2.1	2.8
Boerhavia coccinea	6.0	5.0	4.0	0.5	1.1	0.7	2.2
Hyphaene compressa	0.2	3.3	8.0	0.1	0.7	1.4	2.1
Ipomoea pes-caprae	2.0	1.0	8.0	0.2	0.2	1.4	1.8
Halopyrum mucronatum	3.0	3.8	4.0	0.2	0.8	0.7	1.7
Digitaria argyrotricha	6.0	0.5	4.0	0.5	0.1	0.7	1.3
Dicrostachys cinerea	0.1	2.5	4.0	0.1	0.5	0.7	1.2
Lawsonia inermes	0.1	2.0	4.0	0.1	0.4	0.7	1.1
Maytenus senegalensis	0.1	2.0	4.0	0.1	0.4	0.7	1.1
Cassia occidentalis	0.1	2.0	4.0	0.1	0.4	0.7	1.1
Boerhavia diffusa	1.0	1.3	4.0	0.1	0.3	0.7	1.1
Cissus rotundifolia	1.0	1.3	4.0	0.1	0.3	0.7	1.1

App. 2, cont.

Plant species	D	C	F	RD	RC	RF	IVI
Glinus setiflorus	1.0	1.3	4.0	0.1	0.3	0.7	1.1
Crotalaria retusa	3.0	0.5	4.0	0.2	0.1	0.7	1.1
Stylosanthus erectus	2.0	0.5	4.0	0.2	0.1	0.7	1.0
Asystasia gangetica	2.0	0.5	4.0	0.2	0.1	0.7	1.0
Lobelia fervens	2.0	0.5	4.0	0.2	0.1	0.7	1.0
Waltheria indica	1.0	0.5	4.0	0.1	0.1	0.7	0.9
Desmodium triflorum	1.0	0.5	4.0	0.1	0.1	0.7	0.9
Indigofera vohemarensis	1.0	0.5	4.0	0.1	0.1	0.7	0.9
Jasminium fluminense	1.0	0.5	4.0	0.1	0.1	0.7	0.9
Dune ridges							
Achyranthes aspera	79.0	22.3	20.0	16.0	3.7	3.5	23.2
Justicia flava	33.0	21.0	58.0	6.7	3.5	10.2	20.4
Cordia somaliensis	1.2	75.0	28.0	0.2	12.6	4.9	17.7
Pluchea dioscoridis	57.0	22.5	8.0	11.5	3.8	1.4	16.7
Cyperus crassipes	4.9	53.0	31.2	1.0	8.9	5.5	15.4
Ipomoea pes-caprae	35.0	18.1	18.0	7.1	3.0	3.2	13.3
Phyllanthus reticulantus	1.7	40.3	30.0	0.3	6.7	5.3	12.4
Asystasia gangentica	37.8	7.7	15.0	7.6	1.3	2.6	11.6
Tephrosia purpurea	25.0	7.3	28.0	5.1	1.2	4.9	11.2
Boerhavia diffusa	29.0	17.3	12.0	5.9	2.9	2.1	10.9
Cissus rotundifolia	20.2	5.5	20.4	4.1	0.9	3.6	8.6
Digitaria nuda	27.0	5.0	12.0	5.5	0.8	2.1	8.4
Digitaria argyrotricha	23.7	4.8	10.7	4.8	0.8	1.9	7.5
Dobera glabra	0.1	33.8	4.0	0.1	5.7	0.7	6.4
Garcinia livingstonei	0.1	25.0	12.0	0.1	4.2	2.1	6.3
Momordica triflorum	14.0	3.8	16.0	2.8	0.6	2.8	6.3
Afzelia cuanzensis	0.1	30.0	4.0	0.1	5.0	0.7	5.7
Eragrostis ciliaris	20.5	2.1	6.0	4.1	0.4	1.1	5.6
Pergularia daemia	11.5	2.6	15.0	2.3	0.4	2.7	5.4
Sideroxylon inerme	0.1	27.5	4.0	0.1	4.6	0.7	5.3
Commelina latifolia	13.0	5.0	8.0	2.6	0.8	1.4	4.9
Ximenia americana	0.1	13.8	12.0	0.1	2.3	2.1	4.5
Jasminium fluminense	7.3	5.0	10.7	1.5	0.8	1.9	4.2
Strychnos madagarensis	0.1	16.3	6.0	0.1	2.7	1.1	3.8
Azima tetracanda	0.5	15.0	4.0	0.1	2.5	0.7	3.3
Coccinea grandis	5.5	3.6	8.0	1.1	0.6	1.4	3.1
Rhyncosia velutina	5.5	2.9	8.0	1.1	0.5	1.4	3.0
Pacinum maximum	10.0	0.5	4.0	2.0	0.1	0.7	2.8
Bourreria nemoralis	0.1	7.5	8.0	0.1	1.3	1.4	2.7
Cyphostemma dysocarpus	4.3	1.7	8.0	0.9	0.3	1.4	2.6
Lannea schweinfurthii	4.0	1.8	8.0	0.8	0.3	1.4	2.5
Grewia glandulosa	0.2	6.3	8.0	0.1	1.1	1.4	2.5
Maytenus senegalensis	0.2	8.1	6.0	0.1	1.4	1.1	2.5
Digitaria ciliaris	6.0	1.1	6.0	1.2	0.2	1.1	2.5
Sanseveiria arborescens	0.1	10.0	4.0	0.1	1.7	0.7	2.4
Elaeodendron schweinfurthianum	0.1	10.0	4.0	0.1	1.7	0.7	2.4
Solanum incarnum	0.6	5.0	8.0	0.1	0.8	1.4	2.4
Drypetes natalensis	0.1	5.0	8.0	0.1	0.8	1.4	2.3
Tricalysia ovalis	0.2	6.9	6.0	0.1	1.2	1.1	2.3
Deinbollia borbonica	0.1	8.8	4.0	0.1	1.5	0.7	2.2
Ocimum basilicum	3.0	3.8	4.0	0.6	0.6	0.7	1.9
Kigelia africana	0.1	6.3	4.0	0.1	1.1	0.7	1.8
Grewia plagiophylla	0.1	5.0	4.0	0.1	0.8	0.7	1.6
Acridocarpus zanzibaricus	0.1	5.0	4.0	0.1	0.8	0.7	1.6
Indigofera vohemarensis	3.0	0.5	4.0	0.6	0.1	0.7	1.4
Momordica littorea	2.0	0.5	4.0	0.4	0.1	0.7	1.2
Hyphaene coriacea	0.1	2.5	4.0	0.1	0.4	0.7	1.1
Boscia coriacea	0.1	2.5	4.0	0.1	0.4	0.7	1.1
Dicrostachys cinerea	0.1	2.5	4.0	0.1	0.4	0.7	1.1
Grewia vaughamii	0.1	2.5	4.0	0.1	0.1	0.7	1.1
Launea cornuta	1.0	1.3	4.0	0.2	0.2	0.7	1.1
Oxygonum atriplicifolium	1.5	0.5	4.0	0.3	0.1	0.7	1.1
Salvadora persica	0.1	2.0	4.0	0.1	0.3	0.7	1.1
Azardirachta indica	0.1	2.0	4.0	0.2	0.3	0.7	1.0
Waltheria indica	1.0	0.5	4.0	0.2	0.1	0.7	1.0
Heliotropium gorinii	1.0	0.5	4.0	0.2	0.1	0.7	1.0
Boerhavia erectus	1.0	0.5	4.0	0.2	0.1	0.7	1.0
Oldenlandia affinis	1.0	0.5	4.0	0.2	0.1	0.7	1.0
Jatropha stuhlmanii	1.0	0.5	4.0	0.2	0.2	0.7	1.0