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Plant functional types on red sea coastal sand dunes

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ABSTRACT

Plant distribution on southern Red Sea coastal sand dunes was studied using plant functional types approach. Plants were surveyed for functional types defined by photosynthetic characteristics, life form, and growth habit. Work aimed to relateplant distribution to plant attributes and edaphic gradients. Results indicated that plants could be grouped into two functional groups. Functional Group I dominated by summer annuals with C_3 photosynthesis was restricted to hind dune and desert plain zones. Functional Group II dominated by summer annuals with C_4 photosynthesis occurred in foredune, hind dune, and desert plain. Despite heat sensitivity of C_3 carbon fixation enzymes heat avoidance by short life cycles and fast transition from vegetative growth to flowering enabled occurrence of Functional Group I in hot dry hind dune and desert plain. Functional Group II occurred in all three sand dune zones due to C_4 pathway high water use efficiency and tolerance to heat and salinity. Occurrence of recorded life forms and growth habits in all sand dune zones indicated that these two traits alone could not constitutea syndrome that forms functional type. For plant functional types approach to describe plant distribution it has to consider variety of plant traits including form, habit, and physiological characteristics. Results provide a model that can be applied to predict plant distribution at similar settings in different parts of the world.

Key words : *Coastal sand dunes, Photosynthetic pathways, Plant distribution, Plant functional types, Red Sea.*

Introduction

Coastal sand dunes are geomorphic features important for protecting coastlines against wind erosion and tidal inundation, and providing habitat for coastal wildlife (Grootjans *et al.*, 2008; Reffet *et al.*, 2010; Hanley *et al.*, 2014). Plant distribution on coastal sand dunes is thought to be influenced by plant attributes and environmental conditions (Gilbert *et al.*, 2008). Functional types approach relies on syndromes of correlated plant attributes that allow categorizing plants in groups with similar responses to environmental stress (Gitay and Nobel, 1997; Hobbs, 1997;Walker, 1997; Woodward and Kelly, 1997; Woodward *et al.*, 1997;König,2007; Maun, 2008;Novo *et al.*, 2008; Maun, 2009). This approach proved to be useful for describing plant distribution in relation to environmental gradients (Winter *et al.*, 1976; Winter and Troughton, 1978; Sayed, 1994; Knapp and Medina, 1999; Sage *et al.*, 1999; Sayed and Mohamed, 2000; Labuz and Grunewald, 2007; Masrahi *et al.*, 2011; Masrahi*et al.*, 2012).

Sand dune plants on southern Red Sea coastgrow on mobile soil and tolerate salt spray, heat, and drought (Al-Fredan, 2008). We studied plant distribution on these coastal sand dunes using plant functional types approach. Plant functional types were defined by photosynthetic carbon fixation pathway, plant life form, and growth habit. Work aimed to relate plant distribution on coastal sand dunes to the interaction of plant attributes and edaphic gradients. Work also aimed to provide a model that can be applied to predict plant distribution at similar settings in different parts of the world.

Materials and Methods

Work was conducted on southern Saudi Arabian Red Sea coastline on transectat N17°.32'.982 extending 8 km eastwards (from E42°.33'.555 to E42°.40'.662). Three transect zones were considered, namely; foredune, hind dune, and desert plain at distances from shore of 500m, 500-2500, and more than 2500 m, respectively (Fig. 1).

Foredune zone was defined as ridges parallel to shore from mean tidal line to top of hind dune (Psuty, 2008; Maun, 2009). Hind dune zone included dunes farthest from shoreline (Cusseddu *et al.*, 2016). Desert plain was defined as flatbroad lowland beyond hind dune (Masrahi, 2012). Mean monthly climatic records were provided by Ministry of Environment Water and Agriculture (Riyadh, Saudi Arabia). Three soil samples (20cm depth) were collected from each zone and pH, total dissolved solids (TDS), and electrical conductivity (EC) were determined in 10% soil aqueous solution using multi-meter (Hanna Instruments, Woonsocket, RI, USA). Soil water holding capacity was determined by soil saturation percentage method (Mbagwu and Mbah, 1998). Ground water was collected from boreholes in different zones and chloride and carbonate contents were determined (Florence and Farrar, 1971; Leoppert *et al.*, 1984). All measurements were repeated and standard error was calculated using SPSS software (Armonk, NY, USA).

Ten quadrates (25m^2 each) were permanently established in each zone on transect. Plant species were recorded in these quadrates over six months (April-September) to cover wet and dry seasons and account for annual and perennial species. Collected plant specimens were identified using regional flora literature (Miller *et al.*, 1996; Wood, 1997; Collenette, 1999; Chaudhary, 2001; Alfarhan *et al.*, 2005; Masrahi, 2012) and were verified against specimens in Jazan University Herbarium (JAZUH). Carbon isotope discrimination and photosynthetic CO_2 fixation pathways were assigned to species as per published literature (Winter *et al.*, 1976; Ziegler *et al.*, 1981; Vogel *et al.*, 1986; Batanouny*et al.*, 1988; Rundel *et al.*, 1999; Sayed and Mohamed, 2000; Sayed, 2001; Akhter *et al.*, 2005; Wang *et al.*, 2005; Sage *et al.*, 2007; Sikolia *et al.*, 2008; Christin *et al.*, 2011; Masrahi *et al.*, 2011; Muhaidat *et al.*, 2011; Masrahi *et al.*, 2012; Fisher *et al.*, 2015).

Results

Climatic records indicated mean monthly winter (December-March) temperature of about 34 ºC, summer (June - September) temperature of about 39 ºC, and monthly average relative humidity of 60-70% (Table 1). Records also indicated low total annual precipitation of 97.5mm and mean monthly evaporation of 5-10 mm (Table 1). Soil pH increased from foredune to desert plain, while soil TDS and EC decreased (Table 2). Soil water holding capacity was low in foredune and hind dune and was high in desert plain (Table 2). Ground water level was deeper the farther the distance from shoreline with pH, chloride, and carbonate contents decreasing with increased distance from sea shore (Table 3).

Vegetation records indicated presence of 42 plant species, belonging to 36 genera and 18 families (Table 4). Recorded species included summer annual and perennial herbs, shrubs, and trees exhibiting carbon discrimination values typical of C_3 and C_4 carbon fixation pathways with C_3 plants re-

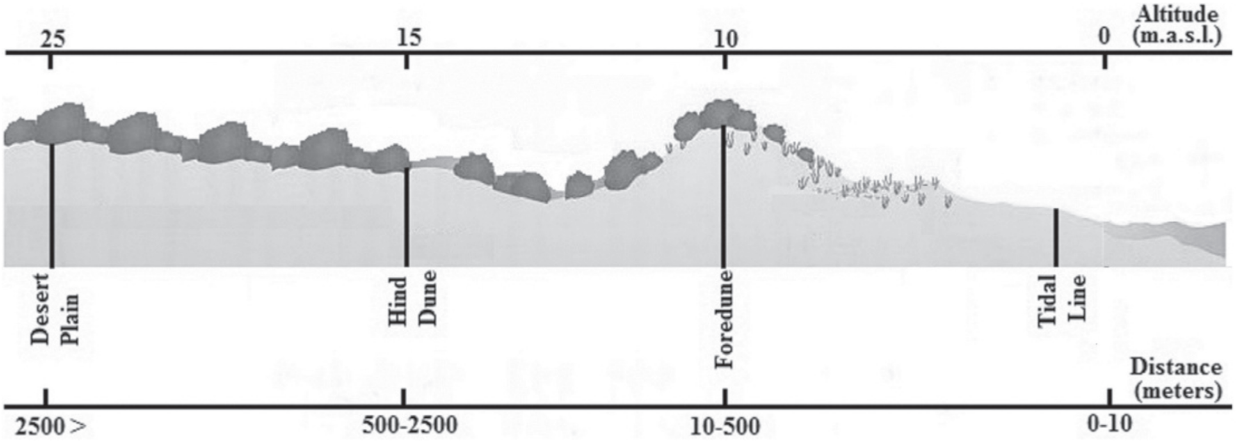

Fig. 1. Transect zones and their distance from Red Sea shore at the study site.

Table 1. Monthly average of climatic norms at the study site.

Parameter	Months											
	J	F	M	A	M	J	J	A	S	O	N	D
Max. Air Temp. (ºC)	31	35	36	37	38	39	40	41	38	37	36	35
Relative Humidity (%)	75	72	70	66	65	64	60	65	67	68	69	70
Precipitation (mm)	5	4.5	4.5	5	4.5	20	8.5	9	9.5	10	9	8
Evaporation (mm)	5	5	7	9	10	9	10	8	9	9	6	5

Table 2. Soil physicochemical characteristics along transect (mean ± se, n =3). (EC Electrical Conductivity, TDS = Total Dissolved Solids, WHC = Water Holding Capacity).

Zone	pH	TDS (mg L^{-1})	EC (mS/dm)	WHC (%)
Foredune	8.0	80 ± 1.2	165 ± 1.2	3.3 ± 0.3
Hind Dune	8.3	25 ± 1.9	48 ± 0.8	2.5 ± 0.5
Desert Plain	8.5	20 ± 2.1	40 ± 0.4	19.5 ± 0.2

Table 3.Ground water physicochemical characteristics along transect (mean ± se, n=3). (GWL = Ground Water level).

Zone	GWL (m)	pH	Cl^- (mg L^{-1})	CO_3^{2-} (mg L^{-1})
Foredune	4.3	8.0	17 ± 1.4	50 ± 3.5
Hind Dune	7.0	7.8	13 ± 2.1	35 ± 1.6
Desert Plain	9.1	7.5	5 ± 1.0	20 ± 2.2

stricted to hind dune and desert plain, while C_4 plants occurring in all three transect zones (Table 4). Recorded life forms indicated that foredune plants were herbs and shrubs at 73%, 27%, respectively, and hind dune plants were herbs and shrubs at 78% and 22%, respectively (Fig. 2a). Desert plain plants included herbs, shrubs, and trees at 78%, 18%, and 4%, respectively (Fig. 2a). Recorded growth habits indicated that summer annuals and perennials were equally represented in foredune,and were 60% and 33% in hind dune (Fig. 2b). In desert plain summer annuals and perennials were 60% and 35%, respectively (Fig. 2b).

Discussion

Climatic records indicated that the study site is characterized by mild winter, warm summer, high humidity, high evaporation, and scarce rainfall (Table 1). Such habitats where evaporation exceeds water supply have negative water balance that imposes plant water stress (Maliva and Missimer, 2012; Subyani *et al.*, 2010). Soil analysis revealed presence of edaphic gradients with soil pH increasing while TDS and EC decreasing with increased distance from shoreline (Table 2). Desert plain soil water holding capacity was higher than that in other

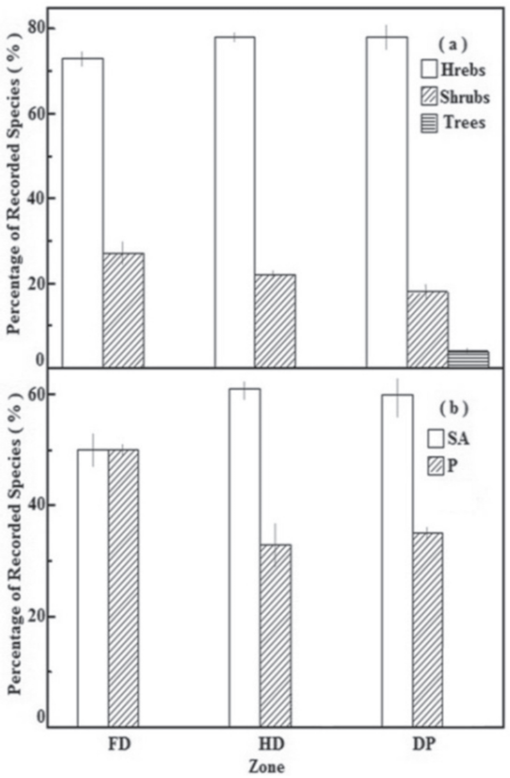

Fig. 2. Life forms and growth habits of plants in different transect zones (FD = Foredune, HD = Hind Dune, DP = Desert Plain, ± se, n = 10).

dune zones due to the silt-loam nature of desert plain soil (Masrahi *et al.*, 2011). Ground water level showed similar gradient by being deeper with pH, chloride, and carbonates decreasing with increased distance from shoreline(Table 3). These results collectively revealed presence of conspicuous edaphic gradients at the study site. These gradients are thought to be prime factors influencing plant distri-

Table 4. Geomorphic forms (GF), plant life form (LF), plant growth habit (GH), and photosynthetic characteristics of plant species at the study site. (FD = Foredune, HD = Hind Dune, DP = Desert Plain), (H = Herb, S = Shrub, T = Tree), (SA = Summer Annual, P = Perennial) (δ^{13}C: Carbon Isotope Discrimination ‰, CF: Carbon Fixation Pathway).

Species	Family	GF	LF	GH	ä^{13}C	CF
Functional Type I						
Abutilon pannosum (G. Forst.) Schlecht.	Malvaceae	DP	H	SA	-27.6	C3
Acacia tortilis (Forssk.) Hayne	Fabaceae	DP	T	P	-20.9	C3
Cadaba rotundifolia Forssk.	Capparaceae	HD	S	P	25.9	C3
Calotropis procera (Ait.) R. Br.	Apocynaceae	DP	S	P	-27.9	C3
Corchorus depressus (L.) Stocks.	Tiliaceae	DP	H	SA	-29.2	C3
Cressa cretica L.	Convolvulaceae	DP	H	SA	-28.0	C3
Digera muricata (L.) Mart.	Amaranthaceae	DP	H	SA	-25.7	C3
Dipterygium glaucum Decne.	Capparaceae	HD, DP	H	SA	28.5	C3
Glinus lotoides L.	Mulloginaceae	DP	H	SA	-26.3	C3
Gypsophila capillaris (Forssk.) C.Christ.	Caryophyllaceae	DP	H	SA	-26.5	C3
Indigofera argentea Burm. f.	Fabaceae	HD,DP	S	SA	-25.2	C3
Salvadora persica L.	Salvadoraceae	DP	S	P	-24.7	C3
Sesuvium portulacastrum (L.) L.	Aizoaceae	DP	H	SA	-24.9	C3
Zygophyllum album L.f.	Zygophyllaceae	DP	S	SA	-26.5	C3
Functional Type II						
Aeluropus lagopoides (L.) Trin. ex Thw.	Poaceae	FD	S	P	-13.3	C4
Aerva javanica (Burm.f.) Juss. ex Schult	Amaranthaceae	FD,HD,DP	H	P	-14.4	C4
Amaranthus graecizans L.	Amaranthaceae	HD,DP	H	SA	-15.8	C4
Amaranthus viridis L.	Amaranthaceae	DP	H	SA	-13.5	C4
Aristida funiculata Trin. & Rupr.	Poaceae	DP	H	SA	-12.7	C4
Blepharis edulis (Forssk.) Pers.	Acanthaceae	FD,HD	S	SA	-14.6	C4
Boerhavia diffusa L.	Nyctaginaceae	DP	H	SA	-12.2	C4
Cenchrus ciliaris L.	Poaceae	HD,DP	H	SA	-12.0	C4
Cenchrus setigerus Vahl.	Poaceae	FD	H	SA	-10.5	C4
Chloris barbata Sw.	Poaceae	DP	H	SA	-12.2	C4
Dactyloctenium aegyptium (L.) Willd.	Poaceae	DP	H	SA	-12.2	C4
Dichanthium annulatum (Forrsk.) Stapf.	Poaceae	FD,HD,DP	H	P	-11.9	C4
Echinochloa colona (L.) Link	Poaceae	DP	H	SA	-11.9	C4
Heliotropium strigosum Willd.	Boraginaceae	FD,HD,DP	H	P	-13.0	C4
Lasiurus scindicus Henr.	Poaceae	FD,HD,DP	H	P	-11.7	C4
Panicum maximum Jacq.	Poaceae	FD,HD,DP	H	SA	-12.0	C4
Panicum turgidum Forssk.	Poaceae	FD,HD	H	P	-12.7	C4
Paspalidium desertorum (A. Rich.) Stapf	Poaceae	DP	H	SA	-12.5	C4
Portulaca oleracea L.	Portulacaceae	FD,HD	H	SA	-12.1	C4
Salsola spinescence Moq.	Chenopodiaceae	FD,HD	S	P	-14.2	C4
Sesuvium sesuvioides (Fenzl) Verdc.	Aizoaceae	FD,HD	H	SA	-12.2	C4
Sporobolus spicatus (Vahl.) Kunth	Poaceae	FD	H	P	-13.8	C4
Suaeda monoica Forssk. *ex* J. Gmel.	Chenopodiaceae	FD	S	P	-14.9	C4
Trianthema portulacastrum L.	Aizoaceae	FD,DP	H	SA	-12.5	C4
Trianthema triquetra Willd.	Aizoaceae	FD,HD	H	SA	-13.3	C4
Tribulus terrestris L.	Zygophyllaceae	FD,HD	H	SA	-10.7	C4
Zaleya pentandra (L.) Jeffrey	Aizoaceae	DP	H	P	-12.3	C4
Zygophyllum simplex L.	Zygophyllaceae	FD,HD	H	SA	-13.8	C4

bution in coastal habitats and, hence, the study site was suitable to applyplant functional types approach (Sayed, 1994; Rogel *et al*., 2001; Angiolini *et al*., 2013; Silva *et al*., 2016).

Vegetation records reflected plant diversity with summer annual and perennial herbs, shrubs, and trees exhibiting carbon discrimination values typical of C_3 and C_4 carbon fixation pathways (Table 4). Defining functional types by photosynthetic characteristics enabled recorded plant species to be grouped into two functional types. Functional Type I included summer annual and perennial herbs, shrubs and trees with C_3 photosynthesis in hot dry hind dune and desert plain (Table 4). Heat and drought sensitivity is a known feature of C_3 photosynthesis (Sage and Kubien, 2007; Sage *et al*., 2007; Yamori *et al*., 2012; Yamori *et al*., 2014), and hence, it is a negative trait for plants to survive in hot dry hind dune and desert plain.

However, heat and drought sensitivity of C_3 photosynthesis is perhaps compensated for by short life cycles and rapid transition from vegetative growth to flowering in plant species growing in hot dry hind dune and desert plain (Chaves *et al*., 2002; Lee *et al*., 2010; Wang *et al*., 2011; Freidman and Rubin, 2015).

On the other hand, Functional Type II included summer annual and perennial herbs and shrubs with C_4photosynthesis occurring in all transect zones (Table 4). The C_4 pathway and morphoanatomical features form the C_4 syndrome in plants with tolerance to abiotic stress (Sage *et al*., 2011; Yamori *et al*., 2014; Sage and Stata, 2015). Therefore, Functional Type IIfits foredunesaline conditions due relative salt tolerance of C_4 photosynthesis (Sage, 2004; Sage and Zhu, 2011; Eallonardo *et al*., 2013; Bromham and Bennett, 2014). In addition, the C_4 syndrome imparts drought tolerance, high water-use efficiency, and an ability to control turgor at low water potential (Sage and Stata, 2015). These features are thought to be responsible for the observed presence of Functional Type II plants in all transect zones. Moreover, The C_4 plants high water use efficiency and improved water relations are inclined to be more expressed in hot dry climates (Edwards and Smith, 2010; Gowik and Westhoff, 2011; Lawas *et al*., 2018). Furthermore, occurrence of recorded life forms and growth habits in all transect zones (Fig. 2) indicated that these morphological traits could not alone constitute a syndrome that forma plant functional type and therefore, are not suitable alone to study plant distribution.

It can be concluded that plant distribution on coastal sand dunes is influenced by the intricate relationship between plant attributes and edaphic gradients. Plant functional types approach is useful for describing plant distribution on coastal sand dunes. For plant functional type approach to be useful it has to be based on a wide variety of plant traits including morphoanatomical and physiological characteristics.

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