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Zonation Pattern of *Avicennia marina* and *Rhizophora mucronata* along the Red Sea Coast, Egypt

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Abstract: The variations in the distribution pattern and growth attributes of the two mangrove species *Avicennia marina* and *Rhizophora mucronata* as related to soil factors and tide levels were investigated along the Red Sea coast, Egypt. The plant height, size index, trunk circumference, number main and lateral branches, leaf number and area and the number of seedlings of *R. mucronata* was high in pure patches than when grow mixed with *Avicennia*. The variation in tide level showed no significant effects on the growth parameters of *R. mucronata* growing in pure community, However, significant difference was recorded for the individuals growing in mixed plots with *A. marina*. *Avicennia marina* showed an opposite trend in most of the recorded parameters. The habitat of *R. mucronata* is characterized by low soil salinity, silt and pH values, compared with that of *A. marina* that grow in more saline habitats and had the highest value of silt. Plots of the association growth of *R. mucronata* and *A. marina* showed an intermediate values for most of the studied soil variables. The results suggest that while abiotic environmental conditions may account for the absence of *R. mucronata* in high saline mud soils along the Red Sea coast of Egypt, but also the tolerance of each species to each particular is more important in the formation of mixed growth of both species.

Key words: Mangroves · aerial roots · size index · soil characteristics · tides

INTRODUCTION

Mangrove formations are one of the important types of wetlands found in the intertidal zone of tropical and subtropical regions of the world. They have a significant ecological and economic importance at global, regional mostly at a local level. For these reasons, the scientific community has led efforts to investigate the structural, functional and dynamic regularities that characterize these fragile ecosystems, which may be aimed at establishing the bases for the sustainable management of littoral resources [1, 2]. Along the Red Sea coast, mangroves reach their northernmost distribution at Hurghada, Egypt, being mainly composed of *Avicennia marina*. However, in the most southern part from Mersa El-Madfa (Lat. 23°N) till Mersa Halaib, on the Sudano-Egyptian border, *Rhizophora mucronata* predominates or dominates with *Avicennia marina* [2]. Domination of *Avicennia marina* and *Rhizophora mucronata* extends southwards to cover the whole Red Sea coast of the Sudan [3].

There is an obvious zonation that is displayed by the two mangrove species along the Red Sea coast. Distribution pattern of the different species is worth noting, since zones can be dominated by a given species, or codominated by two species [4-6]. Zonation is likely the mangrove ecosystem's response to external factors rather than a temporal sequence induced by the plants themselves. It is generally considered that the spatial distribution might also be associated to changes in water level and salinity [7, 8]. The level of nutrients could be an important factor in determining the direction and extent of succession within plant communities [9].

Since plant distribution responds to changes in habitat, the modifications induced by geomorphic processes can occur regardless of biotic factors. This concept has been applied to low tropical coasts, particularly where mangrove communities develop, since these communities frequently grow in habitats that vary substantially in their geomorphological characteristics [10].

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No detailed studies on growth attributes changes of mangrove vegetation have been made in relation to physical factors at more local scale. This study establishes the effects of soil factors and tidal zone position on zonation pattern and growth attributes of *Avicennia* and *Rhizophora* along the Red Sea coast of Egypt.

MATERIALS AND METHODS

Study area: The Field site is located 37 km south Shalateen along the Red Sea coast. Mangrove zonation was observed at this site during May, 2003. Three belt transects dominated by the mangrove vegetation were selected at random to represent the physiographic variations in the study area. The first transect (22° 53' 11"N) represents a mixture growth between *Avicennia marina* and *Rhizophora mucronata*, the second transect (22° 53' 32"N) represents a pure growth of *R. mucronata* and the third transect (22 14 11N) was a pure growth of *A. marina.*

Each line transect was divided into three zones corresponding to the tidal flooding classes (high tide, medium tide and low tide), according to Watson [11] after Galal [12]. At the first and the second transects, three random plots (10×10 m) are selected to represent the different zones of high, medium and low tides respectively. At the third transect, six plots are selected to represent the different tide levels.

In each plot, species density, frequency and canopy cover were calculated according to Muller-Dombois and Ellenberg [13]. Also, plant height (H), diameter (D) of each individual of certain species in the sampled plots were measured and its size index was calculated as follows: [H+D)/2 (14]. The main lateral branches per tree, tree circumference (at d.b.h) and leaf area are measured.

The number of seedlings and the number of aerial roots per plot are counted. The fresh and dry weight of 50 leaves and 50 lateral branches per tree of the two mangrove species are estimated.

From each plot three soil samples are collected and mixed to form a composite sample. All samples were air dried and sieved through 2mm sieve to remove debris and coarse gravel. These samples were analyzed for soil texture, pH, Electrical Conductivity (EC), organic carbon, calcium carbonates, cations e.g. Na, K, Ca and Mg and anions e.g. Chlorides and sulphates, according to Jackson [15] and Piper [16].

F-test is applied to the variances of the two samples of the NULL hypothesis, that they have both been drawn from the population. The F-test was performed using SYSTAT 7 software.

RESULTS

The growth performance of *R. mucronata* was significantly higher in pure stands than in association with *A. marina* (Table 1). *Rhizophora mucronata* in pure community grew twice as tall, had more main and lateral branches and attain nearly 10 times the total number of leaves compared with those growing in mixed community. However, *A. marina* trees growing in association with *R. mucronata* were taller than plants growing in pure community. There were no differences in the number of lateral branches and the number of leaves produced by *A. marina* in the two locations.

The growth attributes of *R. mucronata* did not differ significantly at the three tide types in the pure stands (Table 2). However, the tide level had a significant effect on *R. mucronata* growing in association with *A. marina*. Plants growing at high tide attained the highest values of

Table 1: Comparison of growth performance (mean±SE) of *Rhizophora mucronata* and *Avicennia marina* growing alone (pure) and togather (mixed). Significance levels are shown as (*): p<0.05, (**): p<0.01

	R. mucronata			*A. marina*		
Character	Pure	Mixed	F-value	Pure	Mixed	F-value
Height (cm)	273.62±14.91	101.73±42.14	4.99*	158.57±39.12	199.57±26.72	3.31*
Size index	207.11±10.93	78.36±32.59	4.73*	130.11±36.85	214.52±35.21	3.57*
Trunk circumf. (cm)	21.87±1.42	7.21±2.81	7.57**	34.78±8.91	41.42±6.62	2.07
No. main branches	18.87±1.01	2.42±1.03	53.67**	4.92±0.97	6.73±1.08	3.55*
No. lateral branches	47.12±6.93	11.36±3.55	16.37**	127.28±67.95	101.94±16.95	0.71
Leaf number	315.25±28.75	70.12±28.81	16.09*	1510.1±46.46	1587.3±607.81	2.51
Leaf area	17.88±2.13	10.31±3.01	3.03	8.18±1.11	6.24±0.82	6.34**
No aerial roots	341.01±23.75	197.78±64.23	2.53	445.57±128.3	508.94±60.01	2.62
No seedlings	285.87±35.93	96.42±43.54	4.96*	6.21±0.68	4.78±0.89	4.42*

Table 2: Comparison of growth performance (mean±SE) of *Rhizophora mucronata* growing alone (pure) and with *Avicennia marina* (mixed) at low, medium and high tides. Significance levels are shown as (*): p<0.05, (**): p<0.01

	Pure				Mixed				
Character	Low	Medium	High	F-value	Low	Medium	High	F-value	F-value
Height (cm)	281.00±15.17	297.00±36.00	250.66±30.67	0.74	10.66±10.66	29.22±16.62	234.00±96.64	3.78*	3.62*
Size index	212.33±19.56	229.00±12.00	187.00±17.57	1.27	6.66±6.66	19.33±11.92	185.00±73.44	4.26*	3.86*
Trunk circumf. (cm)	22.66±3.28	24.00±1.00	19.66±1.85	0.73	2.00±2.00	2.55±1.48	15.42±6.46	3.09	4.12*
No. main branches	19.33±0.88	21.00±3.00	17.00±1.52	1.38	0.33±0.33	0.33±0.16	6.00±2.27	5.14*	27.52**
No. lateral branches	46.33±8.64	56.50±27.50	41.66±8.81	0.28	1.33±1.33	8.44±4.49	19.42±6.92	1.92	5.9**
Leaf number	320.33±24.18	345.50±109.50	290.00±50.01	0.23	13.00±13.00	46.00±39.03	125.28±57.04	1.17	5.49**
Leaf area	19.93±5.16	17.35±1.95	16.20±3.28	0.23	6.96±6.96	9.17±4.85	13.17±4.87	0.28	0.58
No aerial roots	296.00±0.00	287.00±0.00	422.00±0.00	0.00	6.00±6.00	232.66±116.33	235.14±85.27	0.82	0.91
No seedlings	169.00±0.00	311.00±0.00	386.00±0.00	0.00	1.66±1.66	172.33±86.16	39.42±17.24	1.49	2.89*

Table 3: Comparison of growth performance (mean±SE) of *Avicennia marina* growing alone (pure) and with *Rhizophora mucronata* (mixed) at low, medium and high tides. Significance levels are shown as (*): p<0.05, (**): p<0.01

Character	Pure				Mixed				
Tide	Low	Medium	High	F-value	Low	Medium	High	F-value	F-value
Height (cm)	319.50±11.48	29.67±5.73	62.50±6.50	304.72**	11.67±11.67	230.11±23.89	240.86±42.59	8.55*	18.14**
Size index	275.33±28.81	17.50±2.97	31.50±0.50	48.55**	10.00±10.00	229.67±20.19	282.71±74.61	4.86*	8.22**
Trunk circumf. (cm)	51.50±15.17	4.83±0.87	4.50±0.50	5.95*	2.00±2.00	48.67±7.09	49.00±11.77	4.68*	4.12*
No. main branches	8.00±1.46	3.00±0.45	1.50±0.00	7.99*	0.67±1.46	6.67±0.45	9.43±0.50	5.28*	5.03*
No. lateral branches	291.00±136.49	5.00±1.44	3.00±2.00	2.77	2.67±2.67	154.78±20.40	76.57±14.74	12.11**	4.98*
Leaf number	330.83±42.16	16.00±2.82	17.00±0.00	34.83**	4.33±4.33	820.67±238.06	3251.43±1464.43	2.74	3.12*
Leaf area	8.18±1.10	0.00±0.00	0.00±0.00	0.00	1.33±1.33	8.10±0.94	5.97±1.16	6.31*	2.81*
No aerial roots	978.00±24.15	43.00±9.84	56.00±0.00	802.57**	316.33±165.52	620.33±82.54	448.29±88.40	2.02	2.74*
No seedlings	8.00±0.45	3.50±0.22	9.00±0.00	57.83**	1.33±1.33	6.00±1.61	4.71±0.81	1.75	17.53**

Table 4: Comparison of soil variables (mean±SE) of *Rhizophora mucronata* and *Avicennia marina* growing alone (pure) and in association with each other (mixed). Significance levels are shown as (*): p<0.05, (**): p<0.01

	R. mucronata			*A. marina*			
Character	Pure	Mixed	F-value	Pure	Mixed	F-value	F-value
Gravel (%)	0.70±0.05	2.36±0.43	12.04**	2.58±1.23	2.36±0.43	1.17	1.87
Sand (%)	79.07±1.93	75.38±2.73	171.86**	76.74±1.24	75.38±2.72	206.88**	0.81
Silt (%)	3.17±0.27	3.44±0.79	5.00*	5.26±0.65	3.44±0.79	7.44*	3.38*
Clay (%)	17.06±1.64	18.75±2.48	11.76**	15.48±1.83	18.75±2.48	10.48**	0.65
pH	6.65±0.11	7.16±0.13	542.73**	7.58±0.09	7.17±0.13	660.20**	17.61**
EC (mmohs cm^{-1})	136.67±9.27	162.77±23.57	11.83**	248.89±53.59	162.77±23.57	5.19*	2.94*
Na (m-equiv l^{-1})	327.83±9.15	546.23±91.89	10.34**	831.88±309.44	546.23±91.89	1.91	1.84
K (m-equiv l^{-1})	36.33±7.02	90.83±25.97	4.10*	19.42±7.02	90.83±25.97	5.31*	5.40*
Ca (m-equiv l^{-1})	23.66±1.36	30.77±6.15	6.71*	34.00±3.19	30.77±6.15	7.14*	1.68
Mg (m-equiv l^{-1})	52.00±3.75	58.77±12.08	6.32*	78.22±12.45	58.77±12.08	5.71*	1.76
Cl (m-equiv l^{-1})	294.00±12.00	518.55±105.50	7.22*	372.00±72.49	518.55±105.51	4.63*	2.36
SO_4 (m-equiv l^{-1})	0.93±0.01	0.99±0.01	1372.19**	0.82±0.05	0.99±0.01	96.11**	7.41**
$CaCO_3$ (%)	26.66±0.44	17.50±3.45	16.87**	10.40±0.81	17.50±3.45	7.24*	15.65**
Organic carbon (%)	1.57±0.05	1.66±0.09	62.28**	1.65±0.22	1.66±0.09	14.86**	0.12

growth attributes. In comparison, *A. marina* growth attributes differed significantly between the two locations of the three tide levels (Table 3). The highest values of the growth parameters were recorded for plants growing at the low tide in pure stands. However, the growth values of *A. marina* growing in mixture with *R. mucronata* were higher at high tide than those at either low or medium tides.

Table 5: Comparison of soil variables (mean±SE) of *Rhizophora mucronata* and with *Avicennia marina* growing alone (pure) and togather (mixed) at low, medium and high tides. Significance levels are shown as (*): p<0.05, (**): p<0.01

		Soil characters						
Species	Tide	Gravel	Sand	Silt	Clay	pH	EC	Na^+
Avicenia	Low	0.2	73.8	5.77	20.47	7.47	130	213.04
		±0.1	±2.15	±0.13	±2.56	±0.13	±20	±26.08
	Medium	0.1	75.8	7.2	16.9	7.4	160	239.13
		0	0	0	0	0	0	0
	High	7.46	80.63	2.8	9.1	7.87	465	2043.48
		±0.56	±1.26	±0.3	±0.4	±0.13	±38.33	±217.39
	F-value	161.7**	5.95*	140.2**	15.0*	5.4*	52.3**	68.9**
Rhizophora	Low	0.76	87.93	2.16	10.56	6.83	150.33	328.23
		±0.08	±0.63	±0.12	±0.23	±0.03	±3.17	±2.32
	Medium	0.96	76.26	3.67	20.83	6.38	164.33	358.03
		±0.17	±0.93	±0.08	±0.08	±0.07	±2.33	±4.36
	High	0.5	73.86	4.03	20.3	6.77	103.33	290.23
		±0.05	±1.04	±0.09	±0.35	±0.08	±6.01	±3.09
	F-value	3.9	71.9**	97.8**	540.1**	12.5*	59.3**	101.9**
Avicenia+ Rhizophora	Low	1.76	70.2	4.7	23.33	6.77	133.33	504.8
		±0.43	±3.72	±2.01	±2.72	±0.03	±16.91	±147.11
	Medium	1.43	70.6	4.23	23.6	7.1	133.33	394.33
		±0.40	±0.29	±0.64	±0.06	±0.12	±8.82	±79.44
	High	3.9	85.37	1.4	9.33	7.63	221.67	739.57
		±0.36	±0.88	±0.2	±0.55	±0.12	±60.85	±205.68
	F-value	10.9*	15.3*	2.2	25.9**	19.9*	1.9	1.3
	F-value	57.6**	10.2**	5.6*	18.0**	14.2**	16.5**	24.2**

		Soil characters						
Species	Tide	K^+	Ca^{++}	Mg^{++}	Cl^-	SO_4	CaCO3	OC
Avicenia	Low	7.09	43.33	128	660	0.87	11.2	1.22
		±0.59	±7.33	±0	±28	±0.09	±1.9	±0.04
	Medium	8.97	28	52	232	0.7	8.2	1.26
		0	0	0	0	0	0	0
	High	42.22	30.66	54.66	224	0.89	11.8	2.48
		±14.19	±1.33	±1.33	±8.00	±0.12	±0.7	±0.28
	F-value	5.8*	3.6	3139**	220.1**	1.5	2.7	19.2*
Rhizophora	Low	25.07	23.67	52.33	273.3	0.8	24.67	1.65
		±0.63	±0.88	±1.45	±6.01	±0.06	±0.88	±0.01
	Medium	17.9	19.67	38	265.3	0.8	28.67	1.37
		±0.95	±0.88	±1.52	±2.91	±0.11	±0.88	±0.04
	High	64.7	29.67	67.67	348.7	1.13	30.33	1.82
		±0.65	±1.21	±1.45	±3.53	±0.14	±0.88	±0.05
	F-value	1098**	25.3**	100.7**	111.3**	3.3	10.9*	39.0**
Avicenia+ Rhizophora	Low	52.83	21	52.67	348	0.99	15.5	1.47
		±21.21	±6.66	±19.43	±115.45	±0.01	±5.68	±0.06
	Medium	80.7	37.33	67.67	534	0.99	17.33	1.68
		±23.95	±11.10	±19.10	±216.85	0	±6.39	±0.15
	High	138.97	34	56	673.7	1	19.67	1.83
		±71.69	±14.57	±30.81	±215.70	±0.02	±8.08	±0.25
	F-value	0.9	0.6	0.1	0.8	0.4	0.1	1.1
F-value		2.3	0.8	3.1*	2.3	3.4*	0.8	7.8

A comparison of soil characteristics in the pure plots and those of mixed growth of both species showed a number of significant variations in silt content, pH, electrical conductivity (EC), CaCO3, K and SO4 (Table 4). The plots of *R. mucronata* had low salinity (136.67 mmhos cm^{-1}) and the lowest values of silt (3.17%), pH (5.65) and Na (327.83 m-equiv l^{-1}). However, the plots of *A. marina* were more saline (248.89 mmhos cm^{-1}) and had the highest values of silt (5.26%), pH (7.58) and Na (831.88 m-equv l^{-1}). Generally, the plots of mixed growth of *A. marina* and *R. mucronata* had intermediate values for most of the studied soil variables compared with those of *A. marina* or those of *R. mucronata* (Table 4).

The different tide levels affected significantly most soil characteristics except for K, Ca, CaCO3 and organic carbon (Table 5). *Avicennia marina* plots at high tide had the highest values of pH (7.87), EC (465 mmhos cm^{-1}) and Na (2043.48 m-equv l^{-1}). On the other hand, *R. mucronata* plots at high tide had the lowest values of EC (103.33 mmhos cm^{-1}) and Na (290.23 m-equv l^{-1}).

DISCUSSION

The distribution pattern and the overlap occurrences of *A. marina* and *R. mucronata* along the Red Sea coast of Egypt indicate overlap in environmental requirements or tolerance of environmental stress. The mangroves are not restricted to specific soil conditions although each community tends to show niche relation to certain soil variable (Table 4). Hence, several soil properties could serve as indicators for community type differentiation [17]. For example, higher acidity (pH-values) prevails in soils associated with *Rhizophora* communities than *Avicennia* communities. *Rhizophora* has extensive fibrous root system which form thick peat-like mud, which lower the pH after decomposition [18]. *Avicennia* does not produce fibrous mud. Consequently, *A. marina* soils are less acidic.

Zonation pattern of the mangroves along the Red Sea coast of Egypt also relates to tidal inundation and morphological characteristics of the species. *Rhizophora* with extensive prop roots can withstand wave action along the main tidal channels, *Avicennia* fringe in the less dynamic parts of shores. This confirms that zonation is also a function of habitat change which may be induced by process of landscape evolution. *Avicennia* cover was greater in the mudflat, with a higher salinity, this being a most important factor, along with substrate type and extreme hydrological and oceanographic regimes [19-21].

Leaf morphology (i.e., area, length and width) has been found to differ significantly between dwarf and long trees of *Avicennia* but not in case of *Rhizophora.* Results of this study, show that leaf number and main branches can be directly compared among forest types, however, plant height, Size index and number of seedlings showed highly significant difference under different tide levels in mixed forest types using a per tree comparison. Differences in mangrove leaf area can be the result of varying environmental stress levels (e.g., salinity, pollutants, nutrient limitation) among forest types [22, 21].

The distribution of both species is subjected to varying condition of salinity concentrations, nutrient levels, substrate structure and tidal movement. However, the influence of other environmental factors need to be analyzed before the current zonation pattern can be properly understood.

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