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SEASONAL VARIATION IN PRODUCTIVITY OF *ATRIPLEX STOCKSII* FROM A COASTAL MARSH ALONG THE ARABIAN SEA COAST

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Abstract

The productivity of *Atriplex stocksii* population located near the coast (Gizri Creek) of Karachi, Pakistan was studied for two years. The net biomass production showed seasonal variation and productivity appeared to be influenced by rainfall during both years. Belowground and above ground biomass showed no change during the dry year, however, considerable biomass was produced after the availability of moisture. The above ground dead biomass remained unchanged during 1997-98 but it registered a substantial promotion during the wet season. The ion concentration of root was much higher than shoot. Na^+ and Cl^- remained high however, the concentration of other ions did not change much during both seasons. Root fresh weight was significantly promoted at low salinity and increase in salinity inhibited root and shoot growth. Fresh weight of shoots at low density was not affected by low salinities, however, at higher salinity concentrations there was no effect of density. Root fresh and dry weight were higher at low density and low salinity, however under high salinity, density had no effect. Succulence on dry weight basis was also higher at higher densities. However, succulence decreased substantially at high salinities on per plant basis. Shoots of *A. stocksii* accumulated large quantities of Na^+ and Cl^- whereas other ions were found in lower amount. Na^+ and Cl^- in root increased but were much lower in comparison to shoot.

Introduction

Atriplex stocksii Boiss., is a short, robust perennial shrub distributed in both inland and coastal marshes and deserts around Karachi, Pakistan. Coastal species receive rare seawater inundation, and both coastal and inland populations either tap underground water sources or rely on monsoon rains that come during July and August. Seeds germinate after monsoon rains and survivorship is high. Dormant plants become active and produce vegetative part immediately, flowers and fruits after about 30 days and seeds after 60 days and become dormant again.

The primary production of salt marshes is associated with the changes in soil salinity, nutrients, climate, marsh physiognomy, sedimentation processes and changes in sea level relative to the land (Irlandi *et al.*, 2001; Masini *et al.*, 2001; Santos & Esteves, 2002; Tyler, 2003; He *et al.*, 2007; Regan *et al.*, 2007). Salt marshes are ranked among the most productive ecosystems in the world and range from about 200-2000 $g.m^{-2}\ yr^{-1}$ (Keenish, 1986). Net annual primary productivity (NAPP) estimates for salt marsh emergent's ranges approximately between 100 and 400 g dry weight $m^{-2}\ yr^{-1}$ but most records of biomass are around 1000-2000 $gm^{-2}\ yr^{-1}$ (Odum *et al.*, 1984). The pattern of accumulation of aboveground biomass differs for each marsh and is different every year which ranges from approximately 300 to 400 $g.dw.m^{-2}\ yr^{-1}$ (Gallagher, 1978). Higher plant densities have a higher production of leaf biomass per unit area and lower densities result in lower branch diameter and an increased proportion of leaf productivity in

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standing biomass (Mittelbach *et al*., 2001). In herbaceous communities, belowground biomass can be 40% of the total biomass and in some cases where animal grazing is high, net productivity (NP) can be underestimated when based only on standing crop-biomass (Paling & McComb, 2000).

Coastal vegetation in and around Karachi is dominated by shrubs and perennial grasses and their distribution seems to be controlled by the degree and frequency of inundation, rainfall and soil type (Khan & Gul 2002). *Atriplex stocksii* usually occupies the dunes and those parts of the coastal vegetation which are rarely inundated by seawater and usually survive on the seawater seepage using an extensive rhizome system where competition appears to play a little role in shaping these habitats.

Salt tolerance of the species found in the area is highly variable and ranges from 25 $dS.m^{-1}$ to 100 $dS.m^{-1}$. *Halopyrum mucronatum* could tolerate up to 20 $dS.m^{-1}$ NaCl (Khan *et al*., 1999). *Sporobolus ioclados* and *Aeluropus lagopoides,* could survive in up to 50 $dS.m^{-1}$ NaCl (Gulzar & Khan, 2005); *Urochondra setulosa, Arthrocnemum macrostachyum, Suaeda fruticosa, Haloxylon stocksii, Avicennia marina, Ceriops tagal* and *Rhizophora mucronata* could survive at salinities (80-100 $dS.m^{-1}$) higher than seawater (55-60 dS m^{-1}) (Aziz & Khan, 2001; Gulzar *et al.*, 2003; Khan *et al*., 2000abc, 2005).

Halophytes vary in accumulation of different ions (Khan *et al.,* 2005). Chenopds are known as salt accumulators and have high Na^+ and Cl^- contents (Gul *et al.*, 2000; Khan *et al*., 2000c). Na^+ increased significantly at salinities greater than 300 $mol.m^{-3}$ NaCl (Naidoo & Rughunanan, 1990; Naidoo & Kift, 2006) and is accumulated in leaves for osmotic adjustment increases succulence (Flowers & Yeo, 1986). Intra-specific competition can influence survival growth and fecundity of population (Ungar, 1991; Wang *et al*., 2006). Morphologically, the halophytes may be plastic in their response to increased plant density but mortality was not directly related with density dependent factors (Riehl & Ungar, 1982). Survival in population appears to be directly influenced by level of salt stress and is not directly correlated with initial plant densities occurring in populations from salt marsh habitats (Riehl & Ungar, 1982, 1983; Jefferies *et al*., 1983; Wilkon-Michalska, 1985; Ellison, 1989).

Little work has been done on the productivity and growth of local halophytes around Karachi. The objectives of this research were (1) to study the seasonal variation in productivity of *Atriplex stocksii* and (2) to determine the role of various sea salt concentrations, planting densities and their interactions on its growth in green house conditions.

Materials and Methods

Study site: The productivity of *Atriplex stocksii* was studied for two years from May 1997 to April 1999. The study site is located at Gizri Creek, Karachi along the Arabian Sea coast.

Experimental design: Two plots with three quadrats (0.5 m^2) were selected randomly every first week of the month for two years. In plot # 1 plant were clipped close to the soil surface and divided into living and dead parts. Litter remaining on the surface was collected separately in plastic bags. Soil was collected from the root zone in each quadrat (approx. 30 cm). All belowground material (root) was collected by washing the soil with water over a 2 mm sieve. In plot # 2 only dead shoot material was removed and stored, living shoot material was tagged and harvested after one month. The plants were harvested and growth parameters i.e., fresh weight, dry weight, root length and shoot length were recorded. Dead material was separated from the living and was weighed.

Soil samples were collected from 0-15 cm and 15-30 cm depths. Fresh and oven dried (80° C for 24 h) weight of soil samples was measured. Soil extracts (1:10) were made by dissolving 5 g soil in 50 ml distilled water and filtered using Whatman No 1 paper. Electrical conductivity was measured by CDM 83 conductivity meter (Radiometer Copenhagen).

Seeds of *A. stocksii* were collected from a population near coast of Karachi. Seeds of *A. stocksii* were collected in January 2001 and stored at room temperature. Plastic pots of 36 cm diameter were filled with thoroughly washed beach sand. Seeds were sown in June and provided sub-irrigation by placing pots in plastic trays under natural conditions. At the second leaf stage, seedlings were thinned by removing excess plants from the pots to produce three density treatments (2, 5 and 8 plant pot^{-1}) and provided with 20, 40, 60, 80 and 100 dS.m^{-1} seasalt solutions fortified with nutrient solution (Popp & Polania, 1989) to supplement the macro- and micro-nutrients required. Salinity concentrations were gradually increased by 20 dS.m^{-1} sea salt solution at two day intervals to reach the maximum salinity levels of 100 dS.m^{-1} after 10 d. The salinity level of the culture solution was maintained in pots through daily sub-irrigation with tap water and solution was replaced at weekly intervals. Seedlings were grown for 60 days after maximum salinity concentration was obtained. The plants were then harvested and fresh and dry weight, root and shoot length were noted. The dry weight was recorded after oven drying at 80°C for 24 h.

For ion analysis hot water extract was prepared. 0.5 g dried plant material was boiled in 25 ml distilled water for two hr at 100°C in a dry heat bath, cooled and filtered. Cl, NO_3 and SO_4 were measured with a DX-100 ion chromatograph while Na, K, Ca and Mg were analyzed using a Perkin Elmer model 360 atomic absorption spectrophotometer. Data were statistically analyzed using ANOVA and individual treatment means were compared by the post-hoc Bonferroni test (SPSS, 1999).

Results

Productivity of *Atriplex stocksii* was studied for the two growing seasons in the coastal sand dunes near Gizri Creek, Karachi. The precipitation data for the years of 1997, 1998 and 1999 showed a highly variable pattern of rainfall (Fig. 1). There was considerable rainfall during summer 1997, few sporadic showers in 1998 and almost no rains in 1999. The higher net productivity was recorded from November to May during both season, however, during 1998-99 growing season net productivity was much higher in comparison to the year 1997-98 (Fig. 2). The months from June to October had lower productivity. Aboveground biomass for the two seasons showed a varied response (Fig. 3). During the year 1997-1998 aboveground biomass production per unit area was low throughout the seasons and there was little promotion during September. However, during 1998-1999 seasons there was a substantial increase in the aboveground biomass in the month of October and it stayed higher until January 1999 (Fig. 3). Standing crop biomass showed similar pattern in both seasons little increase from June to September and higher increase from October to May (Fig. 4). The aboveground dead biomass remained unchanged during the year 1997-98 but it registered a substantial promotion during the season 1998-99 from December to April (Fig. 5).

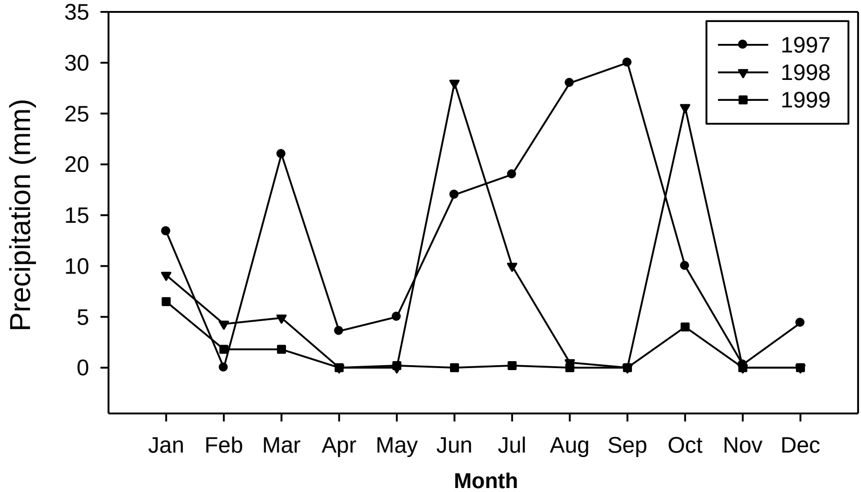

Fig. 1. Seasonal variation in rainfall around coast at Manora station, Karachi.

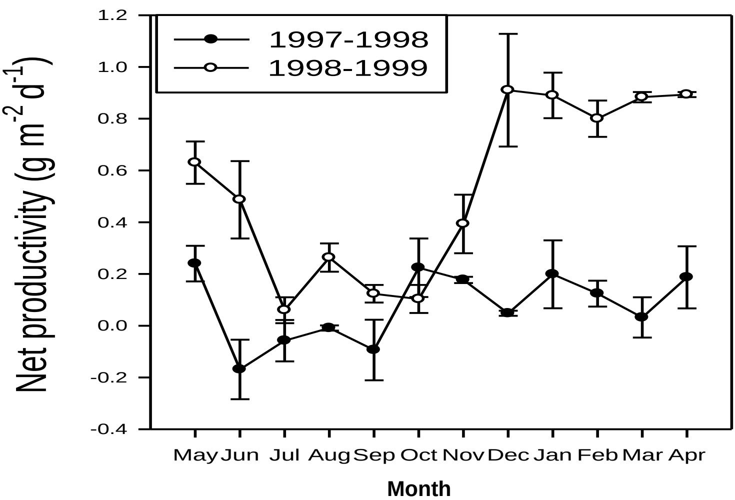

Fig. 2. Seasonal variation in net productivity (g m^{-2} day^{-1}) of *Atriplex stocksii* during the suty.

Soil conductivity showed a progressive decrease from May to September 1997 due to heavy monsoon rains. The soil conductivity progressively increased in May 1998 and remained high for rest of the year (Table 1). Na^+ and Cl^- ion concentrations in shoot remained high during both the seasons (Table 2). The Na^+ and Cl^- in *Atriplex stocksii* roots remained unchanged from May 1997 to January 1998, increased in February 1998 and decreased again during December 1998 (Table 3). The ion concentration root was much higher than roots. K^+ in shoots was substantially higher as compared to the roots. The K^+ in shoots and roots decreased considerably during the months of low salinity (Tables 2 & .3). The concentration of other ions did not change much during both seasons.

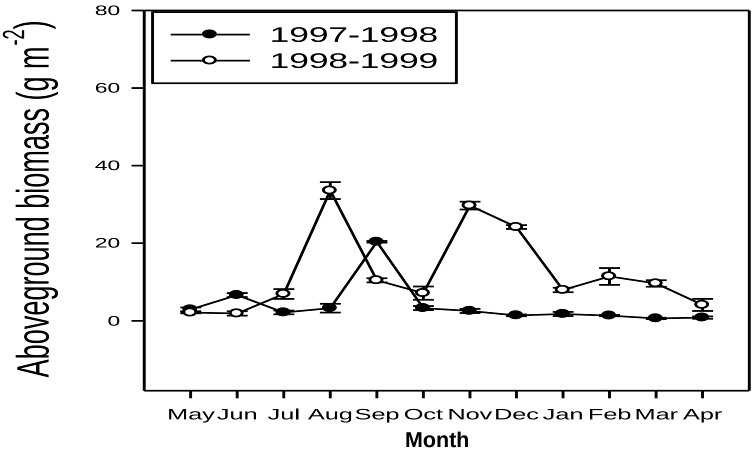

Fig. 3. Seasonal variation in above ground biomass (g m^{-2}) of *Atriplex stocksii* during the stuty.

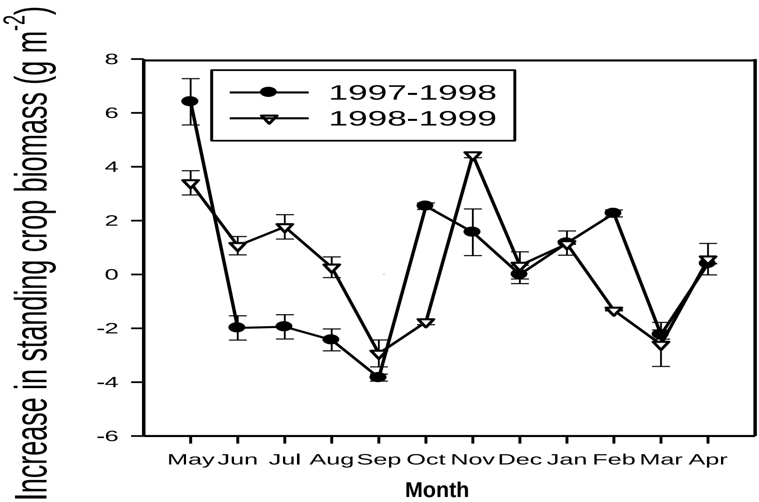

Fig. 4. Seasonal variation in standing crop biomass (g m^{-2}) of *Atriplex stocksii*.

Fresh weight of shoots at low density (2 plants pot^{-1}) was not affected by low salinities (0 and 20 dS.m^{-1}) however; at higher salinity concentrations there was no effect of density (Fig. 6). The dry weight of shoot showed density effects at low salinities (Fig. 6). Root fresh weight was significantly promoted at low salinity and increase in salinity inhibited the root growth (Fig. 7). Both root fresh weight and dry weight had higher weight at low density under low salinity and under high salinity effect of density was absent (Fig. 7). Shoot and root length have shown density effects in non-saline medium and increase salinity has diminished the effects of density (Fig. 8). Increase in salinity decreased the shoot and root length in all treatments (Fig. 8). Root to shoot ratio substantially increased with the density under non-saline conditions (Fig 9) and after the introduction of salinity the effect of density was reduced (Fig. 9).

Table 1. Seasonal variation in soil electrical conductivity (dS m^{-1}) at 15 cm and 30 cm depth in *Atriplex stocksii* community.

Months	1997-1998		1998-1999	
	15 cm	30 cm	15 cm	30 cm
MAY	3.7 ± 0.5	3.4 ± 0.2	10.7 ± 1.2	12.7 ± 0.2
JUN	1.4 ± 0.5	0.6 ± 0.2	4.9 ± 0.7	8.2 ± 1.7
JUL	1.9 ± 0.2	2.5 ± 0.2	5.5 ± 0.3	6.2 ± 0.4
AUG	1.7 ± 0.2	1.7 ± 0.2	5.8 ± 0.7	3.9 ± 0.7
SEP	2.0 ± 0.3	3.1 ± 0.3	3.8 ± 0.6	4.6 ± 0.8
OCT	6.3 ± 0.2	8.7 ± 0.6	3.3 ± 0.3	4.8 ± 0.03
NOV	4.4 ± 0.9	5.0 ± 0.5	2.9 ± 0.6	4.5 ± 0.3
DEC	4.5 ± 1.2	5.0 ± 0.1	4.7 ± 0.3	6.6 ± 0.6
JAN	3.7 ± 1.1	5.3 ± 0.8	5.5 ± 0.9	5.0 ± 0.6
FEB	8.1 ± 0.5	8.6 ± 0.1	3.0 ± 0.3	2.4 ± 0.03
MAR	3.8 ± 1.2	7.0 ± 0.7	2.3 ± 0.3	3.5 ± 0.1
APR	6.2 ± 1.0	5.1 ± 1.5	2.4 ± 0.5	2.3 ± 0.2

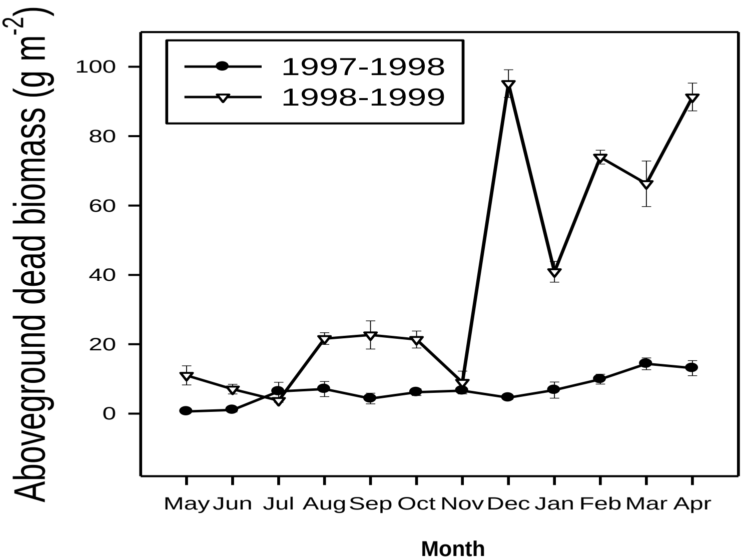

Fig. 5. Seasonal variation in above ground dead biomass (g m^{-2}) of *Atriplex stocksii*.

Shoot tissue water showed little effect in up to 60 dS m^{-1} seasalt but the succulence decreased with a further increase in salinity (Fig. 10). At high densities succulence was higher. However, amount of water per plant decreased substantially at high salinities and the effect of density was highly significant in decreasing succulence in both saline and non-saline treatments (Fig. 10). Root succulence showed a similar response (Fig. 11). Shoots of *A. stocksii* accumulated a high concentration of Na^+ and Cl^- that did not change much with the increase in salinity (Table 4) whereas other ions were found in comparatively low amount. Na^+ in root was higher but much lower in comparison to shoot and Cl^- were present in the similar amount as that of shoot (Table 4).

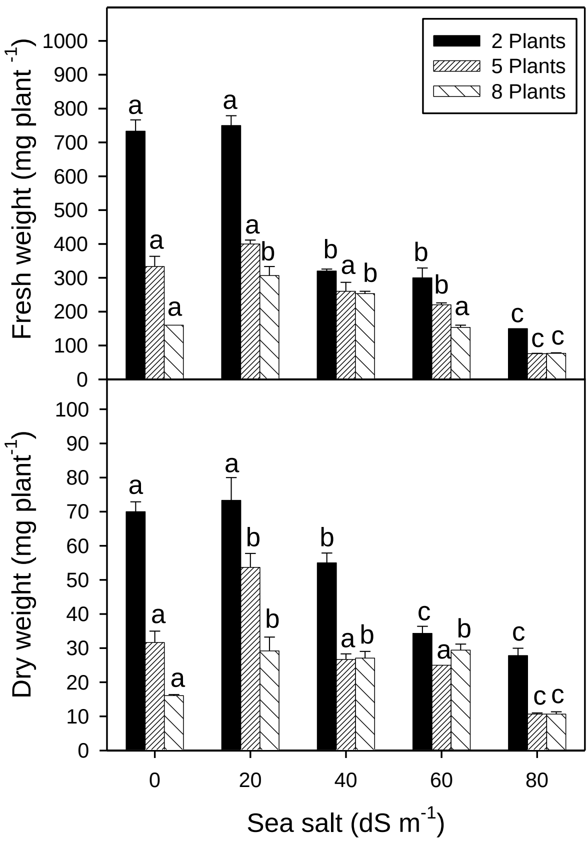

Fig. 6. Fresh and dry weight (mg plant^{-1}) of *Atriplex stocksii* shoot raised at various sea salt concentrations and plant densities (2, 5 and 8 plants per pot). Bar represents means with standard error. Different letters above bar represents a significant difference ($p>0.05$) between salinity treatments within each density.

Discussion

The productivity of *Atriplex* sp. is highly variable, depending on the ecological conditions of the soil and climate (Osmond *et al*., 1980). Over a broad range of vegetation types, aboveground net primary productivity (ANPP) is strongly related with precipitation, temperature (Lieth, 1972; Bates *et al.,* 2006) and evapo-traspiration (Rosenzweig, 1968). The net productivity of *A. stocksii* reported in this study showed strong seasonal pattern. Monsoon rains, associated with reduced ambient temperature and soil conductivity, primarily determines the productivity of *A. stocksii* dominated communities along the Arabian Sea coast. The maximum aboveground biomass fluctuation was observed in 1998-1999 with peaks from November to May while substantially decreasing from June to October. Low plant biomass is commonly related to low rainfall in summer during 1996-1997 while the greater (4-8 g.m^{-2}) net productivity, aboveground biomass and standing crop biomass in 1998-1999 is indicative of favorable moisture conditions due to the 26 mm rainfall in October, 1998. Soil salinities and temperature were higher before the rainfall and may have substantially reduced in aboveground biomass.

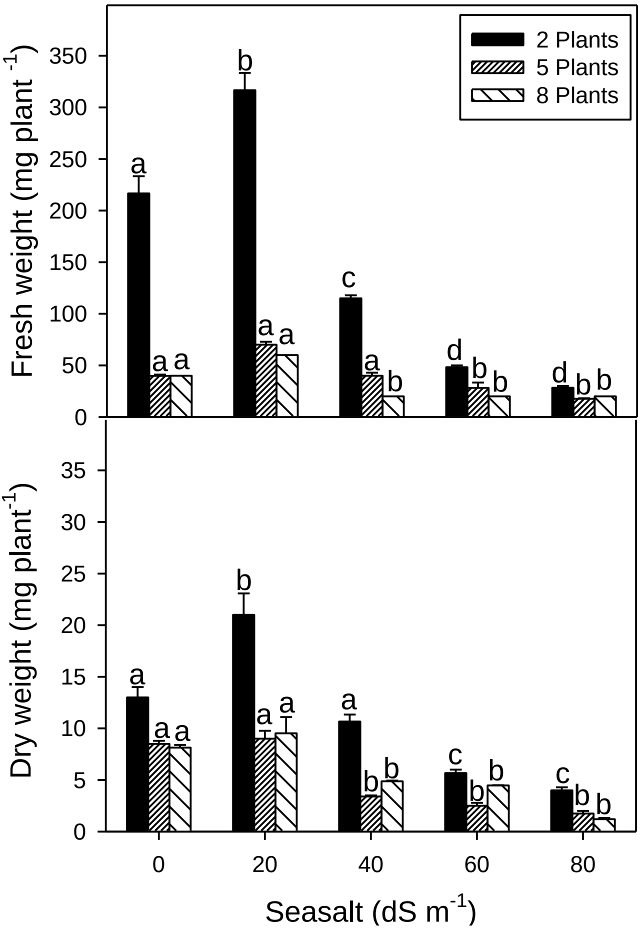

Fig. 7. Fresh and dry weight (mg plant^{-1}) of *Atriplex stocksii* roots raised at various sea salt concentrations and plant densities (2, 5 and 8 plants per pot). Bar represents means with standard error. Different letters above bar represents a significant difference ($p>0.05$) between salinity treatments within each density.

The aboveground dead biomass did not show any significant difference during 1997-1998 probably because of low rainfall and high temperature, while it varied during 1998-1999 summer after the rainfall and remained unchanged for rest of the season. This is in agreement with the reports of *Arthrocnemum macrostachyum* and *Spartina alterniflora* in which dead biomass was higher during the entire summer (Gul & Khan, 1995). The rate of plant decomposition was affected by moisture, temperature, acidity and the nutrients status of ecosystem, primarily nitrogen and phosphorus-related water chemistry variables (Szumigalski & Bayley, 1996; Thormann & Bayley, 1997; Regan *et al*., 2007). The belowground biomass of *Atriplex stocksii* showed a similar pattern in both seasons. The occurrence of seasonal flushes in belowground biomass appears to vary with species. Peak belowground biomass of *Distichlis spicata* was observed in August (Gallagher & Plumley, 1979) and in April and September were found for *Sporobolus virginicus*.

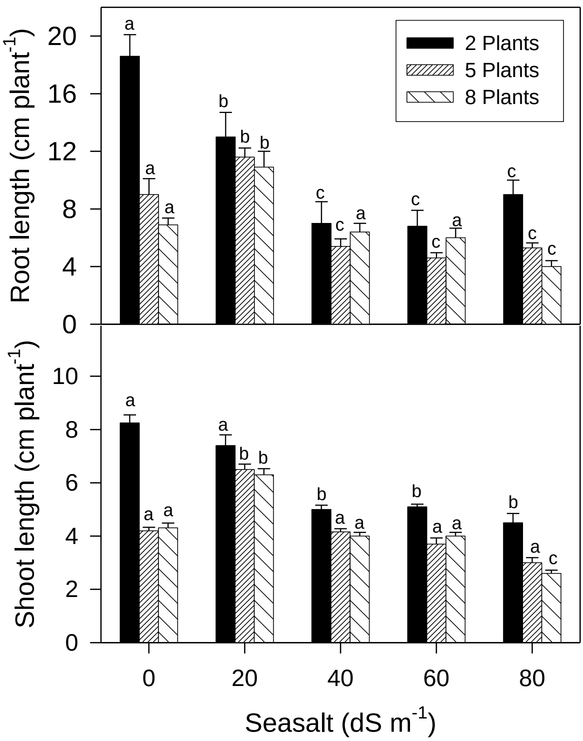

Fig. 8. Root and shoot length (cm plant^{-1}) of *Atriplex stocksii* seedlings raised at various sea salt concentrations and plant densities (2, 5 and 8 plants per pot). Bar represents means with standard error. Different letters above bar represents a significant difference (p>0.05) between salinity treatments within each density.

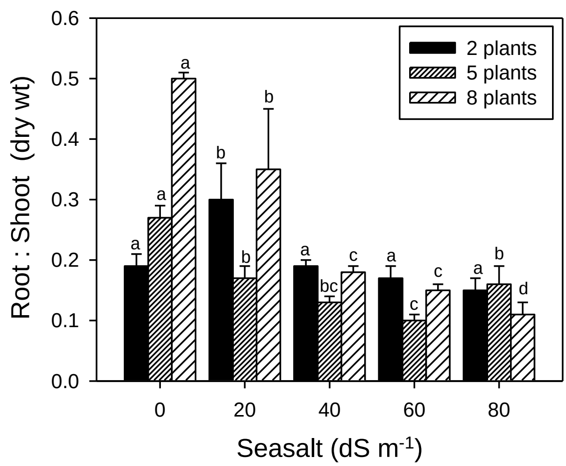

Fig. 9. Root and shoot dry weight ratio of *Atriplex stocksii* seedlings raised at various sea salt concentrations and plant densities (2, 5 and 8 plants per pot). Bar represents means with standard error. Different letters above bar represents a significant difference (p>0.05) between salinity treatments within each density.

Table 4. Element concentrations in shoot and root of *Atriplex stocksii* under various seasalt treatments. Values for electrical conductivity (EC) are in dS m^{-1} and of ions in µmol g^{-1} dry wt.

EC	Na^+		K^+		Ca^{2+}		Mg^{2+}		Cl^-	
	Shoot	Root	Shoot	Root	Shoot	Root	Shoot	Root	Shoot	Root
0	1270 ±60.67	253 ±6.67	27 ±6.67	153 ±6.67	220 ±0	170 ±0	37 ±3.33	60 ±0	1100 ±0	800 ±0
20	2470 ±24.04	560 ±0	20 ±0	19 ±1.33	303 ±3.33	120 ±0	30 ±0	23 ±8.82	2000 ±0	1400 ±0
40	1080 ±40	733 ±35.28	16 ±0	15 ±1.33	200 ±0	127 ±6.67	33 ±3.33	33 ±3.33	2600 ±0	1467 ±33.33
60	907 ±58.12	933 ±66.67	13 ±1.33	16 ±0	130 ±0	83 ±3.33	20 ±0	27 ±3.33	2800 ±0	1600 ±0
80	1267 ±66.67	1107 ±58.12	13 ±1.33	9 ±1.33	140 ±0	100 ±0	13 ±3.33	17 ±3.33	2000 ±0	1700 ±0

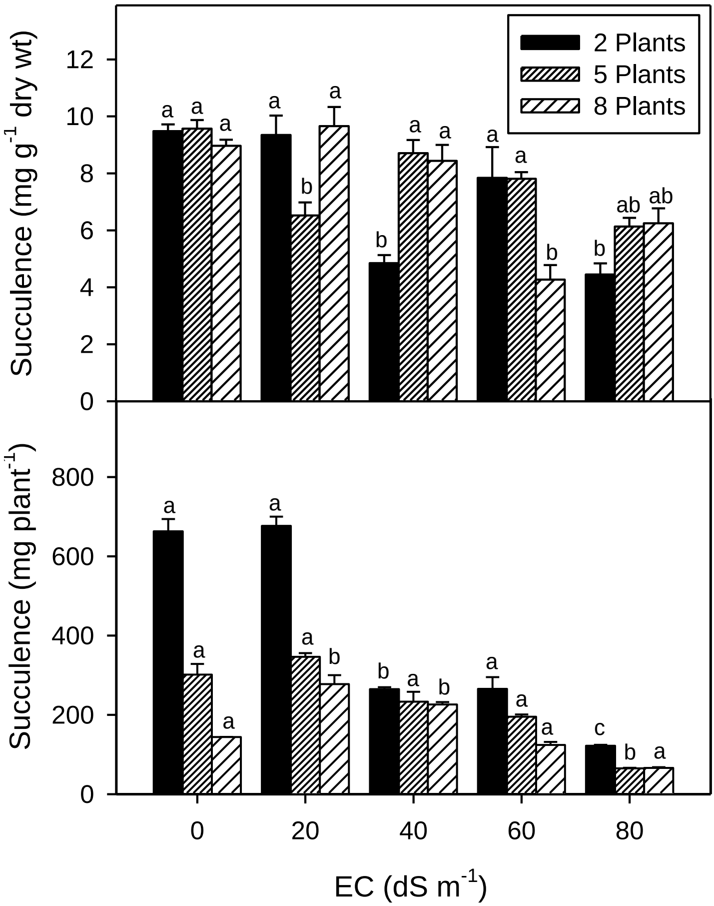

Fig. 10. Succulence of above ground parts of *Atriplex stocksii* seedlings raised at various sea salt concentrations and plant densities (2, 5 and 8 plants per pot). Bar represents means with standard error. Different letters above bar represents a significant difference ($p>0.05$) between salinity treatments within each density.

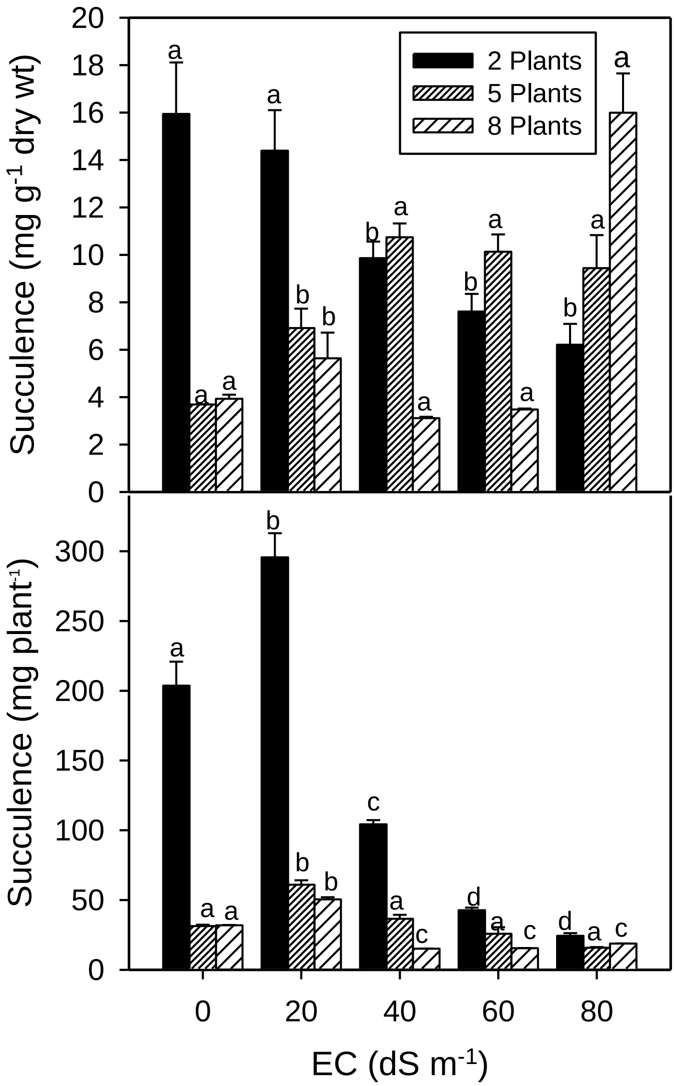

Fig. 11. Succulence of below ground parts of *Atriplex stocksii* seedlings raised at various sea salt concentrations and plant densities (2, 5 and 8 plants per pot). Bar represents means with standard error. Different letters above bar represents a significant difference (p>0.05) between salinity treatments within each density.

Atriplex stocksii, is a salt tolerant halophyte which has ash content of about 40% of dry weight (Khan *et al*., 2000b). Na^+ and Cl^- are the main components of saline soils (Riehl & Ungar, 1983). Growth of *Atriplex stocksii* was substantially promoted at low salinity (20-40 $dS.m^{-1}$), but decreased with a further increase in salinity (Khan *et al*., 2000b). Most halophytes show optimal growth in the presence of salt (Naidoo & Rughunanan, 1990; Rozema, 1991; Ayala & O'Leary, 1995) however, growth of *Atriplex* spp. was inhibited by high salt concentration (Ungar, 1991).

In the absence of salinity, density significantly affected the growth parameters, however, introduction of salinity reduced the density effect and at higher concentrations, the effect of density was completely diminished (Keiffer & Ungar, 1997; Wang *et al*., 2005) however, the role of competition in a perennial population appears to be limited (Gul & Khan, 1998). Gul *et al*., (2000) showed that increased competition caused a progressive reduction in growth of *A. occidentalis*. High planting density decreased growth even at low salinities. Intra-specific competition may affect the biomass production, reproduction, survival, and growth of halophytes in saline habitats (Badger & Ungar, 1990; Ungar, 1991; Foderaro & Ungar, 1997; Keiffer & Ungar, 1997; Wang *et al*., 2005).

Root and shoot tissue water showed little effect up to 60 $dS.m^{-1}$ sea salt but succulence decreased with a further increase in salinity. However, amount of water per plant decreased substantially at higher salinities. Succulence is one of the mechanisms that halophytes utilize to deal with the high internal ion concentrations (Ahmed *et al*., 2004). Succulence plays a key role in the survival and maintenance of halophytes under saline conditions by maintaining positive turgor (Khan *et al*., 1999). Perennial grasses from Karachi also maintained a high water and osmotic potential with progressively lower stomatal conductance with the increase in salinity (Gulzar & Khan, 2005). At high salinity, water content of plants decreased and plant lost turgor causing growth inhibition and increase in mortality.

Deleterious effects of salinity are thought to result from low water potentials, ion toxicities, nutrient deficiencies or a combination of these factors. Nutrient deficiencies can occur in plants when high concentrations of Na^+ in the soil reduce the amounts of available K^+, Mg^{2+} and Ca^{2+} (Epstein, 1972) or when Na^+ displaces membrane bound Ca^{2+} (Cramer *et al*., 1985). Our results indicated that Na^+ and Cl^- in shoots and roots increased with salinity. Ca^{2+} and Mg^{2+} contents were reduced in shoots of *A. stocksii* plants grown at high salinity similar to the results found for other halophytes (Flowers, 1972; Naidoo & Rughunanan, 1990; Ayala & O'Leary, 1995). Ash content in leaves of *A. stocksii* was highest (39% of dry weight) at 360 mM NaCl. These data indicate that *A. stocksii*, an ion accumulator should be considered for use in phyto-remediation of degraded saline lands. This species could also be raised as a supplementary fodder for livestock using saline water irrigation.

Atriplex stocksii is one of the common halophytes distributed in both coastal and inland saline flats and dunes around Karachi. This species is moderately salt tolerant and could have higher productivity if irrigated with brackish water. Productivity in highly competitive conditions makes it a better candidate for rehabilitation of saline lands and the use of biomass as fodder.

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