

1-1-2010

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ÇAKIR, YASEMİN; ÖZBUCAK, TUĞBA; KUTBAY, HAMDİ GÜRAY; KILIÇ, DUDU DUYGU; BİLGİN, ALİ; and HUSEYİNOVA, RENA (2010) "Nitrogen and phosphorus resorption in a salt marsh in northern Turkey," *Turkish Journal of Botany*. Vol. 34: No. 4, Article 6. <https://doi.org/10.3906/bot-0906-64>  
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## Nitrogen and phosphorus resorption in a salt marsh in northern Turkey

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Received: 30.06.2009

Accepted: 18.04.2010

**Abstract:** This study was conducted to investigate foliar nitrogen and phosphorus dynamics, nitrogen and phosphorus resorption, and some leaf traits (i.e. SLA=specific leaf area) in some coastal salt marsh plants located in northern Turkey. The study area is located on the east bank of the Kızılırmak River in the central Black Sea Region. There were statistically significant differences among months (from June to October) in terms of SLA in all species except for *Artemisia santonicum*. However, no significant differences were found with respect to P in all species. The highest N and P resorption efficiencies were found in *Salicornia prostrata*, whereas the lowest resorption efficiencies were found in *Euphorbia paralias*. P resorption proficiency is biochemically complete in all species. N resorption proficiency is biochemically complete except for *E. paralias*. Additionally, Grime's CSR (C: competitive; S: stress-tolerant; R: ruderal) strategies were also investigated and it was found that all of the species exhibit competitive ruderal strategy.

**Key words:** Coastal salt marshes, Grime's strategies, resorption efficiency and proficiency

### Kuzey Türkiye'deki bir tuzlu bataklıkta azot ve fosfor geri taşınımı

**Özet:** Bu çalışma Türkiye'nin Orta Karadeniz Bölgesinde bulunan Kızılıрмаğın doğu kısmında bulunan bazı kıyı tuzlu bataklık bitkilerinde yaprak azot ve fosfor dinamikleri, azot, fosfor ile yaprak özelliklerini (spesifik yaprak alanı SLA gibi) incelemek için gerçekleştirilmiştir. İstatistiksel olarak, *Artemisia santonicum* hariç bütün türlerde SLA yönünden aylar (Haziran-Ekim) arasında önemli farklılıklar bulunmuştur. Bununla beraber, bütün türlerde P içeriği yönünden önemli farklılıklar bulunmamıştır. En düşük N ve P geri emilim yeterliliği *E. paralias*'de bulunurken, en yüksek N ve P geri emilim etkinliği *Salicornia prostrata*'da bulunmuştur. P yeterliliği bütün türlerde biyokimyasal olarak yeterlidir. N yeterliliği ise *Euphorbia paralias* hariç bütün türlerde biyokimyasal olarak yeterlidir. Ayrıca, Grime'in CSR stratejileri (C: rekabetçi; S: strese-dirençli; R: ruderal) de incelenmiş ve bütün türlerin Grime'in stratejilerinden rekabetçi ruderal stratejisi gösterdiği saptanmıştır.

**Anahtar sözcükler:** Kıyı bataklıklar, Grime'in stratejileri, geri taşınım etkinliği ve yeterliliği

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## Introduction

Salt-affected soils are commonly found in arid landscapes where evapotranspiration exceeds precipitation throughout most of the year and may occur naturally or due to human activities (Aschenbach, 2006). Coastal salt marshes comprise areas of land bordering the sea and lakes that are largely covered with vegetation and subject to periodic tidal inundation. These areas have certain qualities, related to the proximity to the sea or lake, that distinguish them from inland salt marshes (Asri & Ghorbanli 1997; Onaindia & Amezaga, 1999). Such ecosystems are generally dominated by halophytic species that have developed mechanisms to avoid and resist salt stress, such as salt glands, osmotic adjustment, increased growth, and selective ion uptake by roots (Kruger & Peinemann 1996; Allahverdiev et al. 1998; Kutbay & Demir, 2001).

Grime et al. (1997) suggested that mineral nutrients, especially nitrogen and phosphorus, should be considered as the major regulating factors of vegetation processes at scales ranging from individuals to ecosystems. Foliar resorption is an important mechanism of nutrient conservation, recycling 50% of maximum foliar N and P content in a wide range of perennial life-forms (Aerts, 1996; Kobe et al., 2005). The rate of nutrient resorption from senescing leaves may also vary with the availability of nutrients in a certain habitat. This implies that, in addition to leaf fall patterns, leaf chemistry can further amend the time-dependent controls on nutrient losses (Niinemets & Tamm, 2005).

Nitrogen and phosphorus are largely withdrawn from senescing leaves before abscission, and they are used for new growth or stored in vegetative tissue until the next growing season. Nutrient resorption efficiency (NRE) is defined as the proportion of a nutrient withdrawn from leaves before leaf abscission (van Heerwaarden et al., 2003; Sans-Pérez et al. 2009).

A new measure of resorption was introduced by Killingbeck (1996) as resorption proficiency. Killingbeck (1996) emphasized resorption proficiency (the content of a nutrient in senesced leaves) over resorption efficiency as proficiency is not subject to temporal variation in nutrient content in green leaves

and timing of sampling (Lajtha 1987; Zotz 2004; Kobe et al., 2005; Yasumuro et al. 2005; Yuan et al., 2005). Proficiency is simply the amount of a nutrient that remains in fully senesced leaves. From a biological perspective, an important advantage of measuring resorption as proficiency rather than efficiency is that proficiency is a more unequivocal measure of the degree to which selection has acted to minimize nutrient loss in ephemeral leaves (Killingbeck, 2004).

Nitrogen and salinity are 2 key factors that have been shown to be correlated with vegetation pattern and zonation in coastal salt marshes. Nitrogen is frequently the major nutrient limiting growth in salt marshes. Halophytes have been demonstrated to accumulate soluble nitrogenous compounds when subjected to stress, such as salinity (Skeffington & Jeffrey, 1988). Although nitrogen and phosphorus resorption have a great importance in salt marshes, the number of studies on nitrogen and phosphorus resorption in salt marshes are very scarce (Shaver & Melillo, 1984; Cartaxana & Catarino, 2002).

The present study addresses 3 main objectives: (a) to show foliar nitrogen and phosphorus dynamics in some coastal salt marsh plants, (b) to determine nitrogen and phosphorus resorption efficiency and proficiency in some coastal salt marsh plants, and (c) to classify salt marsh plants according to Grime's CSR strategies.

## Materials and methods

### The study area

This study is conducted on the east bank of the Kızılırmak River. It is located in the northern and north-eastern parts of Bafra District (41°42'17" and 41°31'46"N, and 36°05'40" and 36°03'01"E) in the central Black Sea Region (northern Turkey).

The mean annual temperature and mean rainfall from June 2005 to October 2005 were 13.7 °C and 806.4 mm, respectively. The maximum temperature for the warmest month (July) was 33.8 °C and the minimum temperature for the coldest month (February) was -2.6 °C during the study period. The pluviometric quotient (Q) is 76.7, and the mean annual relative humidity is 79.81%. On the basis of these data and the classification scheme of Daget

(1977), the area has a semi-humid Mediterranean climate, whereas the precipitation regime is central Mediterranean (Winter, Autumn, Spring, and Summer) (Turkish Ministry of Agriculture, 2002). Taxonomic nomenclature in the present study follows that of Brummitt and Powell (2001).

The mean annual rainfall in the study area is more than is expected for an arid environment. However, it is substantially decreased during summer, and average monthly rainfall values are 39, 36, and 29.5 mm in June, July, and August, respectively. The mean temperatures in June, July, and August are 20, 23, and 23.3 °C, respectively. As a result of this excess evaporation that occurs during summer, the potential evapotranspiration rate is 19 mm during winter, whereas the potential evapotranspiration rate is 58 mm during summer. Additionally, the highest potential evapotranspiration rate is found in June (102 mm) and exceeds rainfall (Köksal, 1972; Engin et al., 1988). These high evaporation rates reduce the natural accumulation of surface water (Wadie, 2002). The Mediterranean climate is characterized by irregular and intense rainfall events and a harsh, dry summer period (Álvarez et al., 2000). Inundation also takes place in the study area and dissolved salts have been raised to the surface. As a result of this, saline soils are dominant in the study area (Avcı et al., 2001).

Two different plant groups occur in the study area. One of them is halophytic species around salt pans. This group is represented by *Salicornia prostrata* Pall. (Chenopodiaceae) and *Spergularia marina* (L.) Gris. (Chenopodiaceae). The other group is salt pan-dune transitional species and this group is represented by *Artemisia santonicum* L. (Asteraceae), *Otanthus maritimus* (L.) Hoffmans. & Link (Asteraceae), and *Euphorbia paralias* L. (Euphorbiaceae).

#### Sampling and chemical analysis

This study was carried out during the growth period from June 2005 to October 2005 (June, July, August, September, and October) including 1 sampling date. On each sampling date 4 quadrats (0.25 m × 0.25 m) were randomly selected and 7 leaf samples from each species were taken. Leaf area was calculated by a Placom digital planimeter (Cornelissen et al., 1997; Kutbay, 2001). For *S. prostrata*, due to cylindrical shape of leaves, surface

area was calculated as  $\pi \times$  measured leaf area values (Cartaxana & Catarino, 2002). Leaf samples were dried at 70 °C until constant weight, and then ground and sieved. Samples were digested in a mixture of nitric and perchloric acids prior to phosphorus (P) analysis. Nitrogen (N) was determined by the micro Kjeldahl method with a Kjeltac Auto 1030 Analyser (Tecator, Sweden) after digesting the samples in concentrated H<sub>2</sub>SO<sub>4</sub> with a selenium catalyst. P was determined with stannous chloride method using a Jenway spectrophotometer.

N and P resorption efficiency was calculated as  $[(NG - NS) / NG] \times 100$ , where NG and NS are either N or P contents in mature green-leaf (G) and senescent leaf (S), respectively. Resorption proficiency was the concentration of a nutrient in senesced leaves (Killingbeck, 1996).

Grime's CSR (C: competitive; S: stress-tolerant; R: ruderal) strategies were used to compare both sympatric species in terms of N and P usage strategies using a program developed in Microsoft Excel. Canopy height, dry matter content, flowering period, the onset of flowering, lateral spreading, dry leaf weight, and specific leaf area were used to find Grime's strategies for the studied species (Hodgson et al., 1999).

#### Statistical analysis

In order to determine if monthly changes in N (%), P (%), and SLA are statistically significant, we performed ANOVA tests on each species. The differences among the sampling periods regarding to the contents of N and P and the changes of SLA were tested by analysis of variance. Significant differences between stages and variables were determined by the Tukey's honest significant difference (HSD) test. All of the tests were performed at the significant level of  $\alpha$  0.001 with the SPSS Version 10.0.

#### Results and discussion

All of the species were characterized as CR (competitive ruderal strategy) strategy using the criteria presented in Table 1.

The studies on resorption efficiency of salt marsh species are rare and P resorption efficiency values have not been reported. N resorption efficiency values

Table 1. Allocation procedure for competitive, stress-tolerant, and ruderal (C-S-R) plants (based on Hodgson et al. 1999).

Variable	Definition		
Canopy Height	Six-point classification	1	1-49 mm
		2	50-99 mm
		3	100-299 mm
		4	300-599 mm
		5	600-999 mm
		6	>999 mm
Dry Matter Content	Mean of percent dry matter content in the largest, fully hydrated, full expanded leaves (%)		
Flowering Period	Normal duration of flowering period (months)		
Flowering Start	Six-point classification	1	First flowering in March or earlier
		2	in April
		3	in May
		4	in June
		5	in July
		6	in August or later, or before leaves in spring
Lateral Spread	Six-point classification	1	Plant short-lived
		2	Loosely tufted ramets radiating about a single axis, no thickened root-stock (in graminoids)
		2	Compactly tufted about a single axis, no thickened rootstock (in non-graminoids)
		3	Compactly tufted ramets appressed to each other at base (in graminoids)
		3	Compactly tufted about a single axis, thickened rootstock present (in non-graminoids)
		4	Shortly creeping, < 40 mm between ramets
		5	Creeping, 40-79 mm between ramets
		6	Widely creeping, > 79 mm between ramets
Leaf Dry Weight	Natural logarithm of mean dry weight in the largest, fully hydrated, fully expanded leaves (mg) plus 3		
Specific Leaf Area	Mean of area/dry weight quotient in the largest, fully hydrated, fully expanded leaves (mm <sup>2</sup> /mg)		

were similar to other salt marsh species. However, P resorption efficiency values were rather low as compared to non-halophytes (Aerts 1996; Cartaxana & Catarino, 2002). The highest N and P resorption efficiencies were found in *S. prostrata*, whereas the lowest resorption efficiencies were found in *E. paralias*. N and P resorption efficiencies were higher in species found in salt pans compared to species found in the salt pan-dune transitional zone (Table 2).

Table 2. N and P resorption efficiency (%) in studied species.

Species	N resorption efficiency (%)	P resorption efficiency (%)
<i>Salicornia prostrata</i>	66.66	50.80
<i>Spergularia marina</i>	64.86	35.89
<i>Artemisia santonicum</i>	37.50	26.18
<i>Otanthus maritimus</i>	44.82	33.82
<i>Euphorbia paralias</i>	31.08	34.21

The highest N content was found in October in *S. prostrata*. N content was decreased from August to September in *S. marina*, whilst it was increased from August to October in *A. santonicum*. Monthly changes of N content in *O. maritimus* were somewhat similar to *A. santonicum*. N content was considerably higher in *E. paralias* as compared to the other species studied. Overall, the lowest N was found in June in all species except for *S. marina* in which the lowest N contents were found in October (Figure 1).

The highest P content was found in June in *S. prostrata*. P content of *S. marina* was remarkably decreased in October. The changes in terms of N and P contents from June to August were similar in *A. santonicum*. However, P content was slightly increased in October in *A. santonicum*. P content of *E. paralias* was decreased from June to August and then increased from August to October. The lowest P contents were found in October in *S. marina* and *O. maritimus*, while the lowest P contents were found in July in *S. prostrata*, in June in *A. santonicum*, and in August in *E. paralias*. P content of *O. maritimus* was constant from June to July, whilst increased in August and after August it had a decreasing tendency (Figure 2).

SLA was decreased from June to October in *S. prostrata*. The highest SLA was found in July in *S. marina*. SLA was decreased in September and increased in October in *A. santonicum*. The changes of SLA in *O. maritimus* were similar to *A. santonicum* like N content. SLA in *E. paralias* was increased from June to October. Except for *E. paralias*, SLA was decreased during September in all species (Figure 3). For example SLA was also decreased over the growth period in *S. prostrata*. SLA may be decreased due to the contraction of cell for loss of water (Wang & Lin, 1999).

The content of elements in the leaves of halophytes under saline conditions changes during leaf development and senescence (Wang & Lin, 1999). N contents (%) were increased during autumn in all species except for *S. marina*. In other words, “accretion” was observed during autumn (September and October) because vegetative and generative plant parts have been competed with each other during autumn (Duchesne et al., 2001). Accretion was only found in *E. paralias* with respect to P (%) contents.

N dynamics and N resorption efficiency values was similar to those of the other salt marsh species. Cartaxana and Catarino (2002) reported 31%–76% resorption efficiency for salt marsh species in Portugal. In the present study, resorption efficiency for all species varied between 31%–67%. No data were available on P resorption efficiency. However, P resorption efficiency of the species studied was similar to those of evergreen species (Mayor & Rodá, 1992).

N and P contents in the present study were rather low. In most salt marshes, nitrogen is very limited. This is in accordance with competition among saline ions ( $\text{Ca}^{+2}$ ,  $\text{Mg}^{+2}$ ,  $\text{K}^+$ ,  $\text{Na}^+$ ,  $\text{Cl}^-$ ,  $\text{SO}_4^{2-}$ ,  $\text{HCO}_3^-$ ) and N and P (Donovan et al., 1997; Kutbay & Demir, 2001). Increase in salinity may decrease a plant’s ability to absorb essential nutrients (Yeo, 1983; Marschner, 1995; Aschenbach, 2006).

Killingbeck (1996) stated that resorption is highly proficient in plants that reduce nitrogen and phosphorus concentrations below 0.7% and 0.05%, respectively, during their senescent stages. According to this threshold values, P resorption proficiency is highly proficient in all species. N resorption proficiency is also highly proficient except for *E.*



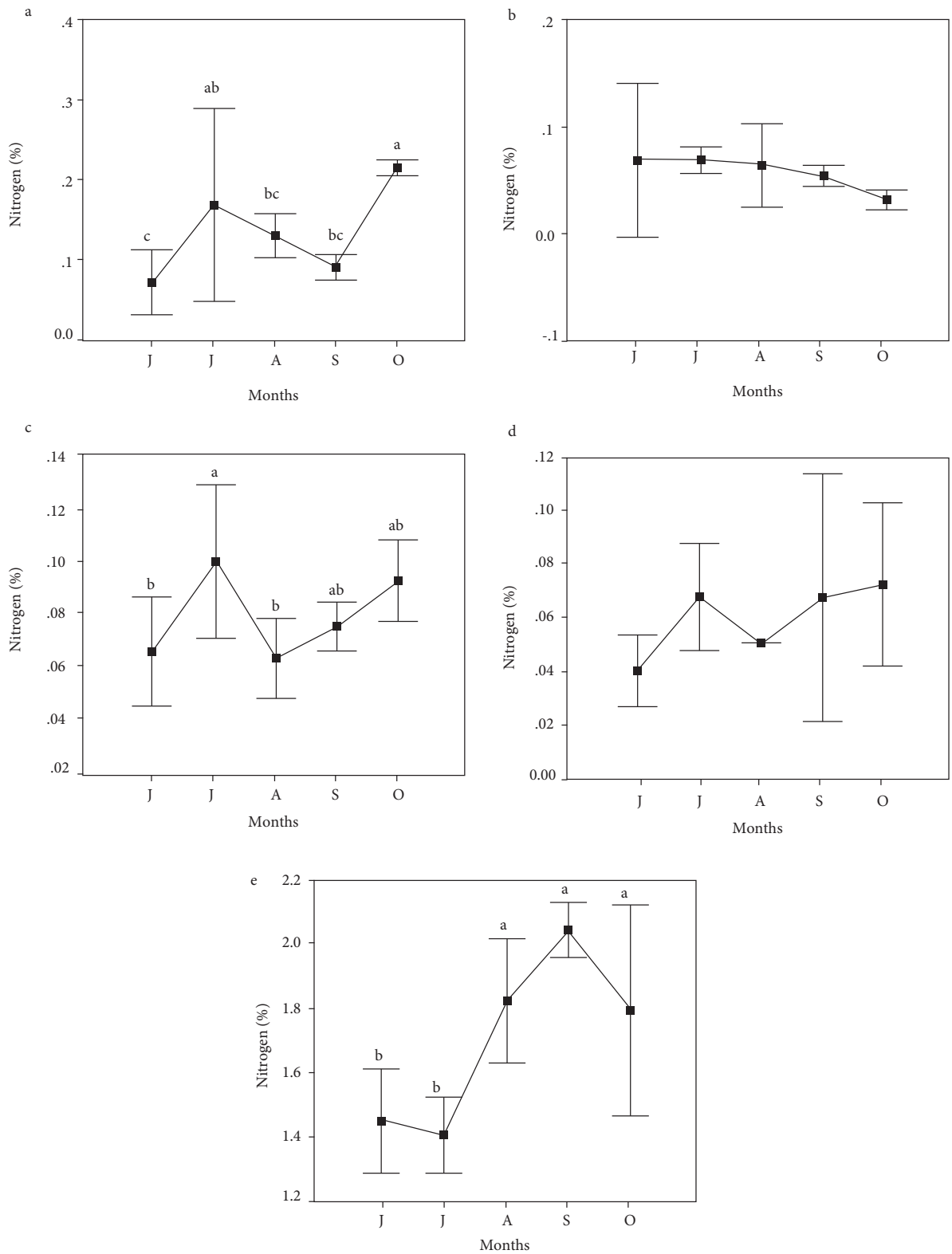


Figure 1. Seasonal changes in N (%) contents of the leaves of (a) *S. prostrata*, (b) *S. marina*, (c) *A. santonicum*, (d) *O. maritimus*, and (e) *E. paralias* (Different letters indicate significant differences between the groups according to Tukey's HSD test) (rejection level 0.05). Error bars depict standart errors of means (n = 7).



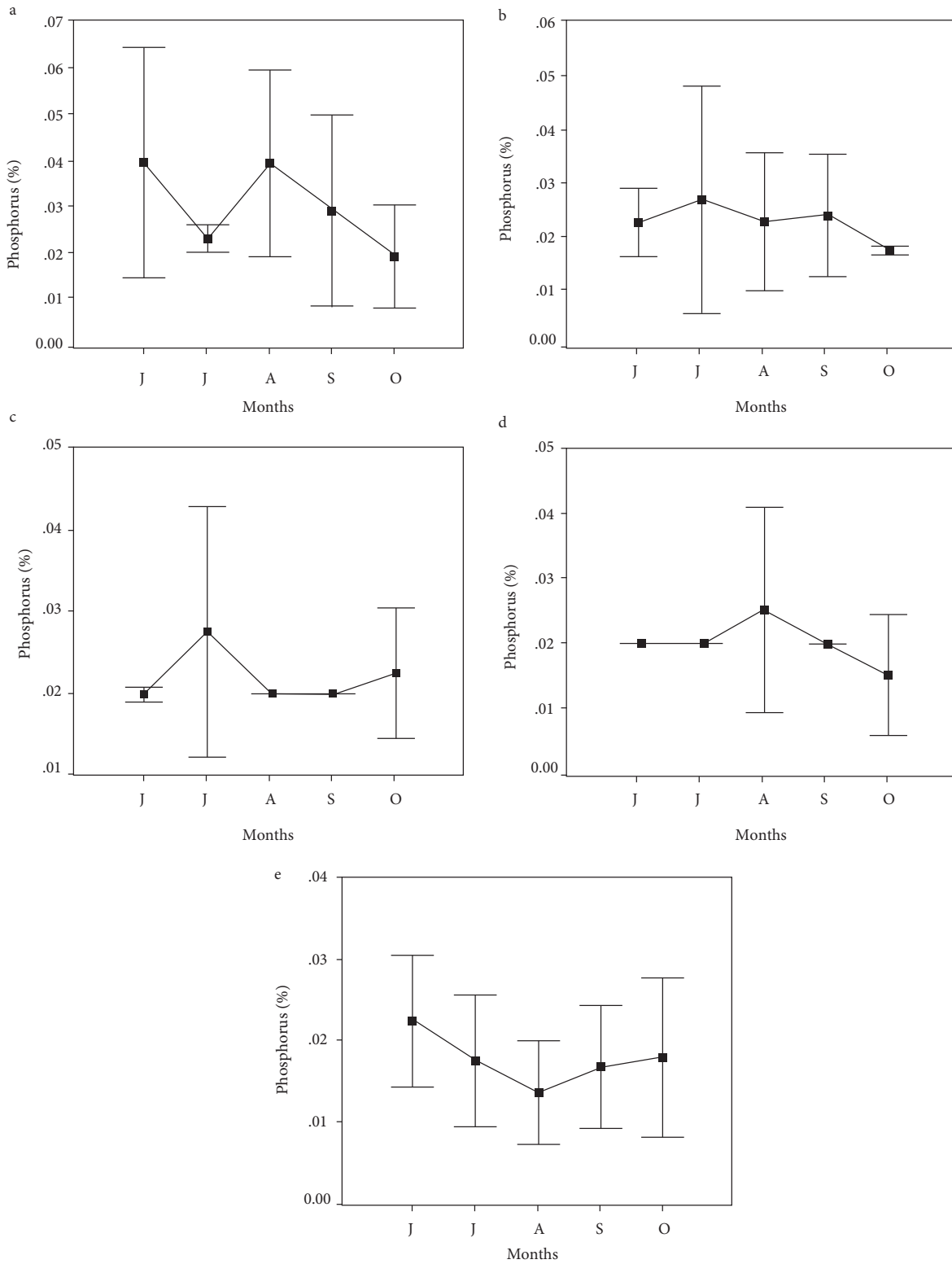


Figure 2. Seasonal changes in P (%) contents of the leaves of (a) *S. prostrata*, (b) *S. marina*, (c) *A. santonicum*, (d) *O. maritimus*, and (e) *E. paralias* (Different letters indicate significant differences between the groups according to Tukey's HSD test) (rejection level 0.05). Error bars depict standart errors of means (n = 7).

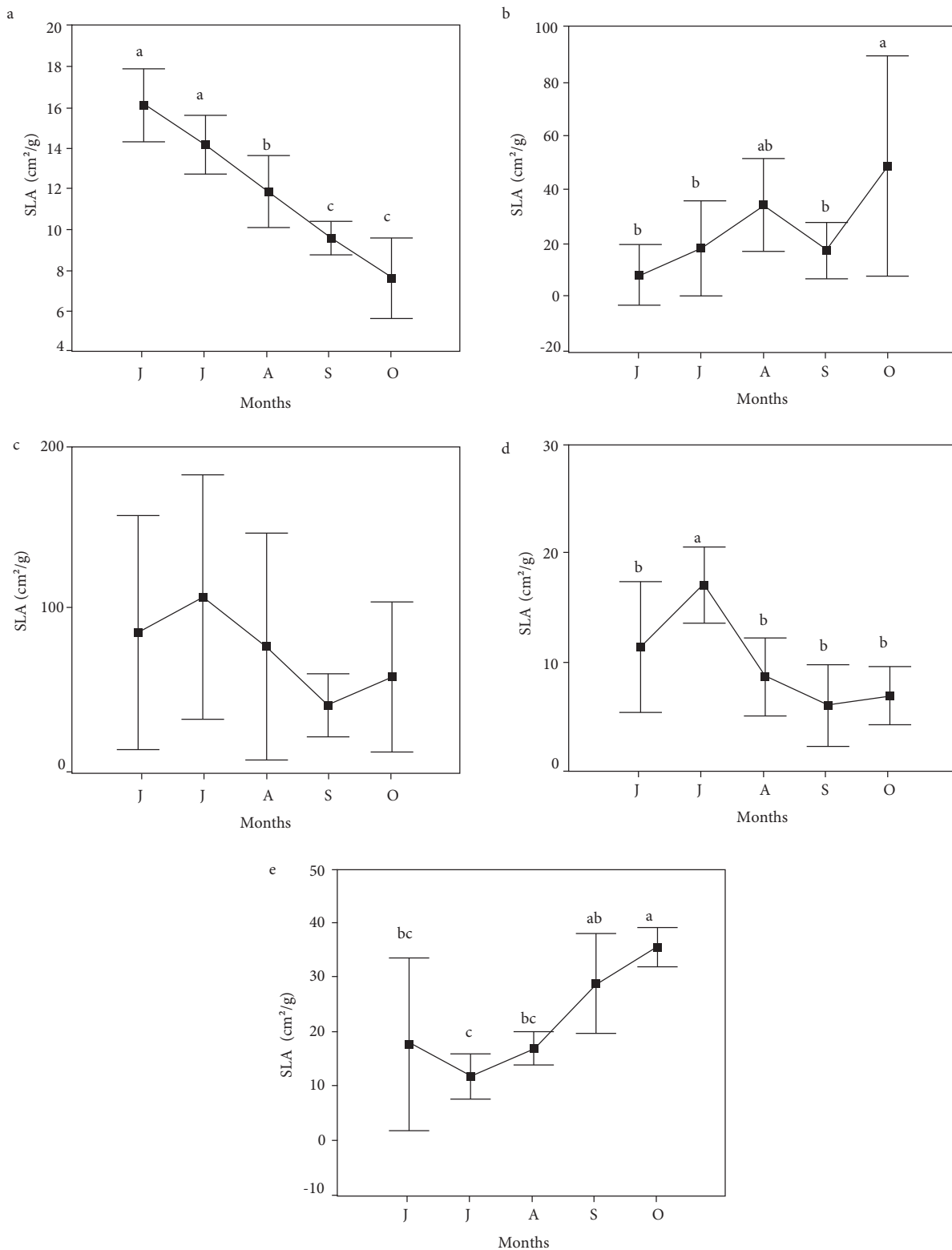


Figure 3. Seasonal variations in SLA of the leaves harvested from (a) *S. prostrata*, (b) *S. marina*, (c) *A. santonicum*, (d) *O. maritimus*, and (e) *E. paralias* (Different letters indicate significant differences between the groups according to Tukey's HSD test) (rejection level 0.05). Error bars depict standart errors of means (n = 7).

*paralias*. This species is a salt pan-dune transitional species and N content was higher than the other species. In addition to this, the lowest N resorption efficiency was found in *E. paralias*.

Ungar et al. (1979) and Munir & Aftab (2009) reported that *Salicornia* species were highly competitive in highly saline soils, because they achieved an optimal growth at salinity levels that would be limiting to other species. Yeo (1983) stated plants that are able to cope with harsh conditions benefit from high availability of water, light, and nutrients, compensate for the “extra cost for tolerance”, and produce a large amount of biomass. *Salicornia* L. and *Spergularia* (Pers.) J. & C. Presl species were also classified as high phenotypic plasticity species (Wilkoń-Michalska, 1985). The studied species were characterized as Grime’s CR (competitive ruderal strategy). CR species usually occurred in seasonally inundated and arid areas. Competitive species, i.e. species with dominant competitive ability (C s.l. strategy: C+CR+CS), which presented high vegetative development, ecological plasticity, and occasionally some allelopathic potential (Vidal et al., 2000). In the study area inundation occurred periodically and dryness was observed due to excess evaporation during summer (Kutbay & Demir, 2001). Environmental conditions in these areas were harmful only once during the life cycle of a certain species. However, they never cause completely removing of the species (Grime, 2002). Plant zonation in coastal salt marshes depends upon competitive processes with poorer competitors being displaced to areas of greater disturbance or stress, which provide refuges from superior competitors in addition to physicochemical factors (Reynolds et al., 2001).

Disturbances as a result of wrack deposition and sedimentation are also significant in salt marshes (Levine et al., 1998; Pennings & Richards, 1998). Because substrate salinity in coastal marshes varies through the growing season in relation to weather conditions and tidal activity (Adam, 1990), there is a high probability of interactions between the temporal pattern of substrate salinity and plant phenological development. Such interactions are likely to affect plant population abundance and distribution in coastal marshes, particularly for annuals that must

necessarily go through germination and establishment phases every year (Reynolds et al., 2001). SLA was increased from August to October in *E. paralias*. In addition, SLA was also increased in *S. marina*, *A. santonicum*, and *O. maritimus* from September to October. Vegetative growth period of these species may be occurred several times during the year and new leaves emerge through autumn.

Plant zonation in salt marshes is affected by physical stress and nutrient limitation. Salinity and sodium toxicity act as ecological filters that reduce species richness in salt marshes (Flowers et al., 1977; Yeo, 1983; García et al., 1993, El Demerdash, 1996 & Abd El-Ghani, 2000). In addition, inundation causes stressful conditions in salt marshes, especially near sea level (Curcó et al., 2002). The notable aspects of seasonal fluctuations in terms of salinity due to excess evaporation occur during summer in salt marshes (Apaydın et al. 2009; Ababou et al., 2010). Notable changes especially in July in the studied plant characters may probably be due to increasing salinity during summer as a result of excess evaporation. Owing to the strong environmental gradients present in salt marsh habitats, marked intra- and inter-specific variation is probably the rule for all species of salt marsh plants (Richards et al., 2005). Jiang et al. (2009) stated that salt marsh plants subject to seasonal variations with respect to specific leaf area owing to the strong environmental gradients especially during summer.

It has been proposed that plant species competition might change the spatial distribution pattern of vegetation. Possibly, the competition played a role for the distribution pattern of the natural vegetation in the studied salt marsh so that the vegetation types have adapted to the local environmental conditions (Ji et al., 2009). The efficiency of the resorption process seems to be related to the plant species (Cartaxana & Catarino, 2002). Salt marshes contain steep environmental gradients, for instance conditions are fairly mild near the terrestrial border of the marsh but become severe in salt pans and these traits are effective on micro-habitat preferences and zonation of salt marshes (Richards et al. 2005; Apaydın et al. 2009). The highest N and P resorption efficiency was found in 2 species belonging to Chenopodiaceae, namely *S. prostrata*

and *S. marina*, while the lowest N and P resorption efficiency was found in *E. paralias*. In other words, the species that are better adapted to saline conditions have also higher resorption efficiencies. *S. prostrata* and *S. marina*, which occur around salt-pans, can use nitrogen more effectively as compared to salt pan-dune transitional species, such as *O. maritimus* and *E. paralias*. Although all species inhabit areas of similar flooding conditions, some species seem to have a higher competitive capability than others. The differences among species in terms of resorption efficiency are probably due to the different adaptation capacities of species against harsh and selective saline

conditions (Sánchez et al., 1998; Kutbay & Demir, 2001; Cartaxana & Catarino, 2002).

High N resorption efficiency values of *S. prostrata* and *S. marina* indicated that nutrient resorption may play an important role on nitrogen dynamics in coastal salt marshes. It is possible to generalize the obtained results to other similar coastal salt marshes for reclamation and rehabilitation purposes (Álvarez et al., 2001; Jafari et al., 2003). When the temporal and spatial factors are established more clearly, the factors affecting nutrient resorption in salt marshes will be explained in more detail.

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