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Effect of Invasion by Exotic *Acacia saligna* (Labill.) H. Wendl. on Native Species Diversity Across an Aridity Gradient Along the Coastal Mediterranean Dunes of Sinai Peninsula

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ABSTRACT

Exotic plant invasions represent a threat to natural and conserved ecosystems. In this study, the effect of the invasive exotic *Acacia saligna* on native floristic diversity was evaluated at Zaranik and Ahrash Protectorates that representing arid and semi-arid climate, respectively along the Mediterranean dunes of Sinai. At each site, 35 plots were randomly established. The community attributes of native species including species number, species richness, species evenness and dominance–diversity curves were measured and compared between invaded and uninvaded patches. Results showed that all the measured community attributes were significantly lower in the invaded than uninvaded patches at both sites. In addition, the dominance–diversity curves indicated that invaded patches had less species richness with monospecific communities. Furthermore, the effect of *A. saligna* on the native flora is dependent on its canopy size and the aridity. Larger canopy at the arid site has negatively greater impact on the diversity of native species. The vitality survey showed that the leaf litter accumulation of *A. saligna* has a detrimental effect on the health of the native dominant *Artemisia monosperma* shrubs in the adjacent uninvaded patches. Markedly, the present study indicates that *A. saligna* has a potential threat to the native plant diversity within the two Mediterranean conservation protectorates. Restoration options to reduce exotic *A. saligna* plants in the North Sinai sand dunes were found to be the introduction and management of native sand trapping plant species.
Keywords: *Acacia saligna***,** aridity, invasive species, plant diversity, sand dunes, Zaranik protectorate.

INTRODUCTION

Invasion by alien plant species is causing major conservation problems in many regions of the world and are viewed as an important component of human caused global change (Vitousek *et al.*, 1997). These alien plants are considered pests for agricultural and horticulture as they pose an economic threat to these industries (Dunbar and Facelli, 1999). The spread of alien species is associated with the consequences of human activities, e.g. disturbance, fragmentation, urbanization, cropping and the use of alien plants for landscaping and erosion control (Van Wilgen and Richardson, 1985; D'Antonio and Vitousek, 1992) and the creation of new landscapes (Vitousek *et al.*, 1997).

The studies on the extent and patterns of invasions in arid lands are few (Loope *et al.*, 1988; Brock and Farkas, 1997; Badano and Pugnaire, 2004; El-Keblawy and Al-Rawai, 2007). Although pristine arid environments appear to be unfavorable for the establishment of alien species, disturbed arid ecosystems can be very sensitive to changes caused by established alien species (Brock and Farkas, 1997). In arid environments, alien species can cause strong ecological changes such as changes in soil water and nutrient availabilities, and consequently lead to biologically degraded ecosystems (Freitag-Ronaldson and Foxcroft, 2003).

Acacia saligna (Labill.) H. Wendl. is one of the potential invasive plants that significantly alter arid and semi-arid ecosystems (Holmes and Richardson, 1999; Yelenik *et al.*, 2004). It is a tree native to the Mediterranean climate of Australia. *A. saligna* was planted to stabilize sand dunes and create forests across the Mediterranean ecosystems in Africa, Asia and North America. It has escaped cultivation and become naturalized and invasive in South Africa (Holmes and Cowling, 1997; Holmes and Richardson, 1999). In Egypt, *A. saligna* have been widely introduced throughout the landscape of the whole country, including within the protected areas, in order primarily to act as windbreaks, and provide wood and sheep fodder (Gibali, 1988; Abou El Nasr *et al.*, 1996; Misak and Draz, 1997; El-Baha, 2003).

Along the Mediterranean coast of Sinai Peninsula, coastal sand dunes have been considered for long time as valueless habitat, thus consequently they were destroyed and disturbed in an irreversible way. These dunes are unique habitats to rich flora and fauna with several vulnerable, endangered and endemic species (Gibali, 1988; Baha El Din, 1992; Boulos and Gibali, 1993; El-Bana *et al.,* 2002). The continuous overgrazing, overcutting and uprooting has led to the disappearance of pastoral plant communities, the paucity of trees and shrubs, the reduction of plant cover, and soil erosion (El-Kady and El-Shourbagy, 1994; El-Bana *et al.*, 2003; Attum *et al.*, 2006). Furthermore, the execution of the North Sinai Agricultural Development Project (NSADP) for cultivation 400000 acres will inevitably provoke major changes of the ecological character of the unique coastal ecosystems. Therefore, less than 15% of the original coastal vegetation remains due to agricultural and urban development, and the remaining tracts are at considerable risk of being replaced by the invasive exotic species *A. saligna*. Despite its introduction since 1962 (Gibali, 1988), no studies have quantified the changes brought with this introduction and no published data on how the continued expansion of this invasive species threat

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native communities. Therefore the main objectives of the present study are: (1) to assess the changes in floristic diversity and community structure caused by the expansion of *A. saligna* along aridity gradient on the Mediterranean dunes of Sinai, and (2) to assess the impact of *A. saligna* on health of the dominant native perennial species.

MATERIALS AND METHODS

Description of the study sites

Field studies were carried out during winter 2004/2005 at two sites selected along aridity gradient on the Mediterranean coast of Sinai running from East to West (length: 80 km) (Fig. 1). The arid site is situated at the southern part of Zaranik Protectorate (31° 14' N and 33°30' E) where the average annual rainfall is 82 mm, while the semi-arid site is located at Ahrash Protectorate, near Rafah (31° 17' N and 34°14' E) where average annual rainfall is 300 mm. Both sites share the same siliceous sandy soils, and vegetation structure and composition were relatively similar (Gibali, 1988; Dargie and El-Demerdash, 1991). Vegetation patches that had been invaded by *A. saligna* and others that were without invasion were mostly dominant in the two study sites. Furthermore, monospecific stands of *A. saligna* are frequent at both sites, but they were not included in the present surveys.

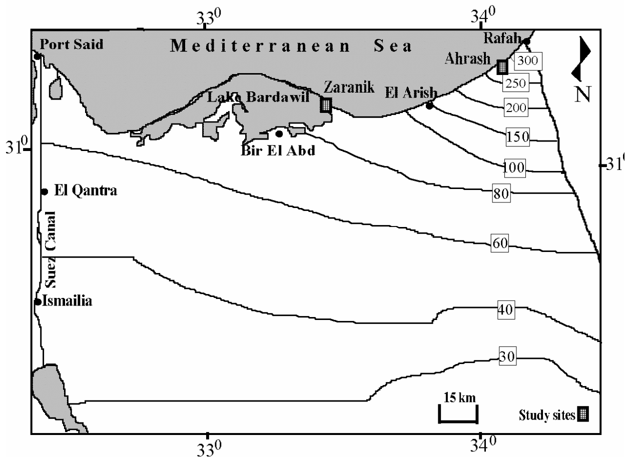

Figure (1): A map indicating the two study sites (Zaranik and Ahrash) with isohyets of precipitation along the Mediterranean coast of Sinai.

Sampling

Thirty-five plots of 25 m^2 each were selected to determine the possible floristic changes due to invasion by *A. saligna* at each of the two sites. In each plot, two patches were identified: one under the canopy of *A. saligna* (invaded patches) and the other at least two meters away from the projection of the canopy (uninvaded patches). A transect of 8 m long was fixed in the center of *A. saligna* trunk, radiating out in the four cardinal directions. Along each transect, a series of four 1 m^2 quadrats were randomly sampled to record the number of plant species, two in the invaded patches and the other two in the uninvaded ones. The mean abundance of species (the number of individuals per species rooted within 25 m^2) was calculated for invaded and uninvaded patches at each study site. Some other community attributes were also estimated, including species number, species richness and species evenness as estimated by Shannon-Weaner index. Species richness was calculated as total number of species occurring per unit area (25 m^2). In order to relate species richness and their relative abundance, dominance–diversity curves (Whittaker, 1972; Kent and Coker, 1992) were computed and plotted for each sampling site.

The individuals of *A. saligna* in each study site varied greatly in their sizes with an almost homogenous density. The canopy diameter and height of *A. saligna* individuals were recorded to assess such different size effect of *A. saligna* on community attributes. Mean canopy diameter was calculated as the average of maximum and minimum canopy diameter. Sizes of *A. saligna* individuals were classified based on their average canopy diameters into small (< 2 m), medium (2–5 m) and large (> 5 m). Nomenclature was according to T?ckholm (1974) and Boulos (1995).

To assess the effect of *A. saligna* leaf litter dispersal and accumulation on the health of native species in the uninvaded patches, a vitality survey was conducted for 150 shrubs of *Artemisia monosperma* at Zaranik Protectorate. The presence or absence of *A. saligna* leaf litter around each *A. monosperma* shrub was recorded and its vitality was estimated. To estimate vitality a rank from 1 to 5 was given according to the proportion of branches in the shrub supporting live biomass. Vitality score decreased in 20% intervals, with class 1 for shrubs having less than 20% of the branches supporting living biomass.

Data analysis

One-way ANOVA followed by Tukey's studentized test was used to compare the total number of species between invaded and uninvaded patches and between different sizes of *A. saligna*. Two-way ANOVA was also applied to test the effect of invasion and tree size on species abundance, evenness, and richness. To test whether there was any difference in the vitality of *A. monosperma* either affected by *A. saligna* litter or not, the respective distribution of plants in the different vitality classes was compared using Kolmogorov-Smirnov tests. All statistical methods were performed according to Zar (1996) and by using SPSS, version 13.0.

RESULTS

Data of the present study showed that site and invasion have a significant effect on the measured attributes of species as evaluated by Two-way ANOVA (Table 1). Invasion by *A. saligna* had a negative effect on species abundance, richness, and evenness at both sites (Fig. 2). In each site, invaded patches had a significantly low species abundance compared to univaded ones. The abundance of species was lower at invaded than uninvaded patches by about 72.2% and 81.3% in semi-arid and arid sites, respectively. Similarly, species richness and evenness were significantly lower in the invaded patches than their counterparts in the *A. saligna* uninvaded ones (Fig. 2, Appendix 1).

The effect of canopy size of *A. saligna* on species abundance, richness and evenness was significant and dependent on the invaded site (Table 2, Fig. 3). In general, the values of the measured community attributes decreased with increasing canopy size and aridity (Fig. 3). For each size class, arid site had a significant low species richness, evenness and abundance compared to semi-arid site. At both sites, large sized individuals accounted for highly significant decreases in species richness and abundance in comparison with small sized individuals (Fig. 3). At arid site, species abundance was decreased by 174%, 88% and 30% under large, medium and small canopies, respectively; compared to their counterparts in uninvaded patches. Similarly, the effect of *A. saligna* canopies on species richness increased with the increasing canopy size. For example, at the semi-arid site species richness decreased from eight and five species under the canopies of small and medium individuals to only one species under the canopies of large individuals.

Table (1): Results of Two-way ANOVA for testing the effect of site (arid vs. semi-arid) and *Acacia saligna* invasion (invaded vs. uninvaded) on species richness, evenness and mean plant abundance (* = p < 0.05; ** = p < 0.01; and *** = p < 0.001).

Source	df	Richness	Evenness	Abundance
Site	1	22.82***	14.54**	32.18***
Invasion	1	9.32***	4.65**	78.41***
Site × invasion	1	4.25*	2.33*	8.13**

Table (2): Results of Two-way ANOVA for testing the effect of *Acacia saligna* canopy size (small, medium and large) and site (arid vs. semi-arid) on species richness, evenness and mean plant abundance (* = p < 0.05; ** = p < 0.01; and *** = p < 0.001).

Source	df	Richness	Evenness	Abundance
Size	2	12.22**	3.93*	16.27**
Site	1	24.16***	10.54**	31.18***
Size × site	1	6.87**	1.74	11.43**

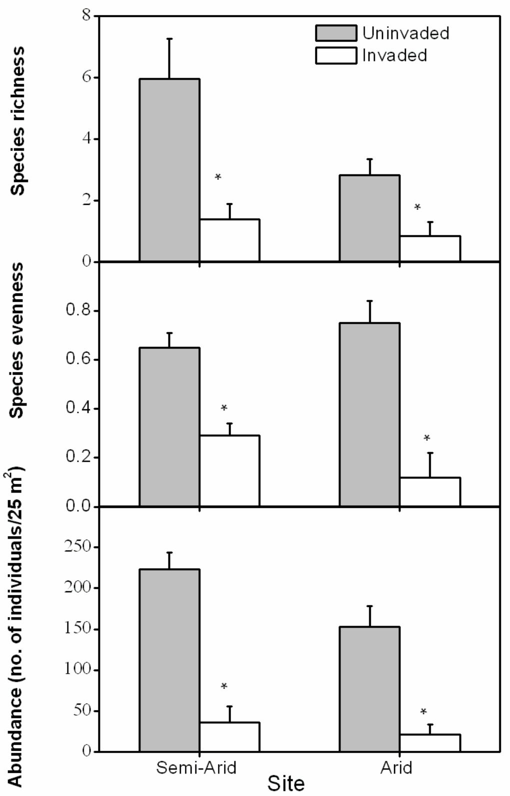

Figure (2): Effect of invasion by *Acacia saligna* on species richness, evenness and abundance of native plants in arid and semi-arid sites. Asterisks indicate significant differences between invaded and uninvaded patches at a given site (Tukey's studentized test, p<0.05).

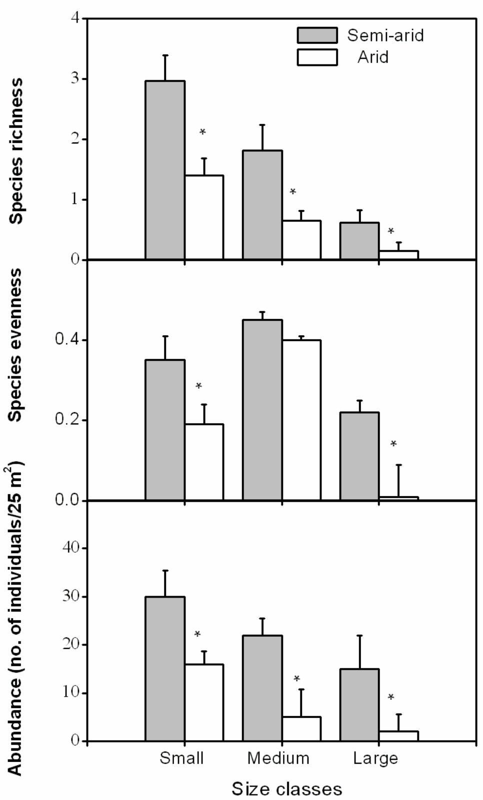

Figure (3) Effect of *Acacia saligna* canopy size on species richness, evenness and abundance of native plants in arid and semi-arid sites. Asterisks indicate significant differences between arid and semi-arid at a given size (Tukey's studentized test, p<0.05).

Figure 4 indicated that both sites (invaded and uninvaded patches) differed not only in overall species richness, but also in the shapes of their dominance-diversity curves. The uninvaded patches had more species richness with three or four common species had approximately similar abundance. On the other hand, the invaded patches had less species richness with only one dominant species.

The classes of vitality of *Artemisia monosperma* with or without *A. saligna* litter had different frequency distribution (Fig. 5). *A. monosperma* without *A. saligna* litter were more likely to be in higher vitality classes than those with litter. About 80% of the *A. monosperma* without litter had a vitality of four and five, while 90% of the individuals with litter had a vitality of three and lower.

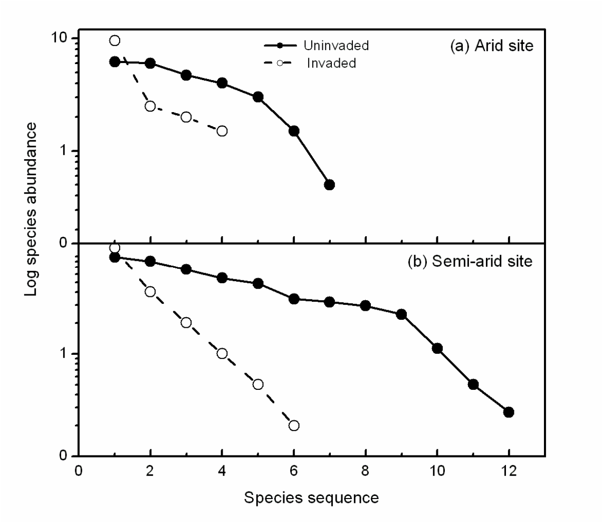

Figure (4): Dominance-diversity curves for uninvaded and invaded patches by *Acacia saligna* in arid and semi-arid sites.

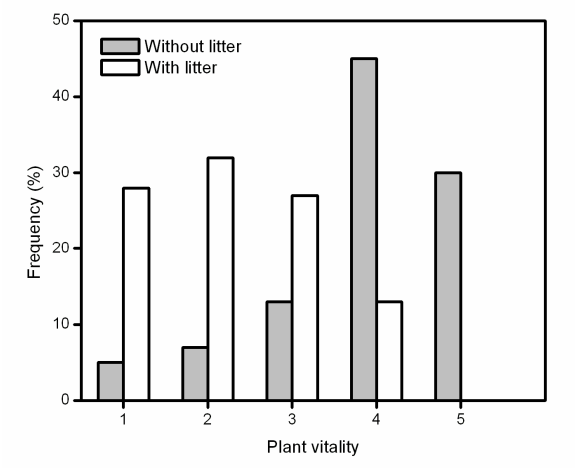

Figure (5): Frequency distribution in different vitality classes (1–5) of *Artemisia monosperma* with and without *Acacia saligna* leaf litter accumulation at Zaranik Protectorate (arid site). In both cases the distribution was significantly different (Kalmogorov-Smirnoff test, $p < 0.05$).

DISCUSSION

The results of this study clearly showed that *Acacia saligna* has a potential threat to plant richness and diversity of Mediterranean dunes in Sinai. In both arid and semi-arid sites, *A. saligna* caused a negative impact on species richness, evenness and abundance. These findings coincided with that obtained by Richardson *et al.* (1989); Musil (1993); Holmes and Cowling (1997); Daehler (1998); Holmes and Richardson (1999); Yelenik *et al.* (2004) on the depressive effects of many invasive *Acacia* species on biodiversity and ecosystem functioning, however they did not test this impact along aridity gradient. In a similar study, El-Keblawy and Al-Rawai (2007) found large sizes and dense sites of invasive *Prosopis juliflora* resulted in significantly lower density, frequency and diversity for most associated plant species in the arid regions of the United Arab Emirates. While in the Mediterranean fynbos of South Africa, Holmes and Cowling (1997) reported a decline in species richness, diversity and abundance both in the standing vegetation and seed banks with increasing duration of invasion by *A. saligna.*

The present study showed significant invasion × site and invasion × *A. saligna* canopy size interactions, suggesting that invasion impacts on community attributes were not consistent across the aridity gradient. Species richness, abundance and evenness declined with increased *A. saligna* canopy size and aridity. The highly depressive effect observed in arid site with increasing canopy size could be attributed to dense canopy and root masses of *A. saligna* (Witkowski, 1991). The dense canopy mass of *A. saligna* may act to decrease the amount of water available in the invaded patches by interception of low rainfall and increasing evapotranspiration rates (Musil, 1993). However, its dense root mass can reduce soil water availability in two ways. First, the dense root mass may be very efficient in rapidly absorbing any water from the surrounding soil. This may reduce the effectiveness of the small rainfall events especially at the arid site, preventing the wetting front from reaching the area of soil exploited by native species. Second, it may compete directly with native species for soil water availability where native plants lose out in such competition (Musil, 1993).

The success and impacts of alien species depends on their biological attributes, the environmental characteristics of the invaded ecosystem and the biotic interactions with the receptive community (Vitousek, *et al.,* 1997; Holmes and Cowling, 1997; Levine *et al.,* 2003; Badano and Pugnaire 2004; Yurkonis *et al.,* 2005). *A. saligna* exhibits many biological traits associated with good invaders such as rapid growth rate, high rates of reproduction (both vegetatively and by seed), long-term viability of seeds (400,000 seeds per square meter), and the ability to tolerate a wide range of soil and climate conditions (Witkowski, 1991; Holmes and Cowling, 1997; Eggleton *et al.,* 2007). It also has the ability to transform the quality of the soil structure, soil chemistry, and hydrology to better suit its own needs (Richardson *et al.,* 1997). Furthermore, since dune native plants are shade-intolerant and naturally adapted to high light levels (Smith and Huston, 1989), *A. saligna* outcompetes local plants by overtopping and shading them (Witkowski, 1991). Additionally, *A. saligna* has the regrowth capacity after pollarding under drought, saline and flooding conditions (Eggleton *et al.,* 2007).

The vitality survey in the present study showed a negative correlational linkage between *A. saligna* leaf litter and health of *Artemisia monosperma* individuals in univaded patches. This suggests that the litter accumulation may play a direct role in its depressive effect on native plant diversity as well as extending of its effect outside the invaded patches. Therefore, it can be assumed that there is persistent accumulation of allelopathic compounds. There are many studies (e.g. Warrag, 1995; Chellamuthu *et al.,* 1997; Bais *et al.,* 2003; El-Baha, 2003; Orr *et al.,* 2005) showing that the detrimental impact of exotic species on native flora could be related to allelopathic effects of dead and live litter of exotic species. For example, El-Baha (2003) found that the water extracts from the soil under canopy and from leaf litter of *A. saligna* has suppressive effects on seed germination of rice and maize.

Plant invasion can alter and move community structure from natural diverse heterogeneity to uniformly homogeneous, dominated by single species or invasive species over wide areas (Freitag-Ronaldson and Foxcroft, 2003). Dominance–diversity curves showed that diversity was higher and species were more evenly distributed in the uninvaded than in the invaded patches. This log normal pattern for the uninvaded patches could be attributed to a higher heterogeneity in microtopgraphy and resources induced by native perennial species (El-Bana *et al.,* 2007). Furthermore, native psammophytes invest more in strategies for their survival rather than for their domination (Danin, 1996). In contrast, the detrimental effect of *A. saligna* resulted in lower diversity values and the dominance of one species in invaded patches.

CONCLUSION

Generally, the results of the present study demonstrated that biodiversity and conservation threat posed by *A. saligna* on the Mediterranean dunes of Sinai is clear. It is currently invading and dominating a number of locations along the eastern and western North Sinai coast, including the conservation protectorates (Zaranik and Alhrash). Furthermore, the name Alhrash is derived from the domination of this exotic species within the protectorate. The established *A. saligna* persists and pre-empts the resources at the expense of native plant species. The large foliage masses and litters produced by *A. saligna* populations have a strong allelopathic effect on the adjacent and even the remote native vegetation. The management strategy should be focused on eliminating the founding population currently established at Zaranik and Alhrash Protectorates. In addition, the introduction of *A. saligna* into new highly diverse areas should be stopped. Alternatively, conserving and restoring plant diversity of the sand dunes can be obtained by introducing and managing the native sand trapping species (El-Bana *et al.,* 2002, 2003, 2007).

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Appendix (1): List of plant species with their presence percentage (percentage out of a total 35 plots) recorded in uninvaded and invaded patches by *Acacia saligna* at the study sites.

Species	Zaranik		Ahrash	
	Uninvaded	**Invaded**	**Uninvaded**	**Invaded**
Adonis dentata Delile	22.85	0	34.28	0
Argyrolobium uniflorum (Decne.) Jaub. & Spach	0	0	5.71	0
Artemisia monosperma Delile	94.28	5.71	42.86	0
Asparagus stipularis Forssk.	0	0	8.57	0
Astragalus annularis Forssk.	0	0	37.14	5.71
Astragalus boeticus L.	0	0	14.28	0
Brassica tournefortii Gouan	0	0	22.85	11.42
Bromus rubens L.	68.57	8.57	42.86	11.42
Calligonum polygonoides L.	22.85	0	34.29	0
Centaurea calcitrapa L.	0	0	37.14	0
Centropodia forskalii (Vahl) Cope	0	0	17.14	0
Convolvulus lanatus Vahl	45.71	0	0	0
Cornulaca monacantha Delile	51.43	0	22.85	0
Crucianella membranacea Boiss.	0	0	31.42	5.71
Cutandia dichotoma (Forssk.) Trabut	97.14	5.71	65.71	14.28
Cyperus laevigatus L.	0	0	22.85	0
Daucus littoralis Sibth. & Sm.	17.14	0	77.14	22.85
Echinops spinosissimus Turra	0	0	48.57	0
Eremobium aegyptiacum (Spreng.) Boiss.	37.14	0	22.85	0
Erodium laciniatum (Cav.) Willd.	65.71	0	34.28	0
Filago desertorum Pomel	97.14	14.28	71.42	8.57
Haplophyllum tuberculatum (Forssk.) A.Juss.	0	5.71	28.57	0
Helianthemum stipulatum (Forssk.) C.Chr.	0	0	31.42	0
Heliotropium digynum (Forssk.) C.Chr.	11.42	0	37.14	17.14
Herniaria hemistemon J.Gay	0	0	62.85	8.57
Ifloga spicata (Forssk.) Sch.Bip.	88.85	11.42	71.42	0
Launaea capitata (Spreng.) Dandy	42.85	0	22.85	0
Lobularia arabica (Boiss.) Muschl.	0	0	51.42	5.71
Lotus halophilus Boiss. & Spruner	0	0	77.14	0
Matthiola livida (Delile) DC.	0	0	28.57	0
Moltkiopsis ciliata (Forssk.) I.M.Johnst.	48.57	0	17.14	0
Neurada procumbens L.	74.28	0	25.71	8.57
Ononis serrata Forssk.	0	0	82.85	14.28
Pancratium sickenbergeri Aschers. & Schweinf. ex C. & W. Barbey	57.14	2.85	0	0
Panicum turgidum Forssk.	37.14	0	0	0
Plantago ovata Forssk.	0	0	48.57	0
Retama raetam (Forssk.) Webb	42.85	0	0	0
Rumex pictus Forssk.	0	0	57.14	0
Schismus arabicus Nees	94.28	14.28	82.85	22.85
Senecio glaucus L.	62.85	0	74.28	0
Silene villosa Forssk.	17.14	0	71.42	0
Stipagrostis scoparia (Trin. & Rupr.) de Winter	42.85	0	0	0
Thymelaea hirsuta (L.) Endl.	62.85	0	54.28	0
Trigonella stellata Forssk.	0	0	45.71	0

تأثيرغزو النبات الدخيل أكاسيا ساليجنا على التنوع النباتي الأصلي للكثبان الرملية من خلال معامل جفاف بطول البحرالمتوسط لشبه جزيرة سيناء

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الملخص العربـــى

يشكل غزوالنباتات الدخيلة تهديدا للتنوع الأحيائي والمحميات الطبيعية. في هذه الدراسة تم دراسة تأثيرغزو النبات الدخيل أكاسيا ساليجنا على التنوع النباتي الأصلي للكثبان الرملية في محمية الزرانيق، ومحمية الأحراش واللتان تمثلان مناخ جاف وشبه جاف على التوالي بطول ساحل البحرالمتوسط لسيناء. ولإجراء هذه الدراسة فقد تم إختيار 35 موقعاً بطريقة عشوائية في كل محمية. وفي كل موقع تم قياس الصفات العشائرية مثل عدد، ووفرة، ومعاملات ومنحنيات التنوع والسيادة للنباتات المحلية ومن ثم مقارنة هذه الصفات بين مناطق مغزوة بأكاسيا ساليجنا وأخري غير مغزوة.

وقد أظهرت النتائج أن كل الصفات المقاسة في المناطق المغزوة كانت أقل بدرجة كبيرة عن مثيلاتها في المناطق غير المغزوة في كلا المحميتين. ولقد أوضحت منحنيات السيادة والتنوع وجود تنوع ووفرة لأنواع نباتية مختلفة في المناطق غيرالمغزوة، بينما توجد قلة في عدد الأنواع وسيادة لنوع واحد في المناطق المغزوة. بالإضافة إلى ذلك، أعتمد التأثير السلبي لنبات الأكاسيا على الزيادة في مساحة ظلل أفراده والجفاف، فلقد كانت للأفراد ذات المظلات الكبيرة في الموقع الجاف تأثيرا سلبيا أكبر على الصفات المختلفة. وقد أظهرت دراسة الحيوية لنبات العادر المحلي أن إنتشاروتراكم بقايا أوراق أكاسيا ساليجنا له تأثيرضارعلى صحة نبات العادر في المناطق غيرالمغزوة .

ومن خلال نتائج هذه الدراسة يتضح أن إنتشارالنبات الدخيل أكاسيا ساليجنا يمثل خطرا على التنوع النباتي للكثبان الرملية وبخاصة داخل المحميات الطبيعية، ولذلك فمن الضروري وضع أليات مثل التخلص من أشجار هذا النبات داخل المحميات ووقف زراعتها كليا أو على الأقل في المناطق ذات الأهمية البيئية، ويمكن الأستغناء عنها بإستخدام الأنواع الأصلية التي لها القدرة على تثبيت الكثبان الرملية وزيادة التنوع الأحيائي دون إستنزاف للمصادر الطبيعية الضئيلة.