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The classification and assessment of vegetation for monitoring coastal sand dune succession: the case of Tuzla in Adana, Turkey

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Abstract: This study aimed to provide an assessment of coastal sand dune vegetation through a number of analyses meant to provide a better understanding of the structure of plant communities and the successional stages of coastal sand dunes in a human-induced coastal landscape, the Seyhan Delta in southern Turkey. Therefore, as a baseline data inventory for monitoring, succession and the community-based classification of sand dune vegetation and human impacts were the major concerns of this study. The zonation of coastal sand dune vegetation was also determined within this scope, providing a contemporary assessment of different successional stages. A total of 96 taxa were recorded in 103 sampling relevés, which were randomly placed along 2 replicated transects perpendicular to the coastline. Multivariate classification techniques (TWINSPAN and DECORANA) were employed to classify sand dune vegetation into groups corresponding to different successional stages and to determine the response of plant community structures to human influence. Multivariate analysis resulted in a clear demonstration of 7 floristically distinct community groups associated with 4 main geomorphologic units. These plant communities were matched to the European Nature Information System (EUNIS) habitat classification. The results of this study provided a baseline data inventory covering plant communities and successional stages that demonstrated the current state of the coastal dunes in the study area.

Key words: Dune succession, sand dune vegetation, environmental monitoring, multivariate analysis, Seyhan Delta

Kıyı kumulları süksesyonun izlenmesinde bitki örtüsünün sınıflandırılması ve değerlendirilmesi: Tuzla örneği, Adana, Türkiye

Özet: Bu çalışmada kıyı kumullarında yayılan bitki toplulukları ve bunların geçirmiş olduğu süksesyon aşamaları, insan etkisine maruz kalmış bir kıyı peyzajı niteliğindeki Seyhan Deltası örneğinde analiz edilmiştir. İzleme için temel veri envanteri olarak kıyı kumulları vejetasyonunun topluluk düzeyinde sınıflandırılması, süksesyonu ve insan etkileri bu çalışmanın temel konularını oluşturmaktadır. Bu kapsamda, kumulların farklı süksesyon aşamalarını birlikte değerlendirmeye olanak veren zonal bitki örtüsü araştırılmıştır. Kıyı çizgisine dik 2 transekt üzerinde, tesadüfi olarak seçilen 103 örneklik alanda 96 takson kaydedilmiştir. İnsan etkileri de dikkate alınarak, süksesyon aşamalarının belirlenebilmesi için elde edilen bulguların değerlendirilmesinde, çok değişkenli ordinasyon (DECORONA) ve sınıflandırma (TWINSPAN) teknikleri kullanılmıştır. Bu sınıflamaya göre, 4 temel jeomorfolojik ünite üzerinde yayılan ve floristik açıdan ayrılabilen 7 bitki topluluğu belirlenmiştir. Belirlenen bitki toplulukları, EUNIS habitat sınıflaması ile eşleştirilmiştir. Bu araştırmanın sonuçları, araştırma alanındaki kıyı kumullarının bitki örtüsü ve süksesyon aşamaları açısından güncel durumunu gösteren bir temel veri envanterini sunmaktadır.

Anahtar sözcükler: Kumul süksesyonu, kumul vejetasyonu, çevresel izleme, çok değişkenli analiz, Seyhan Deltası

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Introduction

The coastlines of the world represent both a dynamic natural environment and an important context in which a diverse range of human activities, as well as geomorphologic and biological processes, interact. Coastal dune systems offer particularly suitable sites to study the ecology of plants and life forms. This is because, unlike many other terrestrial habitats, they frequently provide researchers with sites that are in a state of succession; thus, they combine the special interests of a successional sequence and, because the process of dune formation is often continuous, they may contain the earliest stages of succession as a permanent feature of the area (Shanmugam & Barnsley, 2002). Coastal sand dunes and their adjacent areas are highly favoured by agricultural activities. Therefore coastal areas, and in particular coastal dunes, are ecosystems strongly affected by the invasion of alien plants (Carboni et al., 2010). For this reason, the invasive nature of agricultural practices results in the fragmentation of the coastal dune system and creates heterogeneous landscapes that are composed of cultivated and seminatural areas. These seminatural habitats are very important for ecosystem functioning because they provide refuges for wildlife. Hay meadows, road verges, field boundaries, and other marginal habitats may therefore serve as connecting corridors or stepping stones for the distribution of plants and animals in an agricultural landscape (Koivu et al., 2004).

Sand dune areas on the southern coast of Turkey appear as complex patterns of agricultural patches and fragmented sand dune strips extending parallel to the coastline. Given the fact that the mineral and organic compositions of these geomorphologic structures, and thus the floristic characteristics and life forms that they support, vary according to their distance from the shoreline (Ranwell, 1972), each strip could potentially offer different conditions for wildlife and biodiversity.

Despite the fact that these coastal dune systems have recently been degraded, the successful characterisation and assessment of plant communities on the remaining dunes still has the potential to significantly contribute to environmental monitoring and conservation. Few studies examining the biophysical environment, biodiversity, and human impacts on these coastal ecosystems have been conducted in this area. Yılmaz (2002) used phytosociological data as an indicator of sand dune degradation. In an attempt to aid in the conservation of coastal dune vegetation in Tuzla, Çakan et al. (2005) created an inventory identifying plant communities on sand dunes. Alphan et al. (2005) demonstrated landscape changes along this coastal area. These studies suggest that the biophysical attributes of this coastal ecosystem show high spatial and temporal variation. In this complex ecosystem, landward zonation of the vegetation along the coastal sand dunes is considered to be an important area of interest for ecosystem monitoring and assessment.

Moving from the coast inland, sand dunes become progressively older. Along the distance gradient, burial by sand, salt spray, unstable substrate, high wind velocities, wave action, and human impacts are the most important factors that affect plant distribution and community structure (Henriques & Hay, 1998; Lichter, 2000). These environmental stresses cause dune systems to have diverse habitats that may be favoured by large numbers of plant species (Ranwell, 1972).

The stability of a sand dune has important implications on the spatial distribution of plant communities within the dune system. Communities of stable sand occur on inland dunes, while communities of unstable sand occur on those dunes that are closer to the sea (Musila et al., 2001). Plant communities supported by these dune systems along the coast-inland gradient reflect successional stages of the dune environment. Along this gradient, colonisation, limitation and sand movement represent major environmental constraints during early succession, while competition and limited regeneration determine later succession (Lichter, 2000).

Older stable dunes support a variety of plant covers. Grasses, heaths, or shrubs are generally dominant formations with numerous noncoastal species adding to the diversity of dune flora (Archibold, 1995). Continuous human influence on coastal sand dunes ensures the constant arrival of propagules from many different habitats. Strandline (*Cakiletalia*), foredune, and mobile dune communities (*Ammophiletalia*) are usually very disturbed and their physiognomy and floristic composition change remarkably when invaded by alien and invasive plant species. Increased nitrification and trampling in dune systems result in the spread of ruderal communities such as *Sisymbrietalia*, *Dauco-Melilotion*, and *Trifolio-Cynodontion* (Campos et al., 2004).

This paper demonstrates a classification and assessment of sand dune vegetation in the southeast Mediterranean coastal zone of Turkey by utilising a number of analyses to provide a better understanding of both the structure of vegetation communities and the succession of coastal sand dunes in Tuzla (southern Turkey), an area marked by the presence of sand dunes and extensive agricultural areas. As a baseline data inventory for monitoring, the major concerns of our study were succession and the community-based classification of sand dune vegetation and human impacts.

Study area and land use history

The study area is located near the village of Tuzla, about 40 km south of the city of Adana, on the southeast Mediterranean coast of Turkey (Figure 1). Terrestrial, limnic, and marine ecosystems create a diverse ecological structure on this fertile coastal plain, which is called "Çukurova" (Yılmaz, 1998).

The climate in the region is typical of the Mediterranean, a semiarid climate with mild winters and dry, hot summers. Despite the low precipitation in the coastal zone, especially in the summer, a great amount of water is carried to the coastal plain by rivers running down from the Taurus Mountains.

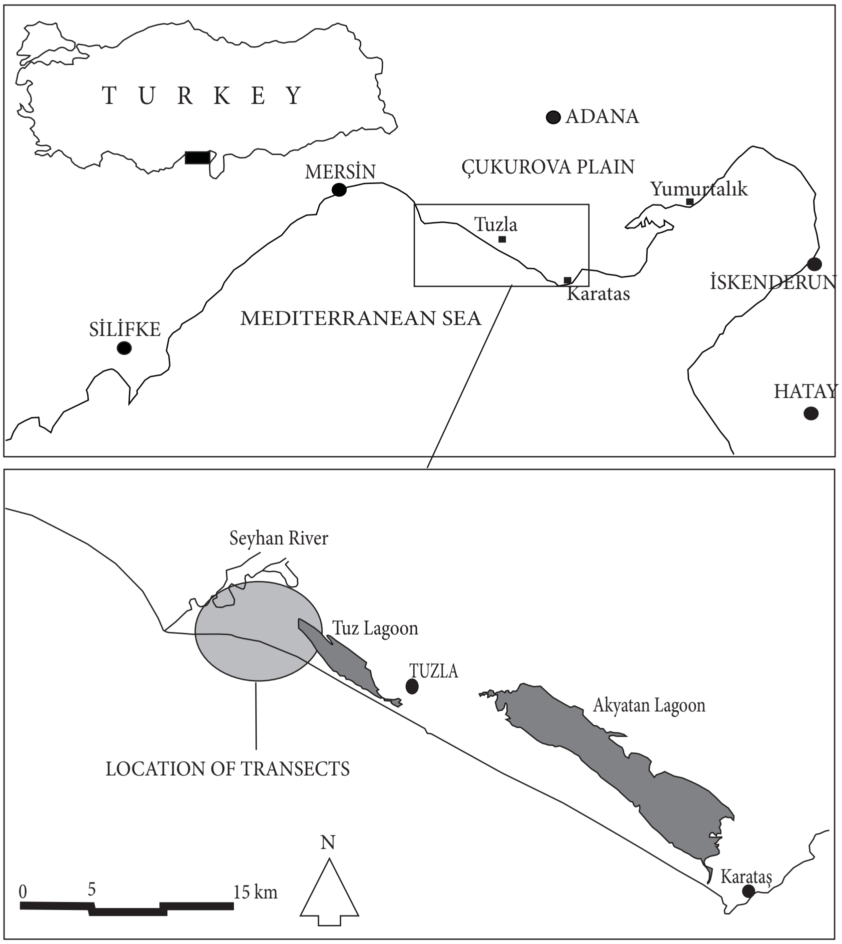

Figure 1. The southeast Mediterranean coast of Turkey, including the location of transects used in our study.

The average annual precipitation, which is about 670 mm, is generally lower than anywhere else along the Turkish Mediterranean coast. The average monthly precipitation is highest in December (180 mm) and lowest in August (1.7 mm). The mean annual temperature is 18.6 °C, with the lowest monthly average being about 5.2 °C in January and the highest being 27.7 °C in August. The relative humidity of the area also shows a significant increase in the summer.

Coastal dunes make a remarkable contribution to the flora of the region. Some 600 plant species have been identified in this coastal area (Çakan et al., 2005). In 2004, *Tamarix duezenlii* Çakan & Ziel. was reported as a species new to science from the dunes of that study's research area (Çakan & Zielinski, 2004). Recently, *Echinops dumanii* C.Vural was described as a new species to science from the dunes of Yumurtalık, an adjacent part of the research area (Vural et al., 2010). Both are considered to be local endemic to Turkey, occupying a very restricted area on the sandy seashore. Over the course of 7 years (2000-2007), 470 taxa occurring in different type of habitats were added to the flora of Turkey; 121 of these taxa were new to science (Özhatay et al., 2009). These figures provide strong evidence that dune floras are in need of continued examination in order to determine their floristic diversity.

The eastern Mediterranean region contains 11 coastal dune areas, 7 of which are located on the coast of Çukurova. With a length of over 100 km, this is the largest coastal dune area in Turkey, and the coastal dunes found here cover an area of 9591 ha (Uslu, 1989). Tuz Lake, the westernmost lagoon of the 5 lagoons along the coast of Çukurova, is located on the boundary of the village of Tuzla. Because of its ecological importance for wetland birds, an area of about 5768 ha, including Tuz Lake and its surroundings, was declared a wildlife reserve. This reserve is one of the Important Bird Areas of Turkey (Magnin & Yarar, 1997).

The coastal zone of Çukurova has witnessed large-scale land cover conversions to agricultural areas. Along the eastern coast of the region, a total of 1164 ha of forest, macchia, sand dune, and wetland area is estimated to have been converted for use in agriculture between 1984 and 1993. This figure further increased during the 1993-2000 period, reaching up to 2780 ha (Alphan, 2005). Between 1953 and 2009, a significant proportion of coastal dunes in Tuzla were turned into agricultural areas despite being owned by the Ministry of Public Works and Housing. In this period, the coastal sand dune area of the region decreased from 3350 to 666 ha while agricultural areas increased from 990 to 5499 ha (Figure 2).

Materials and methods

Vegetation sampling

A total of 103 relevés were marked randomly and surveyed along 2 parallel baselines (Transects A and B), perpendicular to the coast, by using the line intercept-transects technique (Brower & Zar, 1977) (Figure 3). The plant abundance of each relevé along successional stages was assessed using the Braun-Blanquet techniques. Crossing dune ridges from north to south along both Transects A and B, 16 subline transects comprised 7 and 9 ridges, respectively. The length of the subtransects ranged

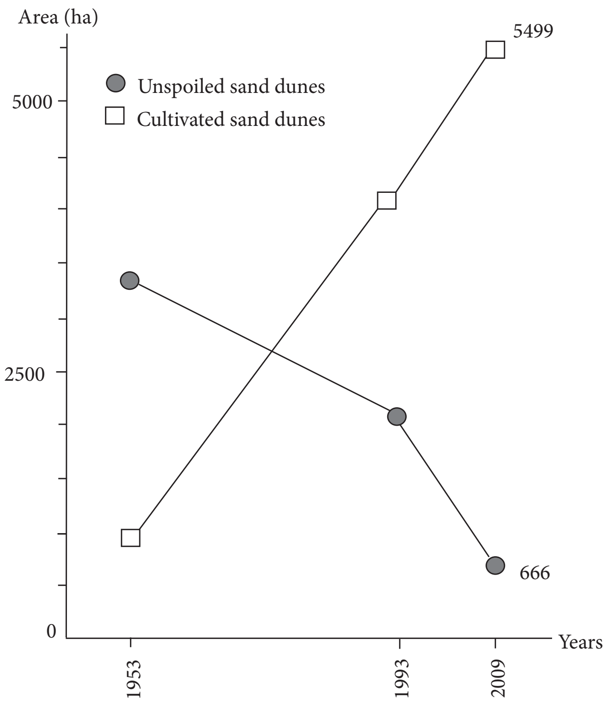

Figure 2. The decline of sand dune areas along an agricultural land use gradient.

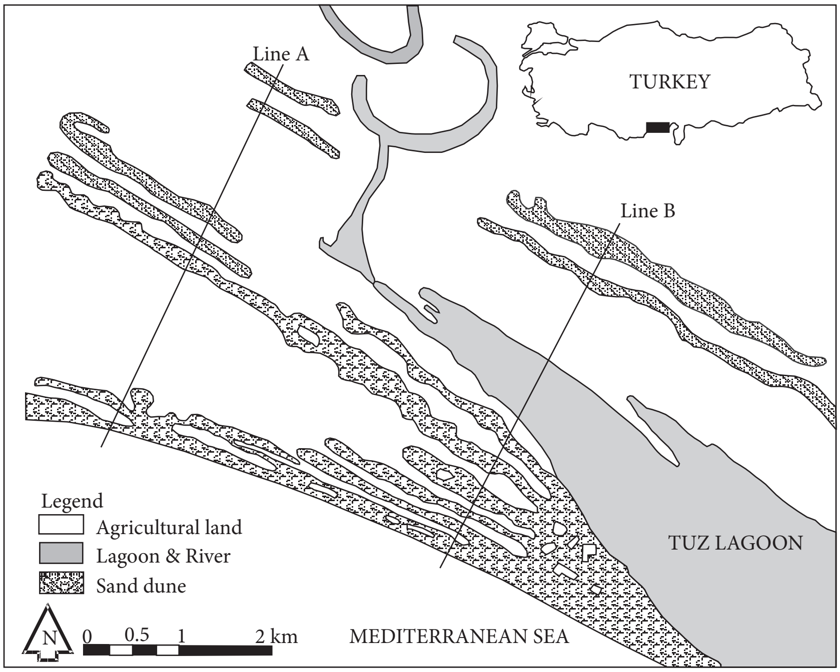

Figure 3. The locations of sand dune strips in relation to Transects A and B.

from 20 to 130 m, depending on the width of the sand dunes. Data were collected from relevés measuring 5 × 5 m, which were treated as separate units in each subtransect. The number of relevés for each sand dune ridge varied between 4 and 9, according to the width of the dune ridges. Sampling was conducted in 53 relevés for Transect A and 50 relevés for Transect B. Relative plant coverage was estimated visually in each relevé. The life-form spectra of plants were determined according to the Raunkiær classification (Raunkiær, 1934). Voucher specimens of each species were collected, identified, and stored in the herbarium of Çukurova University (ADA). *Flora of Turkey and the East Aegean Islands* was used for the identification of specimens and taxonomic nomenclature of species (Davis, 1965-1985).

Data analysis

In order to obtain an effective description for sand dune vegetation and its structure along a distance gradient, a matrix of 96 species × 103 relevés resulting from transect sampling was subjected to standard multivariate ordination and classification techniques (detrended correspondence analysis-DCA and TWINSPAN). Computations were based on a floristic presence/absence data matrix. The sites were ordered by divisive hierarchical clustering before the species were clustered on the basis of the classification of samples. An ordered 2-way table was constructed in order to succinctly express the relationship between the samples and species within the data set.

Results

Species recorded

A total of 96 vascular plant species were identified through vegetation surveys employed on sample plots that represented the various successional stages of sand dunes (Appendix). The numbers of perennial and annual species were 50 and 48, respectively. The identified species belonged to 34 families and 85 genera. *Gramineae* (25 species) and *Leguminosae* (11 species) were by far the largest families, with a species diversity that made up 25.5% and 11.2% of the total diversity, respectively.

Classification of the vegetation

Through the analysis of the relevés × species matrix, we were able to distinguish the main types of dune vegetation along a successional gradient.

The arrangement of relevés by TWINSPAN analysis reflected the influence of a complex gradient representing sand mobility and anthropogenic factors. The TWINSPAN analysis divided the set of 103 relevés into 7 floristically distinct plant community groups on different geomorphologic units (Figure 4). These communities were named with dominant and indicator species being the first and second species of the community name, respectively. Because of the comprehensive and hierarchical structure of the TWINSPAN multivariate analysis system, 7 plant communities and upper geomorphologic units defined by this analysis were easily matched to the units described in the European Nature Information System (EUNIS) habitat classification (Davies et al., 2004). All plant communities were covered by the lower unit of "coastal dunes and sandy shores" (EUNIS code: B1-Level 2) under the main unit of "coastal habitats" (EUNIS code: B-Level 1). Titles and habitat codes of the other lower levels (levels 3 and 4) are summarised in the Table.

Embryonic dunes (EUNIS code: B1.2, sand beaches above drift line - level 3)

Embryonic dunes represent the first stage of dune development. They have small, sandy ridges about 10-50 cm high with sparse vegetation. This geomorphologic unit was separated from other younger geomorphologic units at the second TWINSPAN division. This is a very mobile and unstable unit that occurred near the sea and which, in terms of characteristic plant communities, featured only *Sporobolus virginicus* (L.) Kunth-*Trachomitum venetum* (L.) Woodson (Group G: B1.24, sandy beach ridges with no or low vegetation - level 4). This area may be sporadically inundated by sea water during

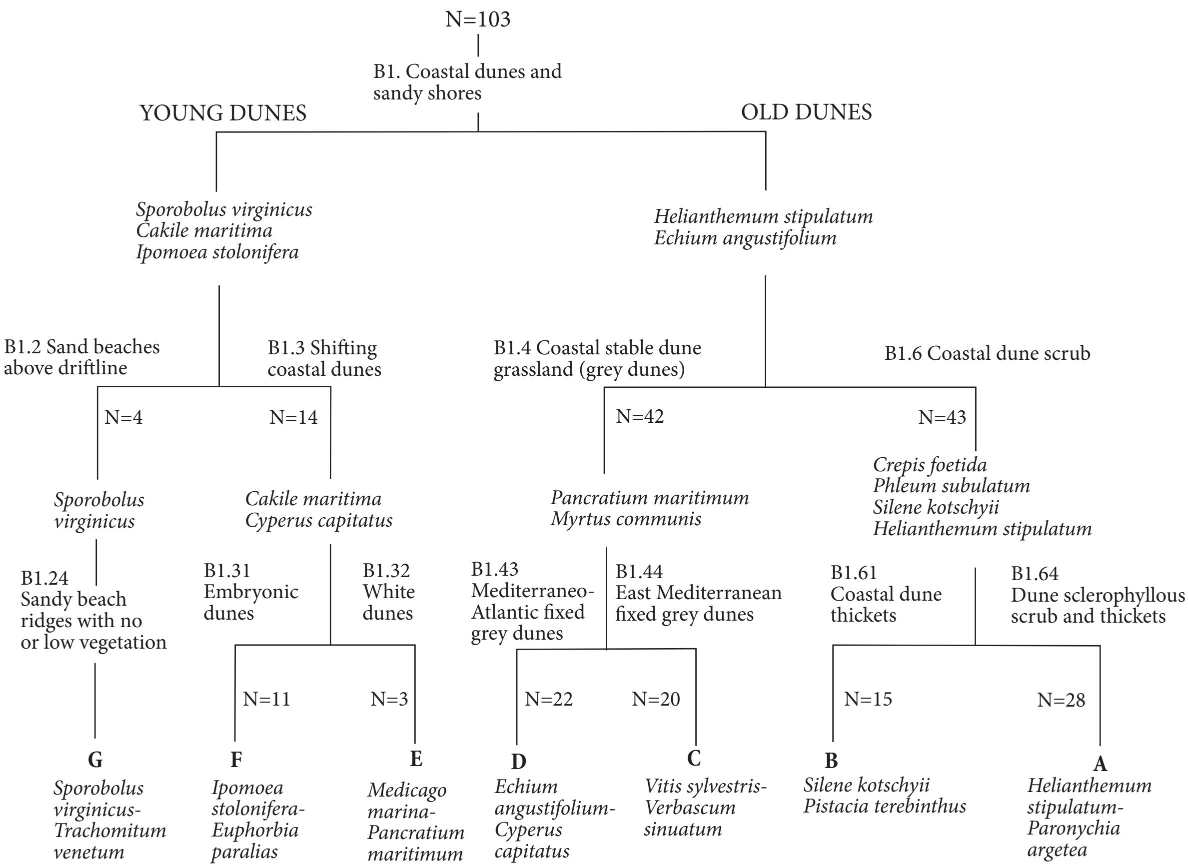

Figure 4. The sand dune communities identified by multivariate analysis (TWINSPAN), including their positions along the dendrogram and the corresponding EUNIS habitat codes. Differential species and relevé numbers (N) of each division are indicated.

Table. The communities resulting from multivariate analyses (TWINSPAN and DECORONA) along with their total species number, the dune morphology, the most abundant species, and the corresponding EUNIS habitat codes at level 4.

Communities identified by TWINSPAN (Total relevé number)	Dune morphology	Most abundant species	Total plant coverage (%) and species number	EUNIS habitat codes and names (level 4)
G: *Sporobolus virginicus-Trachomitum venetum* (4)	Young-embryonic dunes	*Sporobolus virginicus* *Trachomitum venetum* *Polygonum equisetiforme*	(25%) 5	B1.24 Sandy beach ridges with no or low vegetation
F: *Ipomoea stolonifera-Euphorbia paralias* (11)	Young-mobile dunes	*Ipomoea stolonifera* *Cyperus capitatus* *Pancratium maritimum*	(31%) 9	B1.31 Embryonic dunes
E: *Medicago marina-Pancratium maritimum* (3)	Young-mobile dunes	*Medicago marina* *Pancratium maritimum* *Cakile maritima*	(36%) 9	B1.32 White dunes
D: *Echium angustifolium-Cyperus capitatus* (22)	Old-fixed dunes	*Echium angustifolium* *Cyperus capitatus* *Cutandia memphitica*	(46%) 30	B1.43 Mediterraneo-Atlantic fixed grey dunes
C: *Vitis sylvestris-Verbascum sinuatum* (20)	Old-fixed dunes	*Vitis sylvestris* *Verbascum sinuatum* *Saccharum ravennea*	(59%) 55	B1.44 East Mediterranean fixed grey dunes
B: *Silene kotschyii-Pistacia terebinthus* (15)	Old-remnant dunes	*Silene kotschyii* *Pistacia terebinthus* *Myrtus communis*	(43%) 37	B1.61 Coastal dune thickets
A: *Helianthemum stipulatum-Paronychia argentea* (28)	Old-remnant dunes	*Helianthemum stipulatum* *Paronychia argentea* *Vitex agnus-castus*	(50%) 57	B1.64 Dune sclerophyllous thickets

storms. It is characterised by sandy beach ridges with the lowest plant coverage (25%) and a species-poor (5 species) community (Table).

As shown in Figure 5, cryptophytes were the characteristic life form found in this community, while *S. virginicus* was the dominant plant species. It is resistant to sand burial due to its survival and reproduction capability under high rates of sand mobility. *Ipomoea stolonifera* (cryptophyte) and *T. venetum* (phanerophyte) were other accompanying species in this community. *Echinops dumanii* and *Polygonum equisetiforme* Sibth. & Sm. are typical hemicryptophytes of these dunes. All plant species in this community were phytosociologically characteristic to the class *Euphorbio-Ammophiletea* (Figure 6).

Mobile dunes (EUNIS code: B1.3, shifting coastal dunes - level 3)

These dunes develop from sparsely vegetated embryonic dunes. Sand movement and salt spray are the major environmental factors that limit plant growth on these dunes. This geomorphological unit was separated from embryonic dunes at the second division of the TWINSPAN analysis. White dunes occurred closest to the sea and generally existed along the beach, where sand flooding occurs. The size of the dunes increased with the rate of plant coverage and species number. The average height of these units ranged between 1 and 3 m.

Our results showed that the 2 different zones that were recognized on these dunes had 2 distinct plant

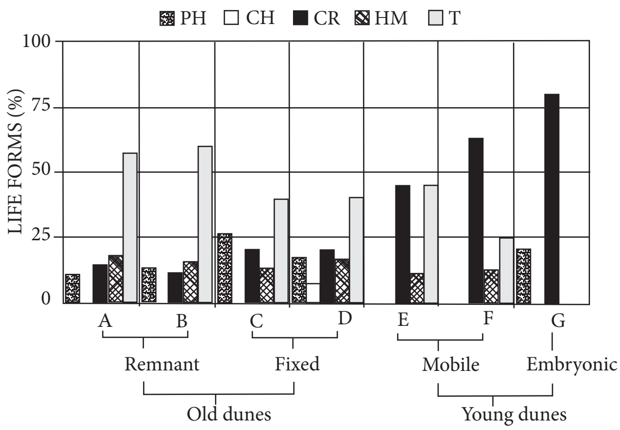

Figure 5. The percentage of plant life forms in TWINSPAN communities (PH: phanerophytes, CH: chamaephytes, CR: cryptophytes, HM: hemicryptophytes, T: therophytes).

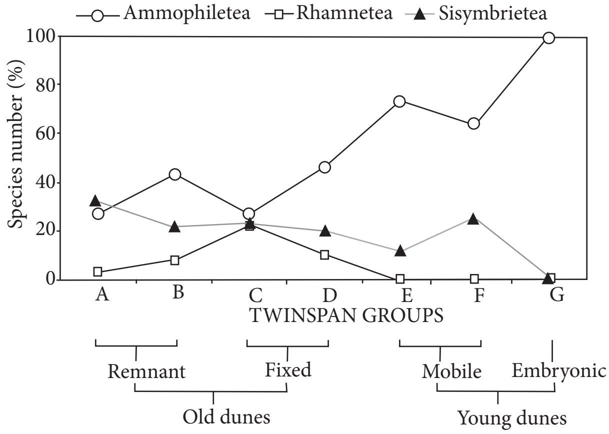

Figure 6. The percentages of characteristic plant species for different phytosociological classes in TWINSPAN communities.

communities in terms of their floristic composition and vegetation structure. These are: *Ipomoea stolonifera* (Cyr.) J.F.Gmel.-*Euphorbia paralias* L. (Group F: B1.31, embryonic shifting dunes - level 4) and *Medicago marina* (L.) Bart.-*Pancratium maritimum* L. (Group E: B1.32, white dunes - level 4) (Figure 4 and Table).

Group F (B1.31) was represented with 11 relevés, mostly located on the south slopes of sand dunes. Environmental conditions here were similar to those seen in embryonic dunes. Plant coverage and species number showed a slight increase in comparison with embryonic dunes (Table). Cryptophytes such as *I. stolonifera* and *Cyperus capitatus* Vand. dominated in this community (Figure 5). A few therophytes, such as *Cakile maritima* Scop. and *Xanthium strumarium* L., also accompany the plant communities along dune succession.

The Group E (B1.32) community was represented in 3 relevés, mostly those occupying the north slopes of the white dunes, with *M. marina* being the dominant species. It had the highest total plant coverage in plant communities of young mobile dunes (Table). This community was codominated by cryptophytes such as *C. capitatus* and *I. stolonifera* (Figure 5). Another cryptophytic species, *P. maritimum* L., also appeared frequently in this community. The most frequent therophytes of this community were *C. maritima* and *Maresia nana* (DC.) Batt. Although the species number of hemicryptophytes was found to be very low, the life form of the dominant species (*M. marina*) in this community is that of a hemicryptophyte. This community showed a floristic structure similar to the previous community, but the rate of *Euphorbio-Ammophiletea* showed a decrease while the species number in the class of *Sisymbrietea officinalis* increased (Figure 6).

Old fixed dunes (EUNIS code: B1.4, coastal stable dune grassland - level 3)

Comprising fixed dunes, this geomorphologic unit was separated from remnant dunes at the second level in the TWINSPAN analysis. The dunes are relatively stable and represent a progressive stage of mobile dunes. These dunes typically occurred inland with plant communities including sparse dwarf scrub and therophytes. The width of these dunes varied between 40 and 130 m, while their height ranged from 5 to 10 m.

This unit, also known as interior dunes, was divided into 2 TWINSPAN community groups: *Echium angustifolium* Mill.-*Cyperus capitatus* (Group D: B1.43, Mediterraneo-Atlantic fixed grey dunes - level 4) and *Vitis sylvestris* C.C.Gmel.-*Verbascum sinuatum* L. (Group C: B1.44, East Mediterranean fixed grey dunes - level 4). Together they comprise fixed grey dunes, formed as a result of the presence and intensity of human intervention and/or natural phenomena. Semimobile dunes in this geomorphologic unit were characterised by the community of Group D (B1.43), which is a transgressive formation between white and grey dunes. Fixed dunes were marked by the community of Group C (B1.44), which is dominated by shrubs peculiar to the class of *Pistacio-Rhamnetea*.

The community of Group D (B1.43) comprised 22 relevés, including mostly herbaceous and sparse dwarf shrubs. It is a plant community that has a high plant coverage and species number (Table). Because of the transgressive character of this community, most of the plants, including the dominant (*E. angustifolium*) and indicator species (*C. capitatus*), are very commonly found along the successional gradient.

Taking the life-form spectra into account, therophytes were regarded as the dominant life form in this community, owing to their highest rate of presence. Hemicryptophytes, cryptophytes, and phanerophytes existed in lower numbers, while chamaephytes were represented in this community only along the successional gradient (Figure 5). An increase in the number of the characteristic species belonging to the class of *Sisymbrietea officinalis* may be associated with the increasing disturbance resulting from agricultural activities. Typical maquis shrubs characteristic of the class *Pistacio-Rhamnetea* disappeared in this zone (Figure 6). On the other hand, the presence of some *Euphorbio-Ammophiletea* members was interpreted as an indication that these dunes were not totally fixed.

The community of Group C (B1.44) was described by 20 relevés located on more stabilised dune ridges that support a high variety of plant species. The dominant species, *V. sylvestris*, forms dense shrub communities with *Pistacia terebinthus* L., *M. communis*, *T. venetum*, *Prasium majus* L., *Rubus sanctus* Scherber., and *Cionura erecta* (L.) Griseb. The total plant coverage was found to be the highest (59.4%), with a high number of plant species (55) in all plant communities described along the successional gradient. Although therophytes seemed to have the highest species number, they had the lowest percentage and coverage when compared with the other plant communities (Table). Phanerophytes that included shrubs showed the highest percentage, while the percentage of cryptophytes such as *Saccharum ravennae* (L.) Murray, *Phragmites australis* (Cav.) Trin. ex Steud., *C. capitatus*, *Cynodon dactylon* (L.) Pers., *Piptatherum miliaceum* (L.) Coss., and *Imperata cylindrica* (L.) Raeusch. was very low. Hemicryptophytes are another frequent life form in this community and were represented by *V. sinuatum*, *E. angustifolium*, *E. paralias*, *Echinops ritro* L., and *P. equisetiforme*. The characteristic species of the class *Pistacio-Rhamnetea* accounted for the highest percentage in this community, but the percentages of *Euphorbio-Ammophiletea* members decreased while that of *Sisymbrietea officinalis* showed a small increase in comparison with embryonic and mobile dunes (Figure 6).

Old remnant dunes (EUNIS code: B1.6, coastal dune scrub - level 3)

Remnant dunes, also known as fossil or ancient dunes, are located furthest away from the coastline along the successional gradient. Still being destroyed by intensive agriculture, these geomorphologic units generally appear as very small patches of old sand dunes in an agriculture-dominated coastal landscape. In the area we studied, the height of these dunes was about 5 to 15 m while their width varied from 5 to 100 m.

This unit reflects the regressive nature of successional stages. It has 2 different plant communities, *Silene kotschyii-Pistacia terebinthus* (Group B: B1.61, coastal dune thickets - level 4) and *Helianthemum stipulatum-Paronychia argentea* (Group A: B1.64, dune sclerophyllous scrubs and thickets - level 4), determined by the level of human disturbance (Figure 4). In some areas, clearing of the vegetation has resulted in dune remobility. Human disturbance on these dunes in the form of sand extraction, grazing, firewood supply, trampling, and agriculture have led to the replacement of phanerophytes of the class *Pistacio-Rhamnetea* with dwarf shrubs and annual nitrophilic plant species of the class *Sisymbrietea officinalis*.

The community of Group B (B1.61) was represented by 15 relevés and mainly found on the south slopes of dunes, where exposure to more sun radiation and wind is characteristic. It had low plant coverage (42.6%) and a relatively lower number of species (37) when compared with old fixed and old remnant sand dune communities (Table). Although the percentage of shrub species decreased, the rate of herbaceous plant species increased. The life form of the dominant species (*S. kotschyii*) in this community is that of a therophyte, which became dominant after the clearing of the shrub layer (*P. terebinthus*). The percentage of therophytes reached a near-maximum percentage, while hemicryptophytes and phanerophytes were found in lower numbers (Figure 5). The percentage of cryptophytes was observed to have the lowest value in this community. The species number of the classes *Pistacio-Rhamnetea* and *Sisymbrietea officinalis* decreased, allowing *Euphorbio-Ammophiletea* members to increase in this community because of the remobilisation of old fixed dunes that resulted from heavy destruction (Figure 6).

Remnant fixed dunes between agricultural fields were largely occupied by the Group B (B1.61) community. It was extensively sampled, with 28 relevés. Although the highest species diversity (57) was observed in this community, an average of 50% of the coverage was essential (Table). Herbaceous and annual species had the highest numbers, despite the presence of shrubs species such as *R. sanctus*, *C. erecta*, *V. sylvestris*, and *Vitex agnus-castus* L. The rate of hemicryptophytes and cryptophytes showed a small decrease in comparison to the previous plant community (Figure 5). The high rate of the species belonging to the class of *Sisymbrietea officinalis* in this community may be attributed to intensive agriculture (Figure 5).

The ordination of plant communities

The detrended correspondence analysis (DECORANA) ordination of the 103 relevés on Axes 1 and 2 appears in Figure 7, which also shows the distribution of the 7 TWINSPAN-based communities with their appropriate EUNIS codes. The main trend of variation, as reflected by DCA-analysis (Axis 1), was related to a gradient of successional stages; the relevés taken from embryonic dunes, which are dominated by herbaceous cryptophytes, appear at one end of the gradient and those relevés representing older remnant dunes are seen at the opposite end, mostly dominated by therophytes and ruderals. Fixed grey dunes were dominated by xerophytic phanerophytes while destroyed semimobile grey dunes were dominated by ruderal therophytes. Axis 1 also represented the gradients of species richness and life forms. However, some patterns emerged, which could be described as follows.

The second trend of variation (Axis 2) seems to be related to human impacts. Relevés dominated by the characteristic species of the class *Sisymbrietea officinalis*, which occur on semimobile dunes destroyed by human activities, appear at the lower end of Axis 2 (Figure 7). Relevés dominated by the

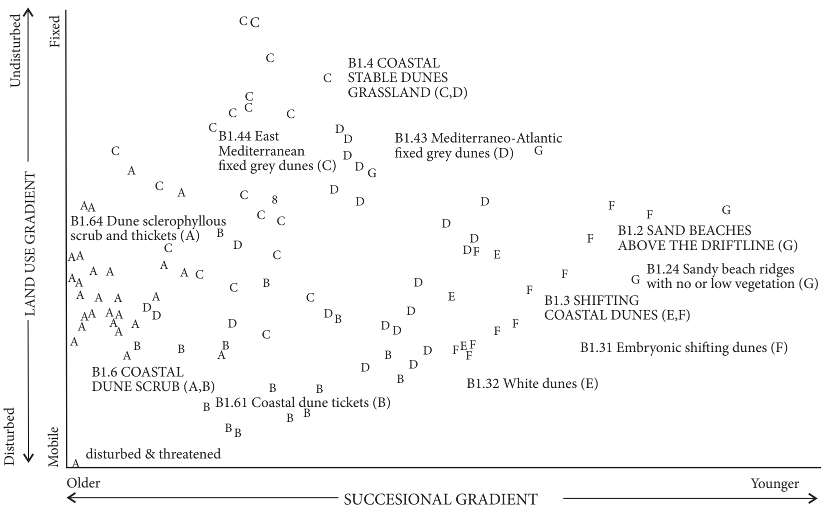

Figure 7. The detrended correspondence analysis (DCA) ordination diagram showing the position of 103 relevés of the dune communities based on 7 TWINSPAN groups and relevant EUNIS codes in relation to the first 2 axes. The letters indicate TWINSPAN groups.

members of *Pistacio-Rhamnetea* and *Euphorbio-Ammophiletea* occupied the upper part of Axis 2. Axis 2 could also be related to the gradient of sand mobility, where relevés belonging to the plant communities of Group B (B1.61) in remnant fixed dunes and Group F (B1.31) in embryonic dunes are located at the lower part of Axis 2. Group D (B1.43) seemed to constitute a transgressive community between old fixed and young mobile sand dunes, and the relevés showed a large distribution between the 2 ends of Axis 2. Plant communities belonging to fixed remnant (Group A: B1.64) and grey dunes (Group C: B1.44) appeared at the upper end of Axis 2.

Discussion

This study showed that the spatial variation of coastal sand dune vegetation was related to the distance from the coast. According to the TWINSPAN analysis of the data matrix, 2 major geomorphological units were singled out as “younger” and “older” according to the age of dunes. Avis and Lubke reported similar findings in 1996, as did Maun in 1998. Communities on older sand dunes occurred as established vegetation in the geomorphologic structures (old remnant and grey dunes) far away from the sea, such as the communities of Group A (B1.64) and Group C (B1.44), while communities of unstable sand dunes occurred after the destruction of old fixed and remnant sand dunes such as Group B (B 1.61) and Group D (B1.43). Finally, Group E (B 1.32), Group F (B1.31), and Group G (B1.24) also tended to occur closer to the sea, where different environmental factors such as wind, sand accumulation, and salt spray were prevalent.

The dominance of therophytes over other life forms was evident in the study area. Therophytes constituted 48.9% of the floristic composition, while hemicryptophytes made up about 16.3%. The dominance of these 2 life forms seemed to be a response to the hot and dry climate and human interference. Our results showed, however, that the plant life-form spectra of species in the sand dune communities showed clear differences according to their distances from the shoreline.

Maun (1998) and Valverde and Pisanty (1990) suggested that hemicryptophytes and, in particular, cryptophytes are more tolerant to extreme environmental conditions than therophytes because of their greater food reserves. Cryptophytes such as *I. stolonifera*, *C. capitatus*, *P. maritimum*, and *S. virginicus* were dominant in the communities on mobile or embryonic sand dunes. Therophytes (annuals) can be seen more commonly in other communities on the stabile sand dunes found in more inland areas (Ranwell, 1972; Cheplick & Demetri, 2000). Increasing numbers of annual species on inland dunes may be caused by the presence and dominance of shrub species, which indicates a favourable habitat for annuals (Tielbörger & Kadmon, 2000).

Distance from the shoreline also influenced the community structure, as distance is strongly correlated with both species richness and diversity. A high number of plant species was a response to the stabilisation of inland dunes. A high frequency of ruderal species belonging to *Sisymbrietea officinalis*, however, was attributed to increasing human use of the area. In terms of the syntaxonomical aspect of the dune vegetation along a disturbance gradient, human impacts resulting from agriculture were associated with decreasing numbers of *Euphorbio-Ammophiletea* J.M. & J. Géhu 1988 and *Pistacio-Rhamnetea* Julve 1993 members, and an increasing number of *Sisymbrietea officinalis* Gutte and Hilbig 1975 species. Remnant and grey dunes included a larger numbers of species than were found in embryonic and white dunes. As can be seen from the analysis of species composition, this was due to the presence of ruderal species that are normally absent in the dune flora.

Conclusion

This study assessed coastal sand dunes in Tuzla (southern Turkey), using vegetation as an indicator for evaluating the successional stages of sand dunes. Once known as very natural and inaccessible, the majority of the sand dunes in Tuzla have been destroyed. Today, these dunes remain as fragmented strips lying parallel to the coastline in an east-west direction and are largely occupied by agriculture. Agricultural patches make up 75% of the total sand dune area in the district. The sand dune environment provides appropriate conditions for rapid growth and early cropping. Therefore, the coastal dune environment in the district is perceived by the local people as space for producing high-value crops such as watermelon. Between 1985 and 2001, the acreage of undercover watermelon production nearly tripled, from 6869 to 20286 ha, while the yield increased from 231 to 655 t. The present study revealed that, despite the unprecedented destruction of dunes as a result of agricultural encroachment, the remaining dune systems in the area are still diverse, representing early, intermediate, and late stages of dune succession. From a resource management point of view, this creates a strong basis for monitoring these systems in order to prevent further destruction.

Coastal sand dunes are susceptible to various direct (e.g. sand extraction) and/or indirect (e.g. cattle grazing) anthropogenic impacts that result in drastic changes in plant species diversity and composition. As demonstrated in this paper, these impacts are primarily responsible for the alteration of the original dune relief and, thus, the changes in the structure and composition of the plant communities on these dunes.

One of the consequences of destroying vegetation is that woody species tend to disappear over time. The dominance of chamaephyte life forms on old remnant dunes (e.g. *H. stipulatum*) may be explained as a response to the clearing of shrub species. Coverage of those species, representing phanerophyte life form and classified in the *Pistacio-Rhamnetea* Julve 1993 class, decreased due to the levelling of the remnant dune strips by the villagers. Species numbers increase as one moves from the coast landward and reaches its highest at the dunes furthest from the coast, bordered on the inland side by extensive agricultural areas. Despite the high species diversity observed in this zone, the majority of the species are noncoastal, meaning that the original structure of vegetation and the species composition of the dunes have been affected by nearby land use.

The plant communities assessed in this study represent a structure that helps describe vegetational development stages, structural complexity, and their response to variations in environmental conditions. These community groups are very well-suited to describing the chronosequence of the dune formations on the coast-inland gradient. Therefore, this unique dune system can be considered an important asset that provides ecological information for the management of coastal dune ecosystems. The information about dune succession may be used as a reference for ecosystem monitoring and assessment of the current and previous states throughout the Mediterranean basin. A wider assessment of dune communities along the Turkish Mediterranean coast according to the EUNIS habitats is suggested in order to reach a comprehensive inventory.

As the most prominent land use in the area, agriculture may create severe damage to these ecosystems and threaten not only plant communities but also the bird species that depend on these habitats. Considering the complex nature of human use and the uniqueness of this ecosystem, critical concerns for the management of this region must include protection of fertile agriculture lands and coastal wetland systems by preventing their misuse.

The information on these trends, such as magnitude and the extent of the land use/cover changes, provides a baseline for more detailed research that may involve a wider range of scientific coverage, from vegetation to hydrology studies. These studies may vary from community-level vegetation studies, as demonstrated in this paper, to detailed surveys for use in detecting beach dynamics. However, finer-scale resource characterisation, as employed in this study, should include not only spatial but also a temporal basis so as to provide up-to-date information on change trends.

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Appendix. A list of plant species, including presence percentage, life-form spectra, and phytosociological class, in different plant communities resulting from TWINSPAN classification.

				Plant communities						
Family	**Species**	**Life[1] forms**	**Class[2]**	**A N = 28**	**B N = 15**	**C N = 20**	**D N = 22**	**E N = 3**	**F N = 11**	**G N = 4**
Amaryllidaceae	*Pancratium maritimum* L.	CR	A		r		1.4	2.6	3.4	
Anacardiaceae	*Pistacia terebinthus* L.	PH	P		1.2	r	+			
Apocynaceae	*Nerium oleander* L	PH	P			1.2	r			
	Trachomitum venetum (L.) Woodson	PH	A			r				1.5
Asclepiadaceae	*Cionura erecta* (L.) Griseb.	PH	A	r		1.2	r			
Boraginaceae	*Anchusa aggregatta* Lehm.	TR	-	+	1.2	r	+			
	Echium angustifolium Mill.	HM	A	2.5	2.6	2.1	29.0	1.6		
	Heliotropeum europeum L.	TR	S	r						
Brassicaceae	*Alyssum alyssoides* (L.) L.	TR	S	r	+	+				
	Brassica tournefortii Gouan	TR	S	r	1.5	1.2				
	Cakila maritima Scop.	TR	-					1.1	1.4	
	Maresia nana (DC.) Batt.	TR	A	r	1.9	r		r		
Caprifoliacaea	*Lonicera etrusca* Santi	PH	P			1.1				
Caryophyllaceae	*Minuartia mesogitana* (Boiss.) Hand.-Mazz.	TR	-	r						
	Silene kotschyii Boiss.	TR	S	r	15.2	r	+			
	Silene pompeipolitana Gay ex Boiss.	TR	A	+						
	Spergularia marina (L.) Griseb.	TR	-	+						
Chenopodiaceae	*Salsola kali* L.	HM	-	r						
Cistaceae	*Helianthemum stipulatum* (Forssk.) C.Chr.	PH	A	22.8	5.7	r				
	Fumana thymifolia (L.) Verl.	TR	-	r						
Compositae	*Tragopogon longirostris* Bisch. ex Schultz	CR	-			+				
	Ambrossia maritima L.	HM	-	+						
	Artemisia scoparia Waldst. & Kit.	HM	-		+					
	Aster squamatus (Spreng.) Hieron.	HM	-			+				
	Chondrilla juncea L.	HM	-	+	r	+	r			
	Echinops ritro L.	HM	-	+		r	r			
	Echinops dumanii C.Vural	HM	A		r				+	r
	Crepis feotida L.	TR	A	1.8	1.1	r	r	r		
	Hedypnois cretica (L.) Dum.Cours.	TR	-	+						
	Senecio vernalis Waldst. & Kit.	TR	S	r	r	+	+	r		
	Xanthium strumarium L.	TR	S			+	+		+	
Convolvulaceae	*Ipomea stolonifera* (Cirillo) J.F.Gmel.	CR	A					1.3	20.5	r
Cuscutaceae	*Cuscuta planiflora* Ten.	TR	A	r	+					
Cyperaceae	*Cyperus capitatus* Vand.	CR	A	r	3.5	r	3.6	2.6	5.0	
Euphorbiaceae	*Euphorbia paralias* L.	HM	A	r	r	1.6	1.0		2.0	
	Euphorbia terracina L.	HM	-				r			
Geraniaceae	*Erodium laciniatum* (Cav.) Willd.	TR	-	1.2	+	r	+			
Gramineae	*Cynadon dactylon* (L.) Pers.	CR	-	+		r	+			
	Imperata cylindrica (L.) Raeusch.	CR	-			r				
	Panicum repens L.	CR	S	r						
	Phragmites australis (Cav.) Trin. ex Steud.	CR	-	r		r				
	Piptatherum miliaceum (L.) Coss.	CR	P			r				
	Saccharum ravennae (L.) Murray	CR	A			1.5	r			
	Sporobolus virginicus (L.) Kunth	CR	A						+	22.5
	Stipagostris plumusa (L.)	CR	-	+						
	Tragus racemosus (L.) All.	HM	S	+						
	Aegilops speltoides Tausch	TR	S	r		r				
	Avena wiestii Steud.	TR	S		+	r				
	Bromus rigidus Roth	TR	A	1.8	+	1.6				
	Bromus psammophilus P.M.Sm*	TR	A				r			
	Bromus tectorum L.	TR	S	r	r	r	r			
	Catapodium rigidum (L.) C.E.Hubb. ex Dony	TR	-	r		r				
	Cutandia memphitica (Spreng.) K.Richt.	TR	A	1.5	r	r	1.8			
	Hordeum murinum L.	TR	S	+						
	Lolium multiflorum Lam.	TR	S	+						
	Parapholis filiformis (Roth) C.E.Hubb.	TR	-	r						
	Phuleum subulatum (Savi) Asch. & Graebn.	TR	S	1.5		r				
	Rostraria cristata (L.) Tzvelev	TR	S	r						
	Triseteria leoflingiana (L.) Paunero	TR	S	r		r				
	Vulpia fasciculata (Forsskal) Fritsch	TR	S	r	+	r	r			
Illecebraceae	*Paronychia argentea* Lam.	HM	-	1.1						

Appendix. (Continued).

				Plant communities						
Family	**Species**	**Life[1] forms**	**Class[2]**	**A N = 28**	**B N = 15**	**C N = 20**	**D N = 22**	**E N = 3**	**F N = 11**	**G N = 4**
Labiatae	*Prasium majus* L.	PH	P			r				
	Teucrium polium L.	HM	-	+						
	Salvia viridis L.	TR	A	r	r					
Leguminosae	*Alhagi mannifera* Desv.	CH	A				r			
	Prosopis farcta (Banks & Sol.) J.F.Macbr,	CH	A				+			
	Medicago marina L.	CR	A		+		1.4	25		
	Lotus corniculatus L.	TR	-		r					
	Medicago littoralis Rohde ex Loisel.	TR	-	r						
	Medicago minima (L.) Bart.	TR	A	1.6	r	r				
	Ononis serrata Forssk.	TR	A		+	+				
	Trigonella cephalotes Boiss. & Balansa	TR	-		r					
	Trigonella halophila Boiss.	TR	-		1.2		+			
	Vicia peregrina L.	TR	S			r				
	Vicia sativa L.	TR	S			+				
Liliaceae	*Allium scorodoprasum* L.	CR	S	r						
	Asparagus officinalis L.	CR	P			1.1				
	Asparagus palaestinus Baker	CR	P			+				
	Asphedelus aestivus Brot.	CR	-	r						
Myrtaceae	*Myrtus communis* L.	PH	P		1.2	4.6	1.0			
Plantaginaceae	*Plantago scabra* Moench	TR	S	r						
Polygonaceae	*Polygonum equisetiforme* Sibth. & Sm.	HM	A	r	+	1.5	1.7			1.0
Primulaceae	*Anagallis arvensis* L.	TR	S				+			
Ranunculaceae	*Clematis flammula* L.	PH	P		+	+				
Rosaceae	*Rosa arvensis* Huds.	PH	-			+				
	Rubus sanctus Schreb.	PH	-	+	+	+				
Rubiaceae	*Rubia tenuifolia* d'Urv.	HM	P			+				
Santalacaea	*Osyris alba* L.	PH	P			+				
Scrophulariaceae	*Verbascum sinuatum* L.	HM	-	r	r	+				
Thymaleceae	*Thymelaea hirsuta* (L.) Endl.	PH	A			r				
Ulmaceae	*Ulmus minor* Mill.	PH	-	r		+				
Umbelliferae	*Eryngium maritimum* L.	CR	S						1.0	
	Daucus carrota L.	TR	S		r					
	Daucus guttatus Sm.	TR	S	+						
Verbanaceae	*Vitex agnus castus* L	PH	A	1.5		+	+			
Vitaceae	*Vitis sylvestris* C.C.Gmel.	PH	P	3	1.1	34				
	Total covarage			**50**	**43**	**59**	**46**	**36**	**31**	**25**

[1] Life forms: PH, phanerophytes; CH, chamaephytes; HM, hemicryptophytes; CR, cryptophytes; TR, therophytes.

[2] Phytosociological classes: A, *Euphorbio-Ammophiletea*; P, *Pistacio-Rhamnetea*; S, *Sisymbrietea officinalis*.

r: rare species (coverage less than 1%), +: very rare species (represented as an individual).