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Trampling impact on vegetation of embryonic and stabilised sand dunes in Montenegro

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Abstract Trampling is one of the human activities that are harmful for plant species and communities of sand dune ecosystems. The aim of this study was to compare the vegetation of embryonic and shifting *Ammophila* sand dunes with and without fencing to limit trampling. Fenced sand dunes appeared to be richer in species but differences were more prominent in embryonic sand dunes. Some species (*Cakile maritima, Pancratium maritimum*) were missing on trampled embryonic dunes. The positive impact of trampling exclusion on embryonic sand dunes was indicated by a lowered slope in a Whittaker graph as well as by rarefaction curves that showed higher species richness on the lower slope. Changes in the vegetation of more stabilised shifting *Ammophila* sand dunes due to trampling are not evident, although species composition is also impoverished. Fencing of parts of sand dunes proved to be an effective measure for vegetation conservation. In addition to physical exclusion of visitors, fences can also have symbolic value for raising public awareness.

Keywords Habitats directive · Conservation · Fencing · Trampling

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Introduction

Sandy beaches are unique as the world's single largest dynamic type of open shoreline and are found at the boundary between land and sea (McLachlan and Brown 2006). Although they seem to be abiotic deserts, they provide habitats for specific biota, determined by three interacting factors: waves, tides and sand particle size (McLachlan 2001). A specific vegetation occurs in this naturally highly dynamic environment, which has developed to be highly resistant to natural disturbances but is very sensitive to anthropogenic ones (Andersen 1995; Ciccarelli 2014; Garcia-Mora et al. 1999). Defeo et al. (2009) summarised the various human stressors to which dune biota is exposed: recreational seashore activities (incl. mechanical impact caused by trampling, camping etc.), beach cleaning, nourishment, pollution, exploitation, biological invasion, coastal development and engineering, mining and climate change.

Trampling by beach visitors is commonly considered to be the most harmful mechanical stressor, identified as being more harmful for plant development than natural stress (Santoro et al. 2012). Mechanical stress on plants causes mobilization of assimilates into storage organs and increases the belowground biomass, which affects the survival of the plants and their reproduction, as well as germination and establishment (Liddle 1975; Puijalon et al. 2008). However, different species have different sensitivity to trampling and physical damage (Seer et al. 2015). Trampling does not affect vegetation (and fauna) only directly but also indirectly through soil compaction, which leads to differences in its properties (Brown and McLachlan 2002). Constant trampling pressure was estimated to be destructive for plant populations even among beach plants adapted to rough site conditions, so the final outcome is a reduction of biodiversity, population size and distribution (Andersen 1995; Scott 1976).

The aim of our study was to focus on diversity changes in dune vegetation with limited trampling. We compared (i) species richness and (ii) species change in plant communities between two habitats of sand dune systems (embryonic and *Ammophila* stabilised dune) in fenced and unfenced parts. Knowledge of the resistance of sand dune communities to trampling and their ability to regenerate plays a key role in landscape planning and conservation (Andersen 1995).

Material & methods

Study area

With a length of 12 km, Velika plaža in Ulcinj (Montenegro) is considered the longest beach on the Adriatic coast. It is located at the south-eastern end of Montenegro and is bordered by the channel of Port Milena to the west and the Bojana River to the east, covering an area of 1270 ha. The average width of the beach and its hinterland is 1.5 km and it is bordered to the north by a regional road. The area is frequently exposed to very strong winds, which carry sand from the shore to the inland and which consequently covers a major part of the area (Mijović 1994). According to the Köppen-Geiger system, the climate of Ulcinj is classified as Csa type – a Mediterranean climate with hot summers. The mean annual temperature is 15.5°C, while mean precipitation is 1258 mm. The warmest months are July and August (24.3°C) and the coldest January and February (6.8°C) (Burić et al. 2014). The psammophytic vegetation of Velika plaža forms two belts. The one closer to the sea is represented by 4 xerohalophytic plant communities: *Cakilo-Xanthietum italici* (Beg. 1941) Pignatti 1958, *Euphorbio paraliae-Agropyretum junceiformis* Tüxen in Br.-Bl. & Tüxen 1952 corr. Darimont, Duvigneaud & Lambinon 1962, *Eryngio-Sporoboletum virginici* Gehu & Uslu 1989, *Medicagini marinae-Ammophiletum australis* Br.-Bl. 1921 corr. F. Prieto & T.E. Díaz 1991, one replacing the other along the salinity and moisture gradient towards the inland (Mijović 1994; Mijović et al. 2006; Šilc et al. 2016b). The second belt, which is not directly influenced by seawater, comprises xeropsammophytic communities of Mediterranean pastures and dry meadows (Mijović 1994).

Eleven NATURA 2000 habitats are reported for the beach and its hinterland: Annual vegetation of drift lines (1210), Embryonic shifting dunes (2110), Shifting dunes along the shoreline with *Ammophila arenaria* (white dunes, 2120), Fixed coastal dunes with herbaceous vegetation (grey dunes, 2130*), Humid dune slacks (2190), Dunes with *Euphorbia terracina* (2220), Mediterranean salt meadows (*Juncetalia maritimae*) (1410), *Brachypodietalia* dune grasslands with annuals (2240), Wooded dunes with *Pinus pinea* and/or *Pinus pinaster* (2270), Mediterranean temporary ponds (3170), and *Salix alba* and *Populus alba* galleries (92A0) (Petrović et al. 2012). Presence of habitat type 2130* that has Atlantic distribution (Houston 2008) is questionable.

The most representative 500 ha of psammophytic vegetation has been recognized as a monument of nature and is therefore protected from trampling and grazing by cattle with a wooden fence, which was installed in 2014. The rest of Ulcinj beach (Velika plaža) is under the major impact of tourism, illegal dumping, sand exploitation and urbanization (Petrović and Karaman 2009; Šilc et al. 2016a).

Vegetation sampling

Since vegetation was not sampled prior to fence installation, we used a synchronic (space-for-time) approach, which enables the best surrogate for studying vegetation succession/changes when permanent plots are not available (Glenn-Lewin and van der Maarel 1992; Walker et al. 2010).

At the beginning of May 2016, we sampled vegetation within fences, where trampling was limited. Fenced sand dunes belong to two habitat types: Embryonic shifting dunes (2110) and Shifting dunes along the shoreline with *Ammophila arenaria* (white dunes 2120). In each of the habitat types (further referred in text as embryonic dunes and shifting *Ammophila* dunes), we selected a number of plots, sized 2 × 2 m, on which we recorded all vascular plant species and visually determined their cover (specific and in total), using the Braun-Blanquet scale. Plots were selected approx. every 30 m to represent microhabitat diversity. For the non-fenced part of the dune system, we used plots of the same size, sampled for sand dune monitoring in May 2015. Plots were laid every 500 m within both habitat types in the most impacted zone of the beach. The same plot size and sampling method were used as with the fenced part of the beach and the same researchers were present. Number of plots sampled is presented in Table 1.

Data analysis

Basic analysis of vegetation data was done in the Juice program (Tichý and Chytrý 2006): calculation of frequency and average plant species cover values. Differences in species richness between different parts of the sand dune system were tested with nonparametric tests (Mann-Whitney) in Statistica 10.0 (StatSoft 2011). Similarity Percentages analysis (SIMPER) (Clarke 1993) was used to identify the taxa mostly contributing to differences between fenced and non-fenced sites. Analysis was performed in the PAST program (Hammer et al. 2001).

Rarefaction curves were used for estimating standardized species diversity (Gotelli and Colwell 2001); they had already been used in a similar study on sand dune vegetation (Santoro et al. 2012). We compared species richness between two sand dune habitats in fenced and non-fenced parts. We calculated

Table 1 Frequency (in percentage) and rank (based on average cover; in superscript) of plant species in each sand dune habitat (for fenced and unfenced parts)

	Embryonic dunes				Shifting *Ammophila* dunes			
	Unfenced		Fenced		Unfenced		Fenced	
Nr. of plots	13		20		13		22	
Alkanna tinctoria			5	8	8	10	55	5
Ammophila arenaria					8	1	14	1
Amorpha fruticosa					8	3		
Anagallis arvensis							9	15
Arenaria serpyllifolia agg.							45	5
Arundo donax			5	8				
Cakile maritima			30	8				
Catapodium rigidum					8	23		
Crepis foetida			10	8	38	3	45	15
Cutandia maritima					15	23		
Cynodon dactylon	8	6			15	10		
Cyperus capitatus	31	1	100	2	54	3	100	8
Dittrichia viscosa							18	15
Echinophora spinosa	31	3	90	5	69	10	77	15
Elymus farctus	23	2	25	8	31	3		
Eryngium maritimum			50	8	31	10	41	15
Euphorbia paralias	8	6			8	10		
Euphorbia peplis	8	3	15	8	23	23		
Euphorbia terracina							9	3
Holoschoenus romanus					8	3		
Hypochaeris radicata							9	7
Inula crithmoides			5	8				
Lagurus ovatus					8	3	9	14
Linum strictum			5	8			68	8
Lophochloa cristata					8	10		
Medicago littoralis			5	2	54	10	100	8
Medicago marina			10	5	8	23	64	1
Oenothera spp.			5	8	15	1	55	15
Onobrychis caput-galli					15	10	14	8
Pancratium maritimum			20	8	23	3	86	15
Polygonum maritimum			20	8	8	10	5	15
Pseudorlaya pumila	8	6	10	5	31	10	100	8
Salsola kali	8	6	20	8	15	10		
Senecio vulgaris							14	15
Silene conica							23	15
Valerianella sp.							5	8
Vulpia fasciculata			5	1	31	10	100	4
Xanthium italicum	62	3	80	2	77	10		

sample-size based rarefaction and extrapolation (Colwell et al. 2012) using iNext online software (Hsieh et al. 2013).

For determination of species changes in plant communities under different disturbance regimes, we used a diversity/dominance (Whittaker) diagram (Magurran 1988; Whittaker 1970). When a community is under shifting disturbance intensity, the shape and slope of the diagram can show differences in species composition due to various kinds of stress.

The diversity/dominance diagram was made as a rank/abundance diagram. For each part of the sand dune system researched, we calculated the average cover for each species, calculated their relative cover to the total cover of species in all sampled plots and then ranked them according to the results. The relative frequency of each species was log transformed. We then plotted each species rank (from the most to the least abundant) on the X-axis and the frequency of particular species on the Y-axis.

Results

Altogether, 41 plant species were found on the researched sand dunes. On embryonic sand dunes, species richness was lower on trampled plots than on fenced ones (5.15 vs. 1.85, Z = 4.13, $p < 0.01$) and the same was found for shifting *Ammophila* dunes (10.64 vs. 6.15, Z = 4.13, $p < 0.01$).

We performed SIMPER analysis to detect species that contribute to dissimilarities between fenced and unfenced sites. Similar differences between sites were found on embryonic (80.09%) and shifting *Ammophila* dunes (84.36%). *Cyperus capitatus* (38.24%) and *Xanthium italicum* (18.97%) have a higher contribution on embryonic dunes. Several characteristic species of sand dunes are missing (Table 1) on unfenced embryonic sand dunes (*Cakile maritima, Pancratium maritimum, Eryngium maritimum*) or their frequency is reduced (*Salsola kali, Cyperus capitatus*). Several characteristic species are also less frequent on unfenced shifting *Ammophila* dunes: *Medicago littoralis, Pancratium maritimum, Vulpia fasciculata,* and *Cyperus capitatus*. *Vulpia fasciculata* (17.03%) and *Medicago marina* (15.74%) make a higher contribution to dissimilarity on stable dunes.

The pattern of increased species richness is also shown by the rarefaction curves (Fig. 1). The rarefaction curves between the two habitats are different, since shifting *Ammophila* dunes are more species rich. There are also evident differences between the rarefaction curves of fenced and unfenced embryonic dunes, with lower species richness in the unfenced part. There are no significant differences in species richness and rarefaction curves of shifting *Ammophila* dunes.

Embryonic sand dunes are characterized by the presence of a few dominant species. There were more species present in the fenced part of the sand dune system, the dominant species were more frequent and the slope of the regression line was lower (Table 1, Fig. 2). Shifting *Ammophila* dunes include more species and there are almost no differences between fenced and unfenced parts. Slope and intercept values are very similar (Table 2).

Discussion

According to our study, there are evident differences in the vegetation of embryonic and shifting *Ammophila* dunes due to trampling impact. Embryonic dunes show low resistance, while more fixed dunes are less impacted. Human impact on sand dunes by trampling has been shown in many studies (Fenu et al. 2013). The impact of trampling is not always negative, since it can be used as a management tool at moderate intensities (Andersen 1995; van der Maarel 1971); however, it is generally considered problematic for conservation and management of biodiversity.

There is a great difference in the trampling impact on different plant communities. They vary in their resistance and resilience to trampling. Meta-analysis of literature related to trampling of vegetation has revealed that the initial resistance of a plant community and the length of recovery period are better predictors of resilience than the intensity of trampling (Pescott and Stewart 2014). Depending on plant traits, different plant species become affected to different degrees following certain impacts, such as trampling (Seer et al. 2015). Vegetation analyses in trampled foredunes and dunes have shown a decrease in vegetation cover and an increase in annuals and trampling-tolerant ruderal and grassy species (Andersen 1995; Garcia-Mora et al. 1999; Labuz and Grunewald 2007). In our case species tolerant to trampling (*Cynodon dactylon*, *Arenaria serpyllifiolia* agg.) and also alien species (*Amorpha fruticosa*) are found in the unfenced part of the beach indicating changes in species composition because of trampling effect. Invasion of alien species and trampling are characteristic for coasts influenced by the coastal suburbanization phenomenon (Carboni et al. 2009).

Although we did not perform a BACI (Before–After Control-Impact) experiment, the results of our study indicate changes of sand dune vegetation after limitation of trampling. A special feature of our study is that we analysed the impact of trampling within two different habitats: Embryonic shifting dunes (2110) and Shifting dunes along the shoreline with *Ammophila arenaria* (2120). There is a rich body of literature on the trampling of sand dune vegetation but mainly from Atlantic coasts, while from Mediterranean areas there have been only a few studies and they concentrate more on embryonic dunes (Kutiel et al. 2000; Santoro et al. 2012).

The two habitats differ in their response to trampling. Species diversity is reduced on embryonic dunes because of trampling, while it remains similar on more stable shifting *Ammophila* dunes. It is important to emphasize difference of substrate between both habitats and consequently the impact of trampling. Higher impact is visible in the not stabilised sandy substrate. Damage to vegetation in water saturated, soft substrates is more likely (Eckrich 2000). One reason is that vegetation of fixed dunes is more resistant to trampling damage (Andersen 1995; Lemauviel and Rosé 2003; Rickard et al. 1994), another is that these dunes are more distant from the sea and less trampled even in an unfenced part of the beach. Vegetation of more fixed shifting *Ammophila* dunes is more abundant and consists of many plant species with spiny fruits

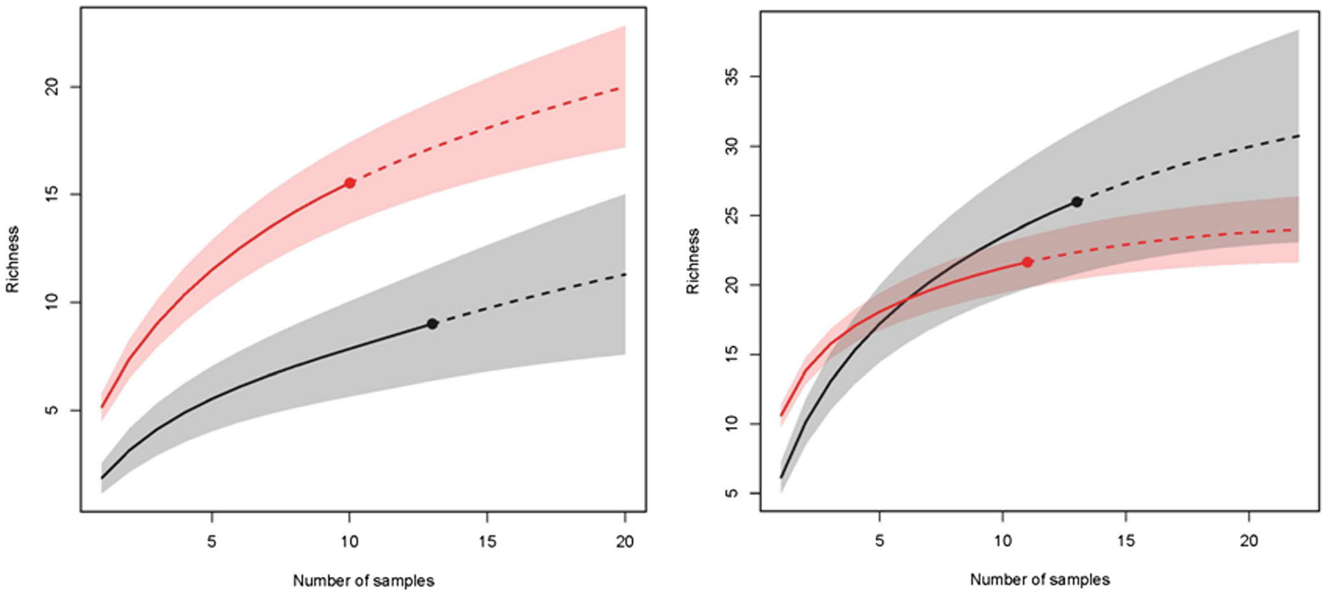

Fig. 1 Rarefaction curves of both dune habitats - on the left the embryonic dunes vegetation, on the right the shifting *Ammophila* dunes (fenced - red and unfenced - grey)

(*Onobrychis caput-galli, Medicago* spp., *Pseudorlaya pumila*). Although plants on embryonic dunes are also spiny (*Echinophora spinosa*, *Eryngium maritimum*) similar plants on shifting dunes have higher cover. We believe that visitors tend to avoid them and trampling is also more concentrated on existing paths.

The speed of recovery of vegetation varies between plant communities. Both Davenport and Davenport (2006) and Hylgaard and Liddle (1981) report slow recovery, while it can be very fast in other cases, since one to two years of trampling limitation enables recovery of the diversity and structure of dune plant communities (Santoro et al. 2012). We did not especially focus on the recovery of sand dune vegetation but our results suggest that embryonic dune vegetation recovered very fast, since the fences were only installed two years ago. Fast recovery of pioneer herbaceous vegetation is related to adaptation of this vegetation type in the Mediterranean to the natural disturbances to which it is usually exposed (Kutiel et al. 2000). It is important to emphasize that recovery of total cover of vegetation is less important than enriched species composition and the presence of particular rare species when recovery is considered (Kerbiriou et al.

Fig. 2 Diversity-dominance (Whittaker) diagram of fenced and unfenced sand dune habitats. Legend: S - shifting *Ammophila* dunes, E - embryonic dunes, n - unfenced, f - fenced. Dashed line - embryonic dunes, solid line - shifting *Ammophila* dunes

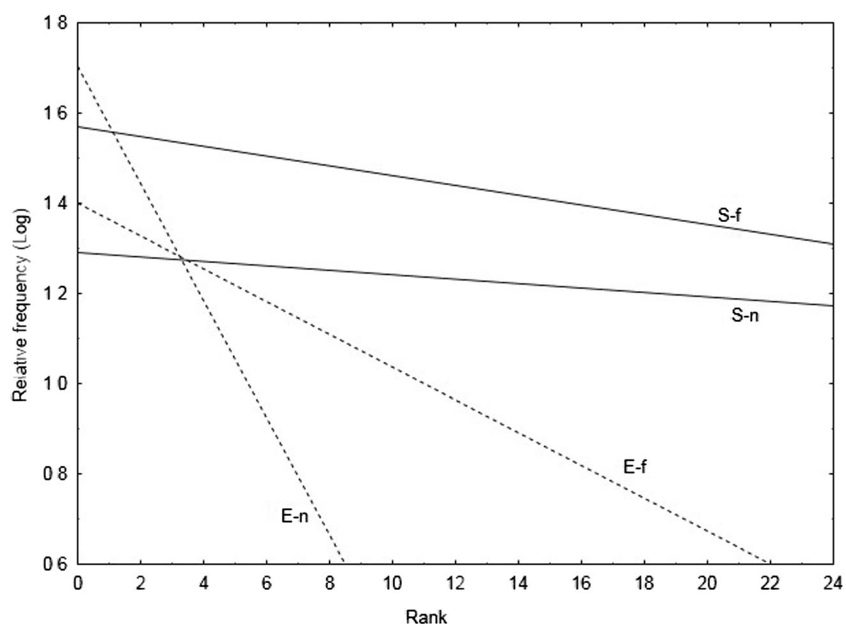

Table 2 Slope and Y-intercept for regressions in the two dune habitats (fenced and unfenced parts)

	Slope	Intercept	R^2	R
Embryonic dunes-fenced	-0.0363	1.3989	0.0420	-0.2050
Embryonic dunes-unfenced	-0.1300	1.7035	0.5488	-0.7408
Shifting *Ammophila* dunes-fenced	-0.0109	1.5715	0.0152	-0.1234
Shifting *Ammophila* dunes-unfenced	-0.0049	1.2907	0.0098	-0.0990

2008). Thus, an area closer to the sea harbouring only few unique and endangered species could be considered of great importance (Acosta et al. 2009).

Most trampling studies have been made on fairly narrow paths (experimental or already established) (for example Brunbjerg et al. (2015)), while our study takes into account a larger area, similar to that of Santoro et al. (2012). This is a better approximation of the real situation on a sand dune system under recreational impact. Vegetation along paths with frequent trampling is much damaged, especially less resilient plant communities, but random trampling (even less intensive) in the wider area of a beach is less preferred even if it is less harmful. A management plan with a controlled flow of tourists is therefore very important.

Our results are important for the consideration of conservation and management measures of sand dunes. The study confirms the importance of fence installation for the prevention of trampling of sand dune vegetation, particularly in highly visited areas, as has already been pointed out by other researchers (Grafals-Soto and Nordstrom 2009; Santoro et al. 2012). Fences are effective in directing visitors and the zonation of recreation into high and low intensity usage is a better conservation strategy than less intensive but widespread trampling (Pescott and Stewart 2014). Another important use of fences is restoration of sand dune vegetation by limiting access that leads to improvement of species cover and richness as well as spatial organisation of plant communities (Acosta et al. 2013).

Fences are a low cost measure for the control of human and animal access on sand dune systems and effectively prevent trampling damage to vegetation. In addition to physical prevention, there is also psychological momentum, indicating vulnerable habitats worth protecting. In such cases, they can be described as symbolic fences. A positive side effect of these fences alone is raising awareness and it becomes even greater with the erection of information boards. In our case specifically, more rigid fences were built in order also to prevent cattle grazing (not only trampling by tourists) but at the same time to allow aeolian transport of the sand (Nordstrom et al. 2000).

The study area was already legally protected in 1968 as a natural object (Sl. list SRCG, 30/68) and in 2007 as a natural monument (Sl. list CG, 30/07). The installation of fences in 2014 marked additional conservation efforts. Three habitat types were fenced: embryonic and shifting *Ammophila* dunes and dune wetlands. Although the first habitat is most impacted by trampling and the latter two are less accessed by tourists due to remoteness from the sea and unattractiveness, it is also important to protect them. Because Montenegro has still not established a NATURA 2000 network and the development of the country is directed towards tourism, conflict between nature conservationists and landscape planners is expected.

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