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The effect on coastal vegetation of trampling on a parabolic dune

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ABSTRACT

This paper examines the effect of trampling activity and intensity on the vegetation growing up the central axis of a tropical coastal parabolic dune at La Mancha, Veracruz State, Mexico. A trampling path was established across the dune with slopes varying from 1° to 34°, and the vegetation cover and richness was sampled after 0, 10, 30, 50, 70 and 100 tramplings. There was a significant decline in relative cover over time as the trampling intensity increased, and rare species disappeared after only 10 tramplings. As the slope increased the rate of decline of relative cover of the dominant species also increased. Within the steeper slope segments of the path (21–25, >25, crest, and relic slipface down-slope segments) between 40% and 80% of the number of species disappear from the survey transect by 100 cumulative tramplings, whereas, only 13–30% of the number of species disappeared from the survey transect within the low/moderate slope segments by 100 cumulative tramplings. Within the 21–25° slope segment, a staircase morphology was gradually created, while at higher slopes, shearing occurred and linear debris slopes were formed. There was a greater decrease in richness values on steep slopes compared to low/moderate slope angles, independent of trampling intensity. Apart from the 21–25° slope, the creation of bare surface area does not appear to be related to slope angle as trampling increases.

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1. Introduction

Increased tourism in recent years has had severe effects on coastal ecosystems contributing to their destruction and reduction of natural and recreational values (Crawford and Liddle, 1977; Anderson, 1994; Lemauviel and Rozé, 2003; Marion and reid, 2007). The attractive ecological diversity and the distinctive land–water interface of the coastal zone make beaches and their adjacent dune landscapes popular areas for tourism and recreation (Williams et al., 1997). Excessive visitor pressure, however, can physically damage dunes leading to the degradation of this diversity (Anderson, 1994; Carter, 1988). Lemauviel and Rozé (2003) argue that human trampling represents the major ecological disturbance of dune ecosystems; and the subsequent monitoring of the resultant ecological change is of noteworthy value as the effects of human trampling are poorly understood and little measured (Liddle, 1975a; Slatter, 1975; Williams et al., 1997; Kutiel et al., 2000; Kerbiriou et al., 2008). In a comparison of the effects of trampling in different environments, Andersen (1995) stated that natural dunes were the most vulnerable to human trampling (cf. Burden and Randerson, 1972).

Several researchers have studied the relationships between trampling by humans and changes in vegetation and other characteristics (Bayfield, 1973; Slatter, 1975; Crawford and Liddle, 1977; Hylgaard, 1980; Hylgaard and Liddle, 1981; McDonnell, 1981; Sun and Liddle, 1993; Anderson, 1994; Williams et al., 1997; Lemauviel and Rozé, 2003). In general, as trampling intensity increases, species diversity decreases (e.g. McAtee and Drawe, 1980; Ikeda, 2003), plant cover, biomass, height, and top and root weights is reduced (e.g. Liddle, 1975b, 1991; Liddle and Grieg-Smith, 1975; McAtee and Drawe, 1980), shoot production is reduced (Bowles and Maun, 1982), the proportion of different species changes (e.g. Westoff, 1971), successional trends are altered (McAtee and Drawe, 1980), some effects are long lasting (Leney, 1974) and species may be eliminated (e.g. Schofield, 1967), evaporation and soil bulk density is higher (Liddle and Grieg-Smith, 1975; McAtee and Drawe, 1981), soil surface stability and threshold friction velocities are lower (Belnap et al., 2007), and the fauna is affected (e.g. Baccus, 1977; Liddle, 1991).

The majority of these studies, however, relate vegetation disturbance strictly to the intensity of human trampling (i.e., the number of trampling passes). Although vegetation disturbance depends a great deal on the intensity of trampling, Bayfield (1973) and Hylgaard and Liddle (1981) suggest that the effects of trampling are also dependent upon the topography of the path. Williams et al. (1997) indicates that the mechanical forces applied to the

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ground surface via trampling has two components; vertical/compression forces, which tend to crush vegetation, and dynamic/shear forces, which tends to rip vegetation away from the soil substrate. Liddle (1975a) estimated that vertical forces applied to the ground surface by a standing person are approximately 20 kg/m^{-1} whereas dynamic/shear forces may exceed 5700 kg/m^{-1}. Therefore, an understanding of the dynamics that these forces have on vegetation, particularly dynamic/shear forces, is of noteworthy importance as vegetation disturbance is not only dependent upon the number of tramplings across a path but also the topographic variability and slope of that path.

Literature exploring the relationship between path slope and vegetation disturbance due to trampling is quite limited, and although some research indicates that dune elevation is an important factor (e.g. McAtee and Drawe, 1980), the actual data is restricted. The objective of the present study is to determine the effect of trampling activity on vegetation disturbance in relation to path slope and trampling intensity.

2. Study site

Field investigations were conducted within the southern downwind portion of the El Farallon–La Mancha dunefield. This portion of the dunefield is a fully vegetated relic headland bypass coastal transgressive dunefield system at La Mancha, Veracruz, Mexico. The La Mancha dunefield is centered around 19°N. The climate is tropical humid with a 1200 mm rainfall, the majority of which falls in the summer months (June–September) (Moreno-Casasola, 1988, 1997; Martínez et al., 2001). The mean annual temperature is 24 °C, and the mean annual humidity is greater than 75% (Perez-Villegas, 1989). Hurricanes only occasionally impact the coastline directly, but the margins of hurricanes frequently affect the coast. Winter storms are common from October to February and can reach speeds of 80–100 km h^{-1}. The dominant wind direction is from the north, but moderate to strong easterly and southerly winds occur at times (Hesp and Martinez, 2008). In the 1970s the study area was dominated by completely mobile and active transverse dunes, but by the 1980s was stabilizing naturally. The vegetation in the portion of the dunefield where the study was carried out is characterized by a second stage grassland succession dominated by *Schizachyrium scoparius*.

3. Field methods

The procedure used in this study involved analyzing vegetation disturbance along a single, continuous 37 m long by 0.5 m wide transect down the central axis of a small parabolic with slope angles ranging from 0° to 33° up- and down-slope (Fig. 1). We could not use all the preferred methods described by Cole and Bayfield (1993), that is, multiple paths and replications, because we wished to minimize the impact of our study in this protected reserve. The vegetation survey line started in the middle of the deflation basin and extended up and over the depositional lobe. The plant species were identified, and the presence/absence of the vegetation species, and their percent cover were estimated in each 0.5 m × 1.0 m quadrat along the 37 m long line. The quadrats were divided into quarter sections, each section representing 25% cover. These data provide the number of species, the total percent cover of the vegetation, and of each plant species. A control was recorded immediately prior to trampling in order to determine the initial state of vegetation cover. Ten adults of varying weight, walked up the stoss slope of the dune, over the crest and down the former slipface, in single file. Following Cole and Bayfield (1993) they walked at a natural gait, varied where they walked within the 0.5 m wide "lane", and turned off the line or lane at a prescribed point past where measurements ended. Vegetation measurements of each quadrat were taken following trampling intensities of 10, 30, 50, 70, and 100 cumulative individual passages. These measurements were always made by rotating groups of five individuals standing outside, and adjacent to each quadrat (with the result that we made two further trampled tracks immediately adjacent to each side of the trampling line (see figures below).

The morphology of the dune axis was measured with an automatic level and staff, at one meter intervals along the path. Slopes were directly measured from this data. The various slope angles across the transect were divided into segments at 5° slope intervals (Fig. 2) in order to examine vegetation disturbance at specific topographic inclinations. Additionally, percent cover data were expressed as a function relative to the control (RC) by using the equation:

$$\mathrm{RC}\ (\%) = \frac{\%\ \text{cover at}\ X\ \text{intensity}}{\text{Initial}\ \%\ \text{cover}} \times 100$$

This method is more informative than simply measuring the decrease in percent cover between trampling intensities as it indicates the percentage of decrease from the initial state of the vegetation. Data collected for many of the individual vegetation surveys indicate initial vegetation cover values less than 100% due to observer error, despite the fact that there was close to, or actually a 100% cover. Despite this, the errors are consistent throughout the data set thereby allowing for the development of general trends.

Fig. 1. Photographic view of the study site. The trampling path lies between the two tapes and extends up and over the central axis of a fully vegetated, small parabolic dune.

4. Impacts of trampling

The initial vegetation composition of the survey transect is provided in Table 1. The dune was completely covered in vegetation, and most 0.5 m^2 quadrats displayed more than 100% cover due to the occurrence of low prostrate herbs and forbs growing underneath and within taller plants. *Schizachyrium* is the dominate species across the transect occurring in each of the eight slope segments having a total cover of 42.7% across the profile. *Chamaecrista* and *Pectis* are the second and third most dominant species comprising 8.0% and 6.9% of the vegetation composition, respectively. All other vegetation species have an individual percent cover less than 5%.

The influence of trampling activity in relation to path slope and trampling intensity has a dramatic affect on vegetation cover and composition (Table 2). Relative cover is dramatically reduced as indicated by just one example species, *Schizachyrium*. Fig. 3 illustrates, that in general, there is a significant decline in relative cover

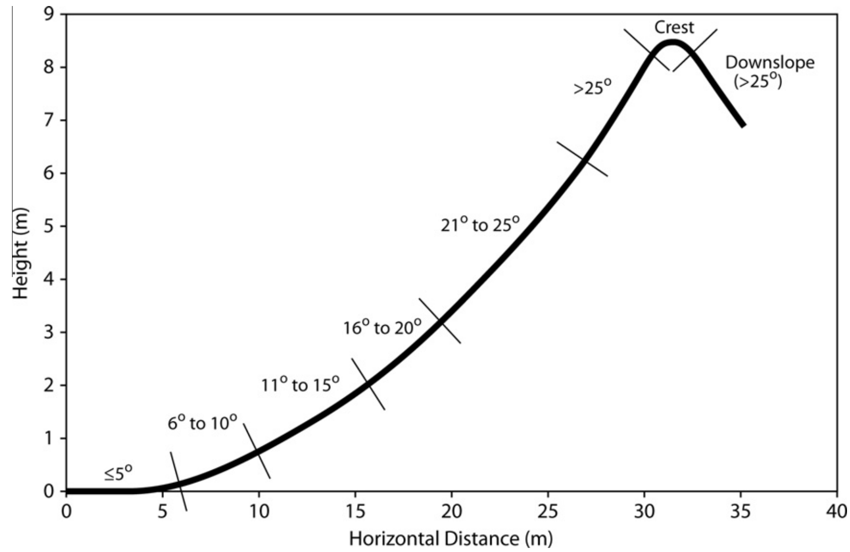

Fig. 2. Topographic survey of the trampling transect illustrating slope segments.

Table 1
Initial vegetation composition and percent cover for each of the eight slope segments.

SPECIES	⩽5°	6–10°	11–15°	16–20°	21–25°	>25°	Crest	Down-slope	Mean % cover
Schizachyrium	37.5	30.0	25.3	16.3	38.1	46.3	60.0	88.3	42.7
Pectis	11.7	21.3	16.2	4.3	1.0	1.3	–	–	6.9
Chamaecrista	7.5	13.8	20.0	7.5	15.0	–	–	–	8.0
Commelina	5.0	4.0	3.0	4.5	2.4	2.0	0.5	1.7	2.9
Triplasis	4.2	2.5	2.0	4.5	1.0	–	–	–	1.8
Walteria	2.5	4.5	–	–	–	–	–	–	0.9
Centrosema	1.7	0.8	–	2.8	1.6	0.3	1.0	–	1.0
Trachypogon	0.8	–	5.3	4.8	4.4	7.5	–	6.7	3.7
Aristida	0.2	–	–	2.0	8.0	–	–	–	1.3
Legume	–	–	–	4.3	12.5	–	–	–	2.1
Ipomoea	–	–	–	–	0.4	1.0	1.5	–	0.4
Bidens	–	–	–	–	0.1	2.8	1.5	–	0.5
Randia	–	–	–	–	–	2.5	–	–	0.3
Metastelma	–	–	–	–	–	0.3	0.5	1.3	0.3
Macroptilium	–	–	–	–	–	–	–	0.3	0.0
Total # of species	9	7	6	9	11	9	6	5	

over time as the trampling intensity increases. While there is no doubt some observer error in the data (two groups rotated conducting the percent cover surveys), at around 50 tramplings there is an increase in percent cover in three of the six slope segments. This is due to the fact that, as the dominant, tall *Schizachyrium* was crushed and flattened, the actual measureable cover increased, then subsequently decreased, as the plants were largely destroyed, buried and pushed aside. Fig. 3 also shows that slope has a major effect. As the slope increases the rate of decline of relative cover of the dominant species also increases.

Within each slope segment the species richness was initially between 6 and 11 total species, which became considerably reduced with increased trampling intensity. After only 10 cumulative tramplings the species richness is reduced by 2–3 species within the steeper slope segments. By 50 cumulative tramplings there has been a reduction in species richness within five of the eight slope segments, and by 100 cumulative tramplings the species richness has been reduced within all eight of the slope segments. Rare species (<5% initial cover) tend to disappear quickly after only very minimal trampling activity.

In addition to a reduction in species richness associated with trampling intensity, there is a significant difference in species richness associated with path slope. Within the steeper slope segments of the path (21–25, >25, crest, and down-slope segments) between 40% and 80% of the number of species disappear from the survey transect by 100 cumulative tramplings, whereas, only 13–30% of the number of species disappeared from the survey transect within the low/moderate slope segments by 100 cumulative tramplings. Even at the lower trampling intensities, there is a notable difference in species loss between steeper slope segments and low/moderate slope segments. By 30 total cumulative tramplings, three of the four steeper slope segments experience a reduction in species richness, while only one of the four slope segments experiences a reduction in species richness for the low/moderate slopes. These findings indicate that for the same trampling intensity, the changes in vegetation composition or richness are strongly related to path slope. Steeper slopes experience a greater degree of impact compared to lower slopes.

The degree of increase in the percentage of bare ground for all trampling intensities is illustrated in Fig. 4. Note that the data for the first 10 tramplings of the crest and down-slope sections were inadvertently lost, but the percent cover of bare ground was less than 10% for both slopes. With the exception of the 21–25° slope angles, there is an observable increase in the percent cover of bare ground with increasing trampling intensity for all slope segments. This indicates that slope controls might be minimal in terms of the effect on the creation of bare areas as trampling increases.

Table 2
Species relative cover values at each trampling intensity for each of the eight slope segments.

	Trampling intensity				
	10	30	50	70	100
⩽5°					
Schizachyrium	82	60	60	49	44
Trachypogon	0	20	180	80	0
Triplasis	104	56	56	32	16
Commelina	53	60	43	63	23
Pectis	63	21	26	13	6
Walteria	67	53	53	33	60
Chamaecrista	89	67	9	58	4
Centrosema	40	80	30	30	0
Aristida	100	0	0	0	0
6–10°					
Schizachyrium	88	58	96	58	46
Trachypogon	833	200	133	33	0
Triplasis	120	90	120	80	50
Commelina	94	94	44	44	38
Pectis	124	41	21	14	9
Chamaecrista	47	49	11	29	4
Centrosema	11	39	0	0	0
11–15°					
Schizachyrium	115	70	86	46	36
Trachypogon	69	28	22	16	0
Triplasis	142	75	75	8	58
Commelina	89	67	39	33	33
Pectis	98	25	28	12	5
Chamaecrista	80	29	28	13	13
16–20°					
Schizachyrium	154	92	131	66	71
Trachypogon	68	21	32	5	0
Triplasis	72	28	22	11	11
Commelina	61	44	44	22	17
Pectis	224	53	47	41	35
Chamaecrista	70	50	3	0	0
Centrosema	100	45	9	9	9
Aristida	75	38	25	63	13
Legume	112	88	35	24	12
21–25°					
Schizachyrium	163	130	126	61	70
Trachypogon	49	86	49	26	0
Triplasis	75	100	13	38	0
Commelina	79	37	42	58	47
Pectis	125	25	25	0	0
Chamaecrista	33	21	3	5	0
Centrosema	123	92	15	0	0
Aristida	30	30	16	3	8
Legume	122	55	69	35	28
Ipomoea	67	33	67	33	33
Bidens	0	0	0	0	0
>25°					
Schizachyrium	89	97	54	22	22
Trachypogon	37	17	3	3	0
Commelina	63	25	38	13	13
Pectis	20	20	0	0	0
Centrosema	0	0	0	0	0
Metastelma	0	0	0	0	0
Randia	150	150	100	50	50
Ipomoea	150	0	25	25	0
Bidens	27	27	0	0	0
Crest					
Schizachyrium	n/a	83	83	46	54
Trachypogon	n/a	150	250	0	0
Commelina	n/a	100	100	100	0
Metastelma	n/a	0	0	0	0
Ipomoea	n/a	33	33	33	0
Bidens	n/a	0	0	0	0
Down-slope					
Schizachyrium	n/a	55	34	9	19
Trachypogon	n/a	25	0	0	0
Commelina	n/a	40	40	60	40
Metastelma	n/a	0	0	0	0
Macroptilium	n/a	100	0	0	0

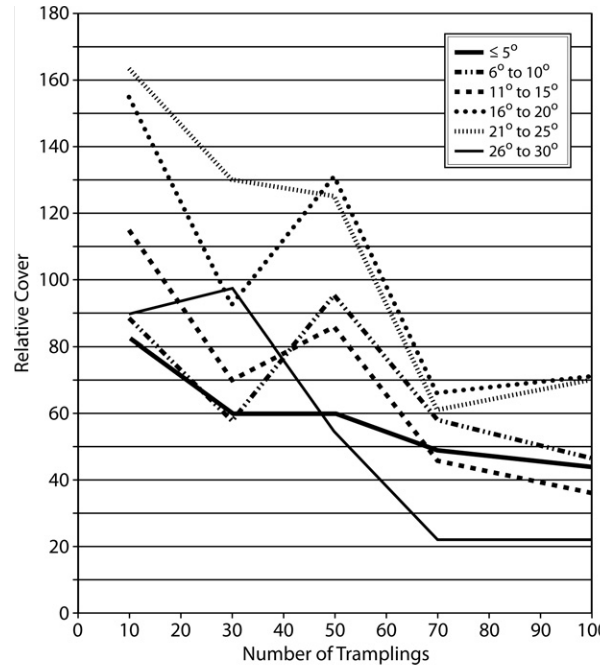

Fig. 3. Temporal changes in the relative cover of the dominant species, *Schizachyrium*, with trampling intensity and slope.

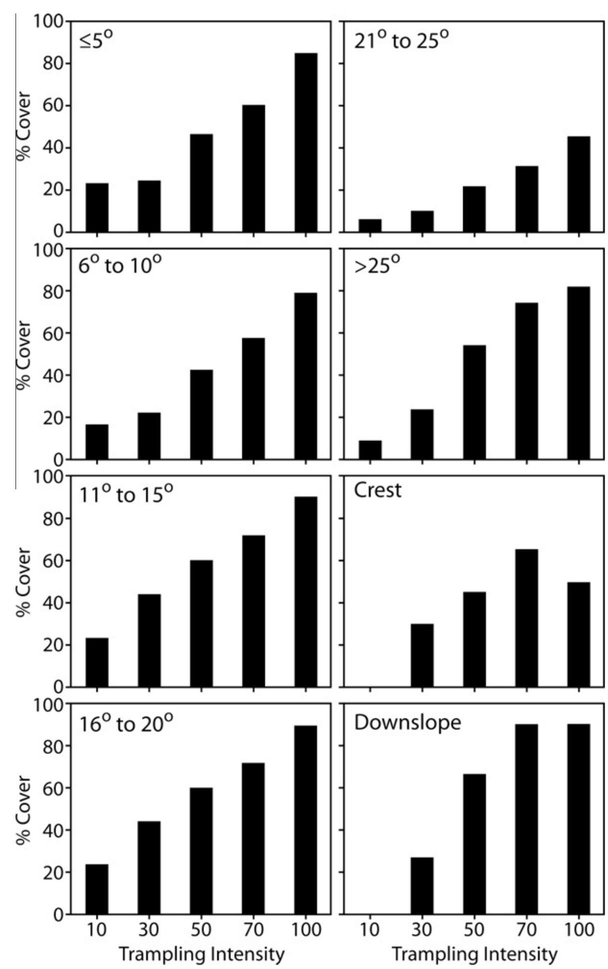

Fig. 4. Percent cover of bare ground vs. trampling intensity for all eight slope segments.

The changes in percent cover of the vegetation, and the increase in open, non-vegetated areas may clearly be seen in Fig. 5 which illustrates the path at different stages of trampling intensity. Even at trampling intensities of only 50 passages, the cover of bare ground often exceeds 50%.

Of note is the fact that there is a markedly lower percent cover of bare ground on the 21–25° slope even though there is a 40% reduction in the species richness. Field observations provide valuable insight into this finding; in the 21–25° slope segment, a remarkably different mechanism of trampling activity and resultant surface morphology occurred compared to adjacent slope angle segments. Within the 21–25° slope segment, a staircase morphology was gradually created. That is, with increasing trampling, clear steps evolved. This process resulted in the creation of flat bare step treads with concentrated, crushed vegetation risers. These vegetation risers (or basal step vegetation clumps) did not deteriorate with further trampling but remained preserved in place. The vegetation comprised torn up and detached plants so the vegetation riser would possibly eventually disappear over the subsequent few weeks as the plants dried and decomposed. Alternatively, the plants may have enough root material left to re-establish from this mass as other studies have found (e.g. Godfrey et al., 1978; Bowles and Maun, 1982). In contrast, on the slope segments of >25° and on the down-slope (slipface) segment, classic shearing of the surface layer took place. Trampling was accompanied by surface–subsurface sliding and the vegetation was pushed downslope, resulting in a greater rate of plant removal and increased bare ground (Fig. 6).

5. Discussion and conclusion

One constraint of this study is the methodology whereby we assessed the degree of trampling disturbance concentrated in time (over a single day) and therefore determined continuous short term impact. Advantages to this methodology are that (i) it eliminates the assumption that vegetation of the whole area was homogenous prior to trampling and that changes in vegetation along a path are the direct result of trampling, and (ii) it probably does simulate a high intensity human impact which often occurs during a single holiday at a dune-beach site. Hylgaard and Liddle (1981) determined that disturbance concentrated in time tended to cause slightly less damage to the vegetation than equivalent intensities at prolonged intervals. This conclusion suggests that multiple follow-up studies assessing the relationship between recovery and continuous versus semi-continuous disturbance of the vegetation community will allow for a better understanding of the overall disturbance of trampling activity. Another constraint is that even only using a 50 cm wide path, there was an edge effect. In order not to walk on the tapes marking the path, and in keeping within a "normal" walking pattern width, the vegetation along the edges of the prescribed trampling path were not impacted very much. If the path had been narrower, we would have recorded a greater impact on the vegetation.

Several important results emerge from this study. The relationship between vegetation composition and trampling activity is highly significant. With increased trampling intensity species richness dramatically decreases as found by other studies (McAtee and Drawe, 1980; Ikeda, 2003). Rare species tend to disappear quickly even after only very minimal trampling activity, and this is a critical finding for dune vegetation conservation. Even a low impact trampling reduces rare species richness and/or eliminates rare species.

Species richness is not only greatly influenced by the number of trampling passages, but in particularly the slope of the path. There was a greater decrease in richness values on steep slopes compared to low/moderate slope angles, independent of trampling intensity.

Trampling intensity has a profound influence on the creation of bare ground. With the exception of the 21–25° slope segment where the increase was relatively moderate, the percent cover of bare ground markedly increased with increasing trampling intensity for all slopes.

Diverse slope evolutionary mechanisms occurred on different steep slope segments. Steps were produced on the 21–25° slopes while linear debris slopes were produced on the >25° slopes. The net medium term effect should be the same, however, as virtually all the vegetation was detached and crushed and may all eventually be lost (although some recovery may be possible on the steps). These findings correspond well with those of Williams et al. (1997). They determined that on low to moderate slope angles,

0 10 30 70 100

Fig. 5. Sequential photographs of the trampling path at 10, 30, 50, 70 and 100 trampling intensities. Note that two adjacent tracks (created during each vegetation survey by survey crews standing outside the quadrats) are also increasingly visible with time.

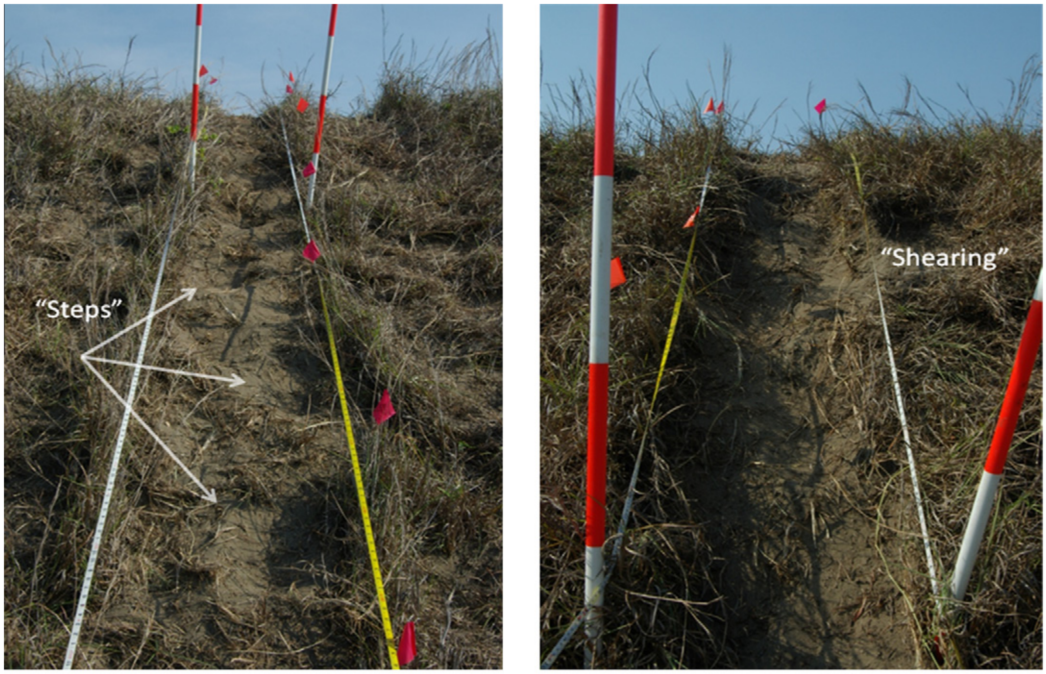

Fig. 6. Illustration of stair creation on the 21–25° slope compared to the continuous linear sheared >25° slope.

vertical forces, which exert significantly less force to the ground surface, are the dominant mechanism affecting vegetation disturbance by compressing and crushing plant species, whereas, the dramatically greater dynamic horizontal shearing forces produced by walking up- or down-slope is the dominate mechanism influencing vegetation disturbance at steeper slope angles.

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