Biological Conservation **21** (1981) 289–301

TRAMPLING EFFECTS ON COASTAL DUNE VEGETATION IN THE PARKER RIVER NATIONAL WILDLIFE REFUGE, MASSACHUSETTS, USA

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ABSTRACT

Long-term human trampling on coastal dune vegetation was analysed using eight 100 × 100 m study areas ranging in trampling intensity from little or no past trampling pressure to severe trampling pressure. All trampling levels significantly reduced species diversity. Total vegetation cover was significantly reduced only in areas with severe and heavy trampling pressure. Where long-term moderate trampling did not affect total cover, it appears to have favoured Ammophila breviligulata *over other more sensitive species. The data suggest that long-term trampling pressure has caused a shift in the horizontal pattern of vegetation, i.e. expanding the width of the foredune plant community, while restricting the interdune community to a narrow strip at the base of the backdune ridge.*

INTRODUCTION

Vegetation adapted to the dune environment is continually exposed to strong winds, moving sand and salt spray. The plant cover is often thin or sparse and forms a fragile network holding the sand in place. The dune system, though well adapted to absorbing the impact of coastal storms, is fragile and can be severely damaged by livestock, pedestrian and vehicular traffic (Clark, 1974; Olsen & Grant, 1975). If a multiple-use approach is employed for coastal dunes, management guidelines must be developed to ensure preservation of these fragile systems.

Much descriptive work has been done regarding dune vegetation and factors affecting its distribution (Oosting & Billings, 1942; Martin, 1959; Willis *et al.*, 1959*a*,*b*; van der Valk, 1974, 1975; Lamoureux & Grandtner, 1977). Within the last

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Biol. Conserv. 0006-3207/81/0021-0289/$02·75

ten years research, particularly in Europe, has been conducted to assess the human impacts on dune systems (Burden & Randerson, 1972; Oldfield *et al.*, 1972; Trew, 1973; Liddle, 1975*a*,*b*; Liddle & Greig-Smith, 1975*a*,*b*; Blom, 1977; Boorman & Fuller, 1977; Richards & Stead, 1978). Along the New England coast (USA) most research of this nature specifically concerns the effects of vehicle traffic on the dunes (Niedoroda & Limeburner, 1975; Broadhead & Godfrey, 1977). Nickerson (1976) studied the impact of human trampling on the dunes in Cape Cod National Seashore and found that vulnerability of the predominant foredune species, *Ammophila breviligulata*, to foot traffic varied with time of growing season, and that shoe traffic was 10 to 20 times more destructive than bare-foot traffic.

Studies by Liddle & Greig-Smith (1975*b*) have shown that wear by vehicles and human trampling on sand dunes reduces species diversity as well as population size and distribution. They conclude that the consequences of this type of impact are as great as the major natural environmental factors.

The majority of research on the effect of human trampling on coastal dunes has been directed toward the response of the vegetation (i.e. specific species) immediately exposed to the impacts. This type of impact research has also been the major focus in other ecosystems (LaPage, 1967, 1968; Goldsmith *et al.*, 1970; Willard & Marr, 1970, 1971; Dale & Weaver, 1974; Foin *et al.*, 1977). In contrast, a second approach which examines the distribution and species composition of plant communities which exist in areas which have had long-term trampling pressures and adjacent areas with little or no trampling pressure provides an assay of the effect of long-term trampling on vegetation patterns.

The objective of this study is to determine the effect of long-term trampling pressure on the composition and horizontal pattern of coastal dune vegetation in the Parker River National Wildlife Refuge.

THE STUDY AREA

The site selected was the dune system on Plum Island, Essex County, Massachusetts (Fig. 1). The island and its flora were described by McDonnell (1979*a*,*b*). Two-thirds of this 12·8 km-long by approximately 0·6 km-wide barrier island has remained relatively natural. About 1,230 ha of the southern portion of the island are now included in the Parker River National Wildlife Refuge and a Commonwealth of Massachusetts State Park, which owns the extreme southern tip. This is one of the largest semi-natural barrier beach dune systems in New England north of Cape Cod.

Plum Island formed after the retreat of the Wisconsin Ice Sheet some 6,300 years ago (McIntire & Morgan, 1964). It is composed primarily of unconsolidated beach and dune sands and marsh deposits (Jones & Cameron, 1976). The southern two-thirds of the island exhibits classical features of a barrier beach dune system. Four

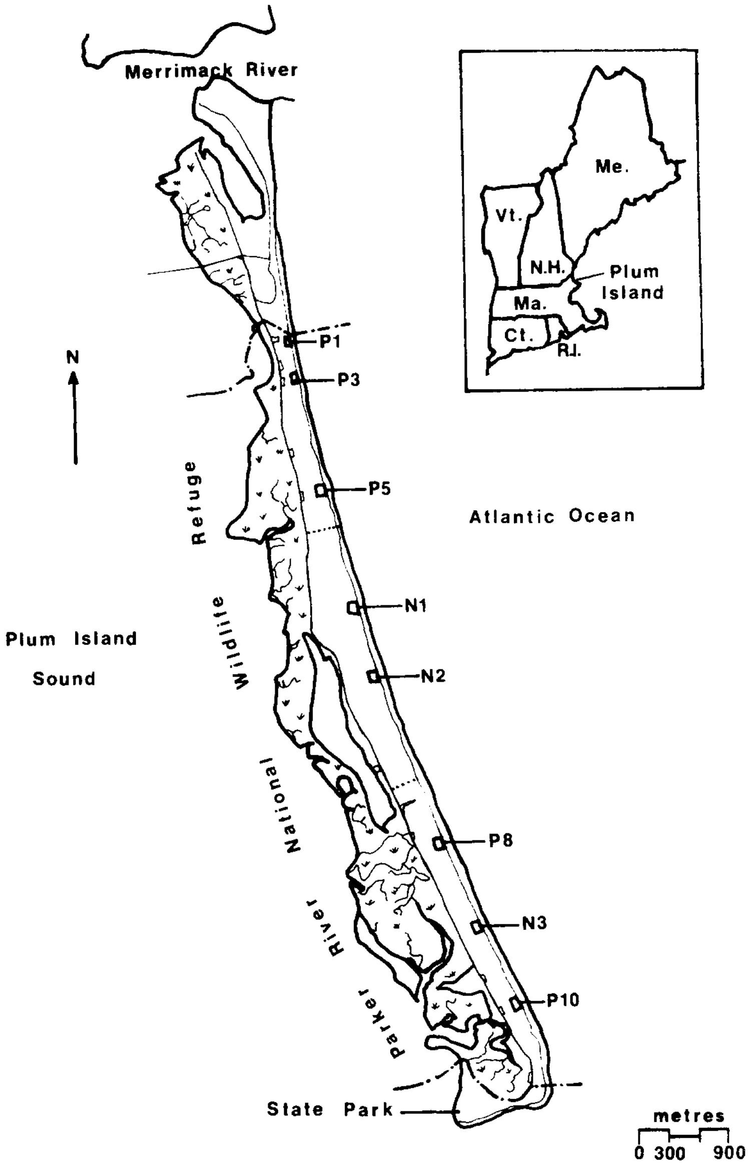

Fig. 1. A map of Plum Island showing the location of the study areas in the Parker River Nationa Wildlife Refuge. Insert is a map of New England showing the location of Plum Island.

major physiographic zones can be identified running east to west across the island (Fig. 2): (1) beach; (2) foredune; (3) interdune; and (4) backdune.

The adjacent ocean is an important moderating factor in the climate. The average annual temperature for this region is 10 °C with a January average of − 1·4 °C and a July average of 19·9 °C. Average annual precipitation is 193·1 cm with the winter season being the wettest due to frequent storms. Winds are primarily westerly or offshore. The storm winds on the other hand are most prevalent from the east, with those most important to beach formation coming from the northeasterly direction.

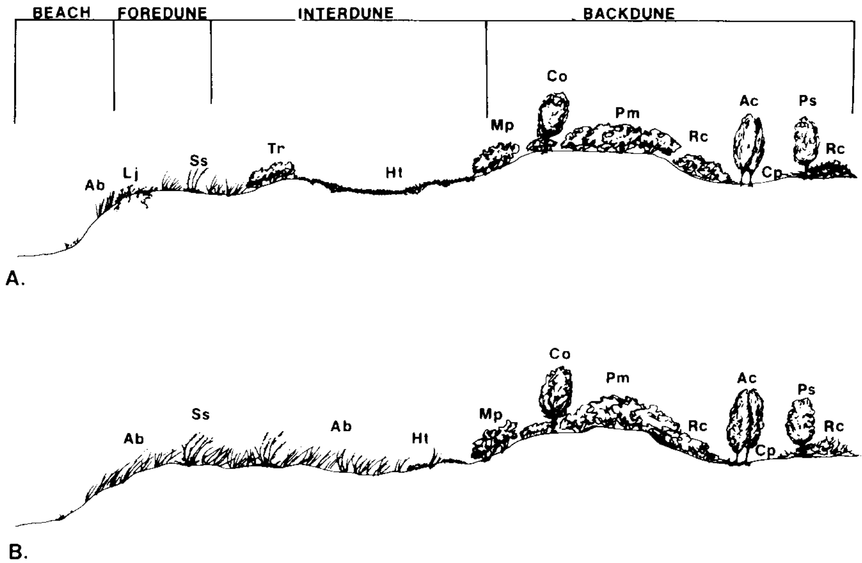

Fig. 2. A diagrammatic sketch of the typical physiographic features and vegetation zones encountered on two east to west transects across Plum Island; A, area of the refuge with little or no trampling pressure; B, area exposed to heavy trampling pressure. (Key: Ab, *Ammophila breviligulata*; Ac, *Amelanchier canadensis*; Co, *Celtis occidentalis*; Cp, *Carex pennsylvanica*; Ht, *Hudsonia tomentosa*; Lj, *Lathyrus japonicus*; Mp, *Myrica pennsylvanica*; Pm, *Prunus maritima*; Ps, *Prunus serotina*; Rc, *Rosa carolina*; Ss, *Solidago sempervirens*; and Tr, *Toxicodendron radicans*).

Because of the proximity of Plum Island to a large metropolitan area (Boston), the refuge management has carefully regulated the number of vehicles entering the refuge area, particularly during heavy-use periods. Access to the dunes has been limited to ten parking areas spaced at intervals along the 9·7 km road to the southern end of the island. Thus trampling pressure has been concentrated in specific well-defined areas of the dune system. In addition, to limit trampling on the dune vegetation adjacent to these parking areas, boardwalks to the beach were established over the past six years. The refuge management has also set aside a large Dune Natural Area for research which receives very little trampling pressure. Since the late 1960s the refuge management has not allowed vehicles on the dunes; thus any trampling is caused by either humans or wildlife (e.g. dogs, rabbits, etc.). Plant nomenclature follows Fernald (1950). Voucher specimens of plants were collected and deposited in the Hogdon Herbarium, University of Hampshire (NHA).

METHODS

A preliminary examination of the impact of human trampling on the dune vegetation in the Parker River National Wildlife Refuge revealed that the foredune and interdune areas were the most severely impacted. These areas are primarily covered with perennial herbs, e.g. *Ammophila breviligulata* and *Lathyrus japonicus*, while the backdune vegetation is dominated by woody trees and shrubs. A few distinct paths extend through the tree and shrub colonies surrounding each parking area but it is not until the path reaches the open interdune and foredune areas that large-scale destruction and even elimination of vegetation can be observed.

To obtain quantitative information on the horizontal structure of the vegetation in heavily trampled and relatively untrampled foredune and interdune areas, eight study areas were established. Five study areas were adjacent to parking lots, alternating among the ten which provide access across the dunes. Study areas were established adjacent to parking lots 1 (P1), 3 (P3), 5 (P5), 8 (P8) and 10 (P10) (Fig. 1).

The study areas were then grouped according to trampling intensity. Accurate estimates of the actual number of visitors or cars present at a parking lot over a season are not available. A request by the author to distribute questionnaires to determine parking lot use patterns was denied due to refuge management policy. Visual observations of each parking lot over an extended time were beyond the resources of this project. However, it is felt that, because the emphasis of the study is on long-term trampling impacts on the area, current parking lot use patterns obtained from first-hand observations and information from refuge personnel, along with knowledge of the history and size of each parking lot, provide an adequate estimate of trampling intensity. Thus, estimates of trampling intensity for each parking lot study area were based on (1) current parking lot use trends; (2) capacity of parking lot to holds cars; (3) number of years open; (4) distance from refuge entrance; and (5) length of time boardwalks were established.

Over the past ten years there has been a dramatic increase in the number of people using the refuge. During a single year, from October 1976 to September 1977, a total of 469,482 people visited the refuge (Parker River National Wildlife Refuge records). The greatest number occurs during the summer months with an average of over 50,000 people per month. With only one entrance to the refuge, at the northern end of Plum Island, there is a distinct gradient of recreational use down the island. The closer the parking lot is to the entrance the greater use it gets. Thus, parking lots 1–6 get many more visitors than parkings lots 7–11. In general most people do not drive 9.6 km down a dirt road to the parking lots at the southern end of the island.

From May through August when the weather is pleasant, all of the parking lots are filled close to capacity. In the last few years they also fill up rapidly during the autumn months (PRNWR records). With such heavy use the capacity of the parking lots provides a good estimate of the intensity of trampling on the adjacent study area. The smaller the parking lot, the less intense the trampling and vice versa. Thus, an area of dune adjacent to a small parking lot at the southern end of the refuge is less intensely trampled than an area adjacent to a large parking lot at the northern end of the refuge.

Using this information, coupled with the number of years a parking lot has been open and the length of time it has had a boardwalk, the parking lot study areas were grouped into three categories according to level of probable trampling pressures: severe P1; heavy P3, P5; and moderate P8, P10 (Table 1).

TABLE 1
PARKING LOT STUDY AREAS GROUPED INTO THREE CATEGORIES OF PROBABLE TRAMPLING PRESSURE ACCORDING TO AGE, SIZE, DISTANCE FROM REFUGE ENTRANCE AND NUMBER OF YEARS BOARDWALKS WERE PRESENT

Study area	*Parking lot*	*Capacity (no. of cars)*	*Approximate no. of years open*	*Distance from refuge entrance*	*Total years boardwalk present*	*Estimated trampling pressure*
P1	1	145	30	0·09 km	2	Severe
P3	3	31	28	0·70 km	6	Heavy
P5	5	22	24	2·08 km	6	Heavy
P8	8	9	13	6·40 km	3	Moderate
P10	10	26	13	8·80 km	3	Moderate

In addition, three study areas (N1, N2 and N3) were established in relatively undisturbed areas as far from potential trampling pressure as possible (Fig. 1). Two study areas were established in the Dune Natural Area: N1 approximately 1200 m south of parking lot 5; N2 approximately 1600 m north of parking lot 6. Study area N3 was established in a relatively undisturbed and inaccessible area of the dunes between parking lots 8 and 9.

Each study area was 100×100 m with the edges oriented north–south and east–west. The eastern edge of a study area was the foredune ridge. The study areas adjacent to parking lots were set up so that the midpoint of the eastern boundary was the intersection of the eastern end of the boardwalk and the foredune ridge. Those study areas not adjacent to parking lots were established so that the midpoint of the eastern boundary was a point originally established on a map and then located in the field. In each study area four 10×100 m transects running north–south were centred on 10, 35, 65 and 95 m respectively from the eastern edge of the foredune ridge. Each transect was further divided into 40 5×5 m quadrats, situated as pairs on either side of a centre line. Due to the fragile nature of the dune system and refuge management policy, destructive biomass sampling was not attempted. Instead, percent cover and frequency values were obtained to determine species composition and abundance of the vegetation in the study areas.

During August 1978 20 randomly chosen 5 × 5 m quadrats in each transect were sampled for percent cover of species present, total number of species present, and total area with vegetation cover. Quadrats were chosen at random because the position of the boardwalks shifts from year to year within about a 50-m area. Thus, no attempt was made to quantify the gradient of trampling away from the boardwalks since the exact intensity of trampling at any one point has varied over the years depending on the position of the boardwalks. The data were statistically analysed using analysis of variance techniques. Because the quadrats sampled were randomly chosen they could not be pooled to form the experimental error term for they may not have the same variance as postulated in the mathematical model. To provide a more rigorous test the percent cover values were averaged over transects, and an error term was constructed using selected single degree freedom sums of squares for transect and location contrasts, set up prior to data analysis. The exact procedure used follows Cochran & Cox (1957) and is described in McDonnell (1979*a*). After completion of the analysis of variance, treatment means were compared using Least Significant Difference (LSD) at alpha 0·05.

RESULTS AND DISCUSSION

Twenty-five species were present in the eight study areas. *Ammophila breviligulata*, *Lathyrus japonicus*, *Artemisia stellariana* and *Hudsonia tomentosa* together account for over 75 % of the total area covered with vegetation in the study areas (Table 2). The percent cover of the less dominant species is presented in Table 3.

TABLE 2
THE PERCENT COVER OF THE DOMINANT SPECIES AND TOTAL AREA COVERED WITH VEGETATION AND THE AVERAGE NUMBER OF SPECIES PRESENT IN EACH STUDY AREA

LSD, Least Significant Difference. In the analysis of variance there were four transects and eight locations; in no case was the transect X location interaction significant, F-test significant at 0.05 level.

Species	*Study areas*											
	P1	*P3*	*P5*	*P8*	*P10*	*N1*	*N2*	*N3*			*ANOVA*⁺	
Trampling pressure:	*severe*	*heavy*		*moderate*		*undisturbed*			*Average*	*LSD*	*Transect*	*Location*
Ammophila breviligulata	6·7	18·0	20·6	30·6	22·5	18·0	18·8	25·0	20·0	8·5	NS	[a]
Lathyrus japonicus	2·8	9·9	2·4	12·4	3·2	9·0	4·9	9·0	6·7	6·1	[a]	NS
Artemisia stellariana	0·1	2·0	1·4	2·6	1·2	7·6	1·2	0·0	2·0	9·7	NS	NS
Hudsonia tomentosa	0·0	0·5	0·3	0·2	5·3	3·0	8·6	9·0	3·3	6·1	[a]	[a]
Total vegetation cover	9·6	36·0	25·8	46·0	39·0	40·0	43·9	53·4	38·4	14·2	NS	[a]
Average no. of species	0·6	2·0	2·5	2·7	2·8	3·2	3·4	4·0	2·7	0·46	[a]	[a]

NS = not significant. [a] = significant.

TABLE 3

THE PERCENT COVER OF THE LESS DOMINANT SPECIES WHICH OCCUR IN THE EIGHT STUDY AREAS LOCATED IN THE PARKER RIVER NATIONAL WILDLIFE REFUGE

Trampling pressure: P1, severe; P3 + P5, heavy; P8 + P10, moderate; N1, N2 and N3, undisturbed.

	Study areas							
Species	*P1*	*P3*	*P5*	*P8*	*P10*	*N1*	*N2*	*N3*
Solidago sempervirens	0·00	0·31	0·41	0·80	1·03	2·34	1·51	0·65
Euphorbia polygonifolia	0·02	0·03	0·43	0·03	0·18	0·10	0·28	0·08
Cyperus sp.	0·00	0·00	0·00	0·00	0·07	0·13	0·11	1·14
Polygonella articulata	0·00	0·02	0·00	0·00	0·06	0·10	0·14	0·76
Cakile edentula	0·00	0·04	0·10	0·38	0·03	0·00	0·03	0·02
Rosa sp.	0·00	0·87	0·00	0·00	0·13	0·00	3·00	0·00
Prunus serotina	0·00	0·00	0·00	0·00	0·06	0·00	0·00	0·00
Polygonum scandens	0·00	0·00	0·00	0·00	0·01	0·00	0·00	0·00
Spiraea tomentosa	0·00	0·00	0·00	0·00	0·00	0·00	0·43	0·00
Viburnum recognitum	0·00	0·00	0·00	0·00	0·00	0·00	0·43	0·00
Fraxinus pennsylvanica	0·00	0·00	0·00	0·00	0·00	0·00	0·25	0·00
Xanthium echinatum	0·00	0·00	0·01	0·00	0·00	0·00	0·00	0·00
Toxicodendron radicans	0·00	4·18	0·00	0·00	1·62	0·00	2·81	0·00
Myrica pennsylvanica	0·00	0·80	0·00	0·00	4·00	0·00	1·43	0·00
Raphanus raphanistrum	0·00	0·00	0·00	0·18	0·00	0·00	0·00	0·00
Prunus maritima	0·00	0·00	0·00	0·00	0·00	0·26	0·04	0·00
Lechea maritima	0·00	0·00	0·00	0·00	0·13	0·00	0·00	0·18
Spartina patens	0·01	0·00	0·00	0·00	0·00	0·00	0·00	0·00
Distichlis spicata	0·01	0·00	0·00	0·00	0·00	0·00	0·00	0·00
Cladonia sp.	0·00	0·00	0·00	0·00	0·44	0·00	0·00	4·50
Geaster sp.	0·00	0·00	0·00	0·00	0·00	0·00	0·00	0·03

An analysis of variance (Table 4) of the percent cover of the total area covered with vegetation revealed that differences among transects (variation within study areas) were not significant, whereas differences between locations (different trampling pressures) were. The parking lot study areas as a group have significantly less vegetation cover than the undisturbed study areas. When the means for each study area are compared (Table 2) only parking lot study areas P1 and P5 (with severe and heavy trampling pressure respectively) exhibited significantly less vegetation cover than the undisturbed study areas (N1, N2 and N3). Moderately trampled parking lot study areas P8 and P10 had significantly more vegetation than study areas P1 and P5 but were not significantly different from the undisturbed study areas or study area P3 (heavy trampling pressure). The relatively high cover value for study area P3 results partially from the fact the boardwalk was moved 50 m north of its previous location just before the study began, thus excluding some of the more heavily impacted area.

The most important species stabilising the foredune and interdune zones is *A. breviligulata*. The analysis of variance (Table 4) indicates that, like total vegetation cover, the only significant factor was location (i.e. different trampling pressures). But unlike the total vegetation cover analysis, the undisturbed compared with disturbed study areas contrast was not significant. Only severely trampled study area P1 had significantly less percent cover of *A. breviligulata* than the undisturbed study areas (Table 2). Study areas with heavy and moderate trampling

TABLE 4

ANALYSIS OF VARIANCE TABLE FOR THE TOTAL AREA COVERED WITH VEGETATION AND *Ammophila breviligulata*

Four transects were sampled at each of the eight study areas. N, undisturbed study areas, N1, N2, N3; P, parking lot study areas, P1 has severe trampling pressure, P3 and P5 have heavy trampling pressure, and P8 and P10 have moderate trampling pressure.

Sources of variation	*DF*	*Total vegetation cover* *Sums of squares*	*Mean square*	Ammophila breviligulata *Sums of squares*	*Mean square*
Overall mean	1	872796		258898	
Transect (T)	3	6484	2161	798	266
Location (L)	7	103880	14840[a]	26322	3760[a]
L1 (N vs. P)	1	32374	32374[a]	128	128[a]
L2 (N1 vs. N2)	1	354	354	12	12
L3 (N1 + N2 vs. N3)	1	6468	6468	2170	2170
L4 (P8 vs. P10)	1	1904	1904	2621	2621
L5 (P3 vs. P5)	1	4270	4270	228	228
L6 (P8 + P10 vs. P3 + P5)	1	10981	10981[a]	4039	4039
L7 (P1 vs. P3 + P5 + P8 + P10)	1	47517	47517[a]	17125	17125[a]
L × T	6	7914	1319	7896	1316
Experimental error	15	26378	1758	14184	945

[a] Significant; F-test, alpha = 0.05.

pressure (P3, P5 and P8, P10, respectively) did not have significantly less cover of *A. breviligulata* (Table 2). In fact, study area P8, with moderate trampling pressure, had significantly higher percent cover of *A. breviligulata* than undisturbed study areas N1 and N2. In the trampled parking lot study areas *A. breviligulata* made up 50 %–80 % of the total vegetation cover while in the undisturbed study areas it contributed only 42 %–47 % to the total cover. It appears that long-term moderate trampling pressure does not affect total cover, but favours *A. breviligulata* over other more sensitive species.

An analysis of variance of the percent cover of the other dominant species, *L. japonicus*, *A. stellariana* and *H. tomentosa*, revealed that only the last could be used to estimate the effect of trampling. Location (different trampling pressures) had no significant effect on the total cover of *L. japonicus* or *A. stellariana* (Table 2). Both of these species occur sporadically throughout the dune system.

An ANOVA table for the percent cover of *H. tomentosa* (Table 5) indicates that, unlike the preceding species, both transect and location factors were significant. The percent cover of *H. tomentosa* was significantly greater in transects C and D, which are farthest from the foredune, than A and B, which are on the foredune. This species commonly forms large mats behind the foredune in the stable protected areas of the interdune (Fig. 2). When the percent cover means for each study area are compared (Table 2), the undisturbed study areas exhibit significantly more *H. tomentosa* than any of the trampled study areas except P10, which has moderate trampling pressure. No *H. tomentosa* was present in the severely trampled study area P1, while in heavily and moderately trampled study areas P3, P5 and P8 respectively, it never occurred in amounts greater than 1 % cover.

TABLE 5
ANALYSIS OF VARIANCE TABLE FOR THE PERCENT COVER OF *Hudsonia tomentosa* AND FOR THE AVERAGE NUMBER OF SPECIES PRESENT IN THE EIGHT STUDY AREAS

	Hudsonia tomentosa			*Average number of species*		
Source of variation	*DF*	*Sums of squares*	*Mean square*	*DF*	*Sums of squares*	*Mean square*
Overall mean	1	7388		1	4665	
Transect (T)	3	5788	192[a]	3	129	43[a]
Location (L)	9	8249	1178[a]	7	576	82[a]
T × L	9	4955	550	6	11	2
Experimental error	12	5802	483	15	98	6

[a] Significant; F-test, alpha = 0.05.

The increased importance of *A. breviligulata* and the virtual elimination of *H. tomentosa* in areas of the dune exposed to trampling pressure suggest that trampling has caused the typical foredune community dominated by *A. breviligulata* to extend inland, reducing the width of the interdune community. Thus, the interdune community has become restricted to a narrow strip near the base of the backdune ridge (Fig. 2).

In general, plant species diversity in the foredune and interdune regions of the dune system is low. An analysis of variance on the average number of species present in the study areas revealed that both transect and location factors were significant (Table 5). Transects farthest from the foredune (C & D) exhibited the greatest species diversity. A comparison of the average number of species in each study area (Table 2) revealed that a significantly greater number of species occurred in the undisturbed study areas as opposed to the study areas exposed to trampling pressure (average 3·5 spp. area in the undisturbed sites compared with 2·3 spp. area in areas with heavy trampling pressure). Thus, long-term trampling pressure, in addition to changing the horizontal pattern of the coastal dune vegetation, has also reduced species diversity.

CONCLUSION

The effects of long-term human trampling on the coastal dune vegetation in the Parker River National Wildlife Refuge varied depending on the intensity of trampling pressure. Severe trampling pressure caused a drastic reduction in both vegetation cover and species diversity (Fig. 3). Somewhat less conclusive, heavy trampling pressure appeared to cause a reduction in cover and diversity. Moderate trampling pressure significantly reduced species diversity, but not total cover. Long-term moderate trampling appears to have favoured *A. breviligulata* over other more sensitive species. In contrast, all levels of trampling pressure significantly reduced the amount of *H. tomentosa* present. Even though moderate long-term trampling pressure has not caused significant and obvious changes in vegetation cover, similar

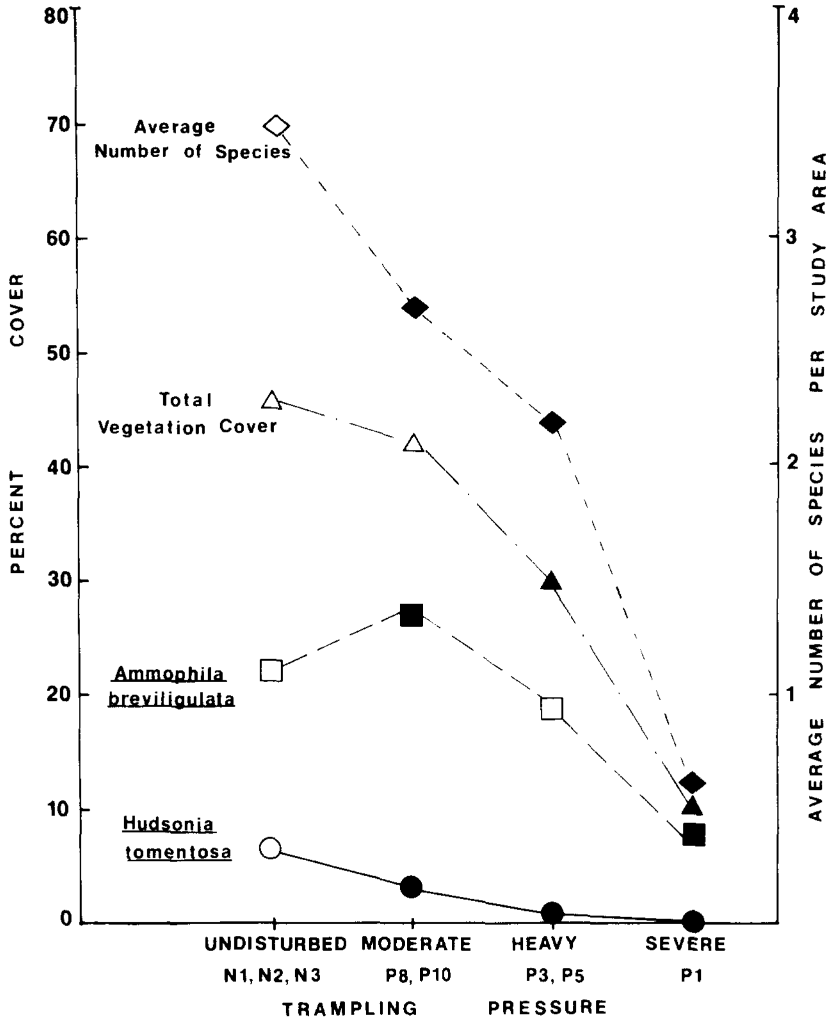

Fig. 3. A summary of the effects of different trampling pressures on the coastal dune vegetation in the Parker River National Wildlife Refuge. N and P refer to numbered study areas. Solid symbols indicate a significant difference from undisturbed study areas at alpha = 0.05.

to severe and heavy trampling, it has caused a loss of species, a shift in relative abundance of species, and a shift in the horizontal pattern of the vegetation. The increased importance of *A. breviligulata*, and the virtual elimination of interdune species such as *H. tomentosa* in all areas exposed to trampling pressure, indicates that long-term human trampling has resulted in the expansion of the foredune community dominated by *A. breviligulata* and the restriction of the interdune community to a narrow strip at the base of the backdune ridge (Fig. 2).

Smaller parking lots and the establishment of boardwalks has successfully reduced the impact of trampling on the vegetation in the foredune and interdune regions in the Parker River National Wildlife Refuge. Results from this study suggest that destruction of dune vegetation by trampling can be minimised if dune access is restricted to specific areas with parking lots designed to hold only 10 to 20 cars and have boardwalks that extend over the dunes to the beach.

ACKNOWLEDGEMENTS

I would like to express my gratitude to Dr Garrett E. Crow and Dr Russell Kinerson for their help throughout this study. I wish to thank George Gavutis, manager of the Parker River National Wildlife Refuge: without his cooperation this study could not have been completed. The following persons assisted with the field work: Lisa Bandazian, Lynn Bohs, Allison Buck, Bill Cotreau and Dennis McKearin. Dr Jerry Warren and the staff of the office of Academic Computing at UNH provided valuable assistance in the statistical analysis of the data. I would also like to thank Dr Richard T. T. Forman and an anonymous reviewer for their constructive criticism of the manuscript. This study was supported in part by two Central University Research Grants (CURF S86 and S106) from the University of New Hampshire.

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