ELSEVIER

0006-3207(94)00031-X

Biological Conservation 71 (1995) 223–230

0006-3207/95/$09.50+.00

RESISTANCE OF DANISH COASTAL VEGETATION TYPES TO HUMAN TRAMPLING

Ulla Vogt Andersen

Botanical Section, Department of Botany, Dendrology and Forest Genetics, Royal Veterinary & Agricultural University, Rolighedsvej 21, DK-1958 Frederiksberg C, Denmark

(Received 14 January 1994; revised version received 20 May 1994; accepted 8 June 1994)

Abstract

Five coastal communities under influence of human trampling, i.e. a natural salt marsh, a natural dune, a man-made dune, and two man-made coastal grasslands, were studied. The vegetation of five paths (one in each community) created and sustained by human trampling was analysed with respect to floristic composition and species cover. The total number of vascular plant species, species diversity, and the total vegetation cover were significantly reduced. The therophytes and hemicryptophytes were significantly reduced, while the geophytes were indifferent to the impact of human trampling. Man-made and natural dunes were most vulnerable, coastal grasslands were intermediate, and the salt marsh was the most resistant to human trampling.

Keywords: human trampling, disturbances, species resistance, man-made ecosystems, coastal communities.

INTRODUCTION

For holiday makers of Northern Europe seashores rank among the most attractive areas. At present, employment and income in many coastal areas are largely dependent on the tourist industry, and tourism is a growth sector with a large potential in economic terms (Meijer, 1992; Jensen, 1993). Tourist activities, however, can have severe effects on coastal areas, and contribute to their destruction and reduction of their nature and recreational values. A direct result of leisure activities is disturbance to the flora and fauna. Several researchers have studied the impact of human trampling in dunes and other seashore plant communities. The natural responses are soil compaction (Bates, 1935; Liddle & Greig-Smith, 1975*a*), reduction in soil organic matter (Boorman & Fuller, 1977; Hylgaard & Liddle, 1981), decrease of vegetation cover (Burden & Randerson, 1972; Bowles & Maun, 1982), decrease in biomass production (Edmond, 1962; Liddle & Greig-Smith, 1975*b*), reduction in number of flowering species (Goldsmith *et al.*, 1970; Hylgaard, 1980), disappearance of vulnerable species (Bates, 1935; Chappel *et al.*, 1971), creation of paths (Bayfield, 1973; Hylgaard & Liddle, 1981), erosion (Frederiksen, 1977; Carlson & Godfrey, 1989), interference in the natural succession (Goldsmith *et al.*, 1970; Hosier & Eaton, 1980), and loss of biodiversity (McDonell, 1981). Because the impact results in soil modification, the changes in vegetation composition and structure can be irreversible (Beeftink, 1979). Low levels of trampling can, however, have a beneficial influence on species diversity (Liddle & Greig-Smith, 1975*b*; Boorman & Fuller, 1977), by keeping the communities in a dynamic stage (Magnusson, 1986).

Careful planning of recreational impact is necessary and a knowledge of the resistance of seashore communities is an important basis for planners. The aims of the present study were to compare the vulnerability of five different plant communities, i.e. a natural salt marsh, a natural dune, a man-made dune, a man-made coastal grassland under management, and a man-made coastal grassland without management. These communities were analysed with emphasis on (1) the trampling-induced changes in vegetation composition and species diversity; (2) the ability of individual species to withstand injury; and (3) the possible differences in resistance between man-made and natural coastal areas and between managed and unmanaged plant communities. Plant nomenclature follows Hansen (1981).

STUDY AREAS

The studies were made in Denmark in Køge Bay Seaside Park and Ølsemagle Revle (Fig. 1), both offshore barriers situated 20 km apart, on the coast of the Baltic Sea. Ølsemagle Revle was created by natural processes: interaction of sand deposition and plant growth during the period 1900–1930. In contrast, Køge Bay Seaside Park was planned by architects and constructed for recreational purposes, in the years 1978–1980.

Ølsemagle Revle covers 200 ha and consists of a 5 km sandy beach with a well-developed strandline vegetation, a row of dunes with a height of approximately 3 m, and a salt marsh with a *Phragmites–Scirpus* swamp on the landward side of the barrier which encloses a lagoon. The salt marsh has never been grazed or mown. The only man-made facility is a constructed dam with an access road. A comprehensive study of the vegetation was made by Gravesen and Vestergaard (1969).

Køge Bay Seaside Park covers 500 ha and consists of 8 km of sandy beach with 3-m high artificial dunes

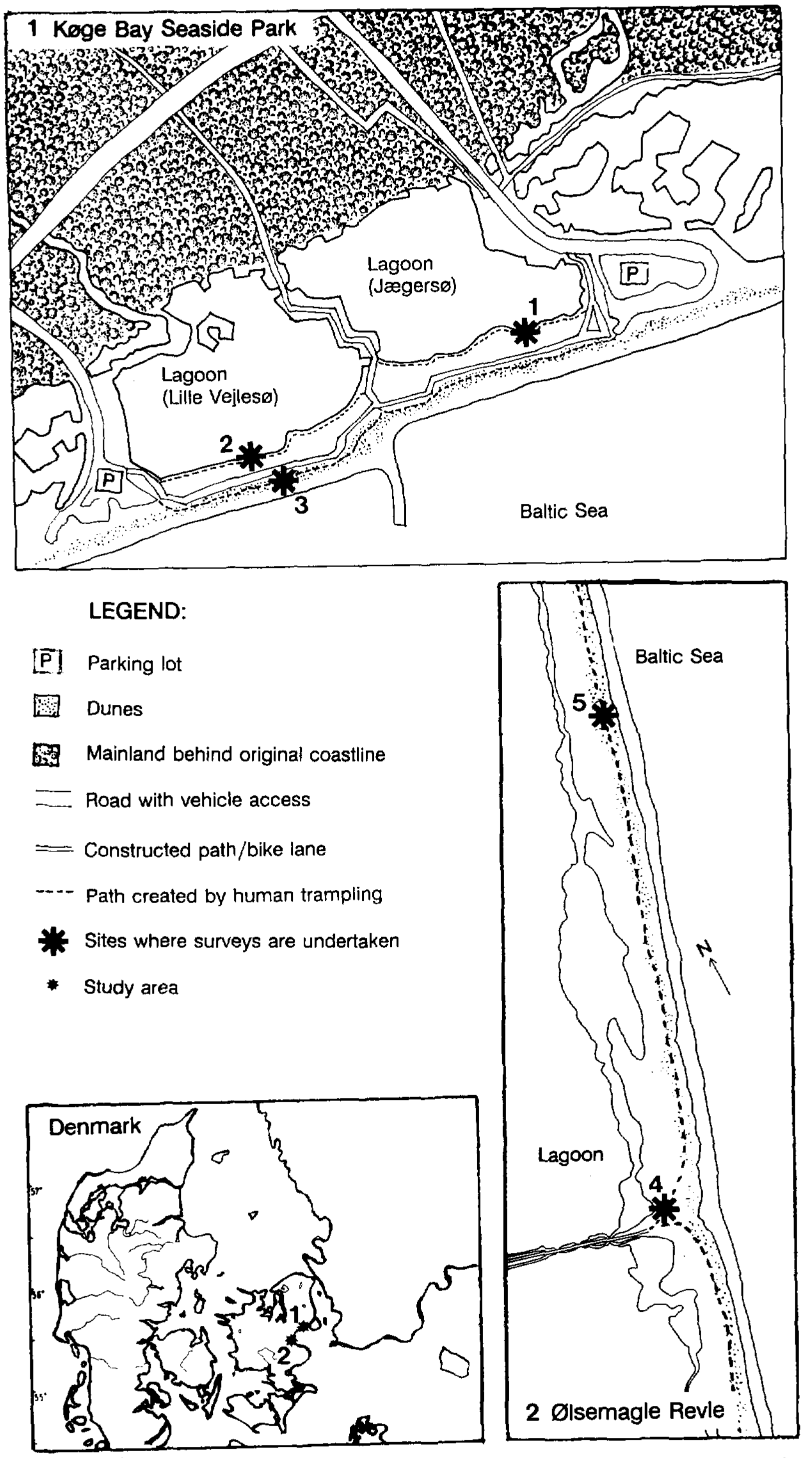

Fig. 1. Map showing the location of the study areas in Denmark (inset bottom left), and the position of the study sites 1–5 in Køge Bay Seaside Park (top) and Ølsemagle Revle (bottom right).

constructed on two long, narrow offshore barrier islands. The new artificially advanced coastline is connected with the original natural coastline by bridges and dykes. Behind the offshore barriers are six lagoons. The following vegetation types and plant communities are present: sandy beach, sand dunes, grasslands, former tidal meadows, lagoon shores, roadsides, shrubberies, and small planted groves. The grasslands were sown in 1979 with a seed mixture of grasses consisting of *Festuca rubra, F. arundinacea, Lolium multiflorum* and *L. perenne*. In the artificial dunes *Ammophila arenaria* was planted in 1978. All other species occurring in the area in 1992 have been invading as a result of primary succession (Hansen & Vestergaard, 1986). Several facilities for visitors are available: harbours, roads, parking areas, toilets, life guards, ice-cream stands, etc. Being closer to Copenhagen city and having all the recreational facilities, Køge Bay Seaside Park is visited by more than 500,000 people each year. In contrast, Ølsemagle Revle receives less than 100,000 visitors in the same period.

Table 1. Percentage frequency of 32 taxa including bare soil in +, trampled path centre, and –, untrampled surroundings at five sites

Site 1, mown grassland; site 2 unmown grassland; site 3, artificial dune; site 4, natural salt marsh; site 5, natural dune. The species are tested by likelihood-ratio χ^2 for whether their occurrence is independent of trampling impact. Results are divided into groups according to their response. G^2 = Likelihood ratio value (d.f. = 1) *** $p < 0{\cdot}001$, ** $p < 0{\cdot}01$, * $p < 0{\cdot}05$. Favoured, species occurring only on the paths; Vulnerable, species occurring only in untrampled situations; Indifferent, species occurring in both situations.

Species	Site 1		Site 2		Site 3		Site 4		Site 5		G^2	Significance
	+	–	+	–	+	–	+	–	+	–		
Favoured												
Bare soil	100	100	100	25	100	100	85	–	100	60	52·099	***
Elytrigia repens	—	—	—	—	90	30	—	30	—	—	3·897	*
Festuca arundinacea	10	—	80	5	—	—	—	—	—	—	20·103	***
Glaux maritima	—	—	—	—	—	—	55	15	—	—	4·916	*
Leymus arenarius	—	—	—	—	—	—	—	—	75	25	5·788	*
Vulnerable												
Bryophytes	70	90	65	70	—	100	—	20	60	85	23·971	***
Lichens	—	—	—	5	—	80	—	—	—	10	28·338	***
Cirsium arvense	5	30	—	15	15	55	—	—	—	—	13·101	***
Cerastium semidecandrum	—	—	—	—	—	30	—	—	—	25	15·890	***
Erigeron acer	5	—	5	5	5	55	—	—	—	—	6·220	*
Holcus lanatus	—	—	—	95	—	—	—	—	—	—	28·338	***
Hypochoeris radicata	—	—	—	—	—	—	—	—	15	60	6·220	*
Rumex acetosella	—	10	5	95	—	—	—	—	20	50	25·034	***
Tanacetum vulgare	—	—	—	—	—	—	—	—	15	80	10·700	**
Trifolium arvense	10	90	—	65	—	20	—	—	—	—	30·969	***
Viola tricolor	—	—	—	—	—	—	—	—	5	65	12·978	***
Indifferent												
Agrostis stolonifera	—	—	90	90	—	—	100	95	—	—	0·021	ns
Ammophila arenaria	—	—	90	100	—	—	—	—	—	—	0·130	ns
Ammophila × *Calamagrostis*	—	—	—	—	—	—	5	—	95	100	0·000	ns
Chamaenerion angustifolium	—	—	—	—	30	65	—	—	—	—	2·911	ns
Dactylis glomerata	15	30	65	60	—	—	—	—	—	—	0·142	ns
Festuca rubra	100	100	100	100	30	—	100	100	—	20	0·088	ns
Festuca ovina	—	—	—	—	80	100	—	—	—	—	0·543	ns
Hippophaë rhamnoides	30	—	5	30	—	—	—	—	—	—	0·082	ns
Honckenya peploides	—	—	—	—	—	—	—	—	25	30	0·096	ns
Lathyrus japonicus	—	—	—	—	60	45	—	—	5	30	0·000	ns
Odontites verna	—	—	—	—	—	—	95	95	—	—	0·00	ns
Phragmites australis	25	—	—	—	—	—	55	60	—	—	0·666	ns
Plantago maritima	—	—	—	—	—	—	100	80	—	—	0·543	ns
Poa pratensis	—	10	10	15	—	—	5	5	15	25	1·629	ns
Scirpus maritimus	—	—	—	—	—	—	45	65	—	—	0·821	ns
Taraxacum spp·	100	100	95	95	95	100	—	—	10	10	0·021	ns
Trifolium repens	30	5	100	100	—	—	5	5	—	—	0·677	ns

METHODS

Five paths, with a width of at least 1 m, and their surrounding communities were selected as survey sites. Three are situated in Køge Bay Seaside Park: one on top of the artificial dunes (site 3) and two in the grasslands behind the dunes. The grassland at Jægersø (site 1) is cut once a year and *Hippophaë rhamnoides* is controlled with herbicides, while the grassland at Lille Vejlesø (site 2) is undergoing natural development without any management. Two paths are situated on Ølsemagle Revle: one on the dune top (site 5) and one in the salt marsh (site 4). (Fig. 1). The paths in Køge Bay Seaside Park are used by approximately 10 visitors each day (yearly average, according to the Park headquarters). The use of the paths at Ølsemagle Revle is not known. However, from counts during the survey it is estimated that the paths are used by five visitors daily.

In July 1993, 20 1-m^2 quadrats were placed along the centre of all five paths 0.6 m apart, and a similar set of quadrats placed in the vegetation alongside, 2·5 m from the centre of the path. Other studies have shown that people tend to follow paths very strictly (Bayfield, 1973; Frederiksen, 1977; Kardell, 1978; Hylgaard, 1980), and therefore the vegetation outside the paths can be regarded as untrampled. A total of 100 untrampled and 100 trampled plots were thus analysed.

In each plot the cover of individual species was measured using the Hult-Sernander-DuRietz scale of cover classes (Malmer, 1974). In the statistical treatment of data the cover values were transformed into the following percentage values (Hansen & Jensen, 1972): less than 1/16 = 2%; 1/16–1/8 = 9%; 1/8–1/4 = 18%; 1/4–1/2 = 36%; and more than 1/2 = 72%. Frequency of species was measured as the percentage occurrence in the 1-m^2 plots. Species diversity was measured as number of species per plot based on an average from 20 plots. Plant nomenclature follows Hansen (1981).

Table 2. Percentage frequencies of 33 taxa grouped according to their relative occurrence on either trampled path (+) or untrampled surroundings (–)

For explanation of sites and categories, see Table 1.

Species	Site 1 +	Site 1 –	Site 2 +	Site 2 –	Site 3 +	Site 3 –	Site 4 +	Site 4 –	Site 5 +	Site 5 –
Favoured										
Lolium perenne	—	—	20	—	—	—	5	—	—	—
Poa annua	—	—	5	—	—	—	—	—	—	—
Spergularia marina	—	—	—	—	—	—	35	—	—	—
Tussilago farfara	5	—	—	—	—	—	—	—	—	—
Vulnerable										
Aira praecox	—	—	—	—	—	—	—	—	—	10
Anthyllis vulneraria	—	5	—	5	—	—	—	—	—	—
Arenaria serpyllifolia	—	—	—	—	—	5	—	—	—	—
Atriplex prostrata ssp. *prostrata*	—	—	—	—	—	—	—	5	—	—
Carduus crispus	—	—	—	5	—	—	—	—	—	—
Conyza canadensis	—	—	—	—	—	5	—	—	—	5
Galium verum	—	—	—	—	—	5	—	—	—	—
Leontodon autumnalis	—	—	—	—	—	—	—	10	—	—
Melilotus alba	—	5	—	5	—	—	—	—	—	—
Plantago lanceolata	—	—	—	15	—	—	—	—	—	—
Rosa canina	—	—	—	5	—	—	—	—	—	—
Rumex crispus	—	—	—	—	—	5	—	—	—	—
Tragopogon pratensis	—	—	—	—	—	10	—	—	—	—
Trifolium dubium	—	—	—	30	—	—	—	—	—	—
Triglochin maritimum	—	—	—	—	—	—	—	5	—	—
Senecio vernalis	—	—	—	—	—	10	—	—	20	85
Vicia sativa ssp. *angustifolia*	—	10	—	5	—	—	—	—	—	—
Vicia hirsuta	—	—	—	35	—	—	—	—	—	—
Indifferent										
Artemisia vulgaris	10	15	5	—	—	—	—	—	—	—
Carex arenaria	—	—	—	—	30	5	—	—	—	—
Cerastium fontanum ssp. *triviale*	5	5	—	5	—	—	—	—	—	—
Elytrigia junceiforme	—	—	—	—	—	—	—	—	35	10
Juncus gerardi	—	—	—	—	—	—	15	15	—	—
Lotus tenuis	—	—	—	—	—	—	10	25	—	—
Potentilla anserina	—	—	—	—	—	—	10	15	—	—
Rosa rugosa	—	—	—	5	10	30	—	—	—	—
Trifolium pratense	15	5	—	10	—	—	—	—	—	—
Triglochin palustre	—	—	—	—	—	—	5	15	—	—
Vicia cracca	—	—	—	—	—	—	5	10	—	—

Species resistance to human trampling and their ability to regenerate is to a large extent dependent upon the position of their growth points and surviving buds (Burden & Randerson, 1972; Liddle & Greig-Smith, 1975*b*; Hylgaard & Liddle, 1981). Raunkiær's (1934) life-form classification of species is therefore used here. Graminoids (including Poaceae, Juncaceae and Cyperaceae) are treated as a special group because of their flexible, linear leaves, and their ability to regenerate after trampling (Bates, 1935; Chappell *et al.*, 1971; Page *et al.*, 1985).

Paths and untrampled surroundings were compared with respect to the frequency of occurrence of 30 species, together with bare soil, lichens, and bryophytes, using a likelihood-ratio χ^2-test. The remaining number of species (22) occurred too infrequently for the χ^2-test to be valid.

RESULTS

Frequency of species measured on the trampled path centres compared with the untrampled surroundings at all sites is shown in Tables 1 and 2. Figure 2 shows the number of species in each plant community. The highest number of species (24), was found in the unmown grassland of site 2. The total number of species was reduced significantly by the trampling impact at all sites (Table 3), although in the mown grassland (site 1) the same number occurred in both situations, and in the natural salt marsh (site 4) little difference was found. The reduction was most noticeable among the forbs, in contrast to the grasses of which there are generally more species on the trampled path.

The species diversity of the communities was generally low and the highest diversity (>8 species/m^2) was found in the unmown, untrampled grassland (site 2) (Fig. 3). The diversity decreased significantly as a result of the trampling impact. The reduction was largest in the natural dune and in the unmown grassland, whereas no reduction occurred on the path in the salt marsh, site 4.

The total vegetation cover was decreased by trampling impact (Fig. 4). Bryophytes and lichens were severely reduced while grass cover was most reduced in

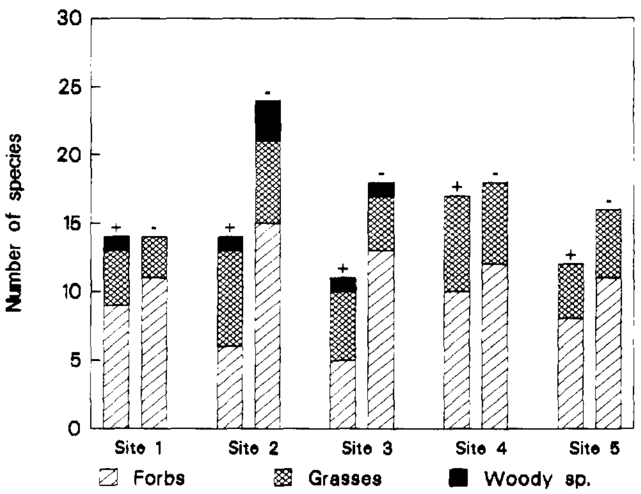

Fig. 2. Number of vascular plant species at five sites: site 1, mown grassland; site 2, unmown grassland; site 3, artificial dune; site 4, natural saltmarsh; site 5, natural dune. The species are divided into forbs, graminoids (Poaceae, Juncaceae and Cyperaceae), and woody species on the trampled centre of the paths (+) compared with the untrampled surroundings (–).

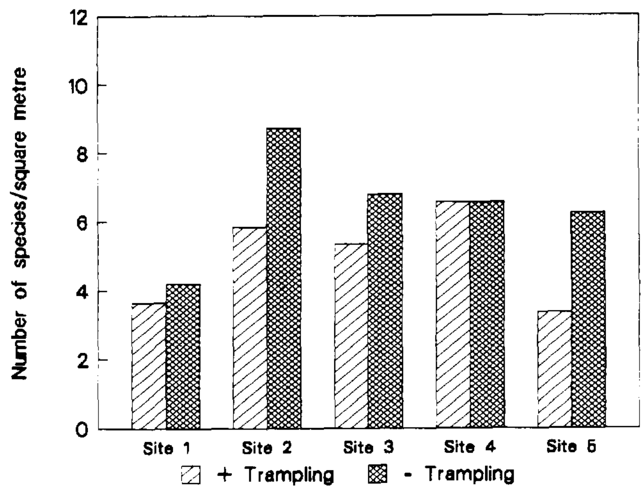

Fig. 3. Diversity measured as number of species per m^2 (average based on 20 m^2) on the trampled path centre (+) compared with the untrampled surroundings (–).

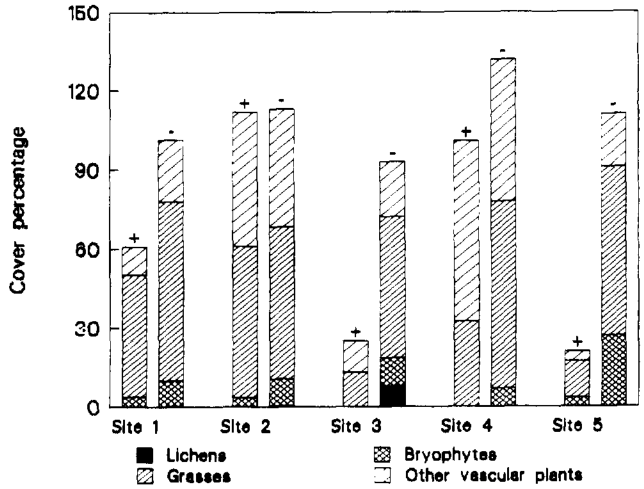

Fig. 4. Percentage cover of lichens, bryophytes, graminoids (Poaceae, Juncaceae and Cyperaceae), and other vascular plants on trampled path centres (+) and untrampled surroundings (–).

the dune communities (sites 3 and 5). In contrast the percentage cover of other vascular plants was not significantly reduced (Table 3). For instance, *Trifolium repens* and *Taraxacum* spp. showed higher cover values on the trampled paths.

Figure 5 shows the percentage distribution of life-forms in the five sites (untrampled surroundings). It appears that the vegetation of the grasslands as well as the salt marsh is strongly dominated by hemicryptophytes. In the artificial dune, annuals (therophytes) are the prevalent life-form, whereas in the natural dune the therophytes, hemicryptophytes and geophytes are almost equally important. The category 'others' (which includes chamaephytes and phanerophytes) was only represented on the sites in the man-made Køge Bay Seaside Park. The number of therophytes was strongly reduced and there was also a significant reduction in hemicryptophytes. The number of geophytes increased

Table 3. Results of a t-test based on the differences between trampled path and untrampled surroundings, calculated from the everage and standard deviation of the five sites

	Increase/ decrease[a]	t-test, d.f.=4	
Total number of species	(–)	2·4650	*
Diversity (species per m^2)	(–)	2·1738	*
Number of graminoids	(+)	1·6771	ns
Number of forbs	(–)	3·1534	*
Number of therophytes	(–)	2·9418	*
Number of hermicryptophytes	(–)	6·7083	**
Number of geophytes	(+)	1·1181	ns
Number of other life-forms	(–)	0·6594	ns
Percentage cover of graminoids	(–)	3·8351	**
Percentage cover of other species	(–)	0·6416	ns

[a]+, overall increase as a result of the tramplings; –, overall decrease.

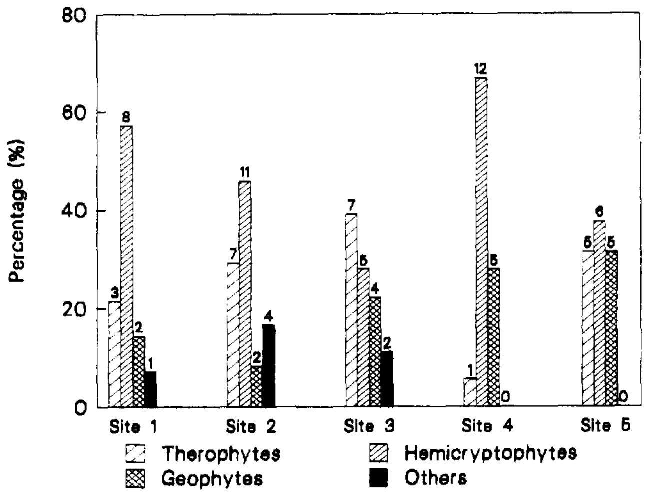

Fig. 5. Percentage distribution of the life-forms (according to Raunkiær, 1934) in the five communities in the untrampled situations. The category 'others' includes chamaephytes and phanerophytes. The numbers above the columns indicate the number of species in each category.

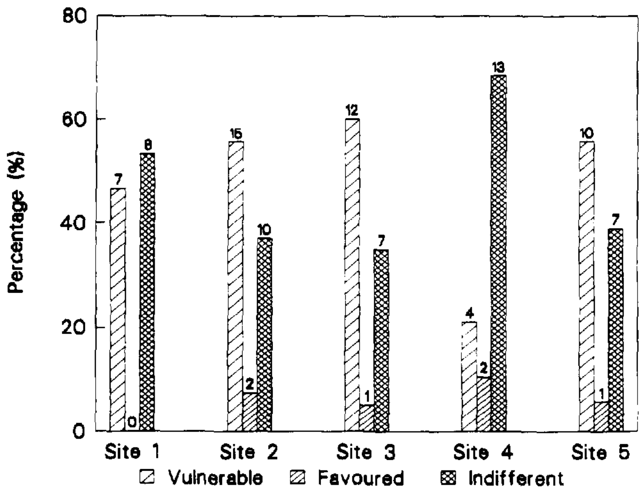

Fig. 6. All species were divided into three categories, i.e. vulnerable, favoured, or indifferent. Their percentages in the untrampled situation of the five communities were recorded. Numbers above the columns indicate the actual number of species in the category.

on the trampled paths in all communities, but this increase was not significant (Table 3).

All species are classified as vulnerable, favoured, or indifferent according to their scores in the χ^2-test (Table 1), or their relative occurrences on either the paths or the untrampled surroundings if their numbers are too low for the test to be valid (Table 2). There appeared to be a significantly lower number of occurrences on the path centre of all species in the 'vulnerable' group, whereas species in the 'favoured' group showed a strong significance for occurrence on the trampled path. Figure 6 shows the distribution of species in the three categories in untrampled surroundings at the five study sites. Vulnerable species contributed the majority in the dunes (sites 3 and 5) and in the unmanaged grassland (site 2). The mown grassland (site 1) had an almost equal number of vulnerable and indifferent species, while the salt marsh (site 4) was dominated by indifferent species. All five sites were tested for differences in number of vulnerable and resistant (= favoured + indifferent) species. The salt marsh, site 4, differed significantly from the unmown grassland, site 2 ($G^2 = 5{\cdot}718$, d.f. = 1, $p = 0{\cdot}017$ *), and the dune communities, site 3 ($G^2 = 6{\cdot}325$, d.f. = 1, $p = 0{\cdot}012$ *), and site 5 ($G^2 = 4{\cdot}794$, d.f. = 1, $p = 0{\cdot}029$ *).

DISCUSSION

The trampling in the five communities (estimated to be 1815–3630 passages per year) can be considered as very light, even though it creates paths and reduces the vegetation cover and species diversity, because the paths retain a persistent vegetation. The actual use of the paths, i.e. the number of visitors per year, is very difficult to measure, as it varies throughout the year and is largely dependent on weather conditions. According to Burden and Randerson (1972) 7500 passages per year would cause complete loss of vegetation in both dunes and salt marsh; 2889 passages were found to reduce the vegetation cover of *Ammophila*-dominated dunes by 50% (Boorman & Fuller, 1977).

Like any other disturbance, trampling can create open spaces for new species to become established (Sousa, 1984). For example, *Spergularia marina*, an annual which is unable to establish in a dense, saturated community, was only recorded on the path in the salt marsh. Similarly some species, such as *Glaux maritima*, cannot persist in untrampled situations where faster-growing more competitive species tend to dominate (Burden Randerson, 1972).

Some vascular plants, such as *Trifolium repens*, can withstand light trampling and take advantage of the suppression of more sensitive neighbours by forming dense mats as on path 2. On the other hand, both lichens and bryophytes appear to be very vulnerable to trampling, as found by Hylgaard (1980) and Bowles and Maun (1982). The reason is that these plants break easily under dry conditions and trampling in coastal ecosystems is often more prevalent in dry weather. Lichens are hardly ever able to regenerate after trampling, as they are dependent on organic matter (Johnsen & Søchting, 1993), which is also reduced by wear.

Species like *Trifolium arvense, Viola tricolor* and *Cerastium semidecandrum* are easily damaged mechanically, because their delicate, erect stems dry out early in the season. As they possess no buds from which they can regenerate, they are very vulnerable to trampling. It is often considered that rosette plants can withstand trampling impact (Bates, 1935; Burden & Randerson, 1972), but the present study indicates that some rosette species are vulnerable, for instance *Hypochoeris radicata* and *Leontodon autumnalis*.

Grassland and salt marsh

After 15 years the grasslands in Køge Bay Seaside Park consist mainly of naturally colonized species (Hansen & Vestergaard, 1986). They differ from the natural salt marsh, because they are never flooded and therefore lack typical halophytic vegetation. The grasslands contain a lower number of resistant geophytes and a higher number of vulnerable therophytes compared with the salt marsh and therefore appear to be significantly more vulnerable to the impact of human trampling.

Although the mown grassland (site 1) and the unmown grassland (site 2) are on similar soils, have the same initially sown species, and have been open to colonization from the same sources, they are quite different as a result of management. The mown grassland possesses fewer species overall and a lower species diversity, but more species indifferent to trampling than the unmown grassland. The vegetation structure and the floristic composition of both trampled and untrampled situations in site 1 are very similar to those of the trampled situation at site 2. Species which are favoured by trampling are to some extent also favoured by mowing (Grime, 1979; Bakker, 1985). The mown grassland does not differ significantly in vulnerability to trampling from the natural salt marsh, which has a naturally resistant vegetation. It appears that mowing once a year can change the vegetation towards a more resistant type, but mowing has not increased either the number of grasses or the total vegetation cover. Both these features are believed to contribute to increasing the resistance of a community (Hylgaard & Liddle, 1981; Bakker, 1985).

Dunes

The dunes appear to be the most vulnerable of the communities studied in respect to vegetation cover, as they have a high percentage of sensitive species and few that benefit from trampling. Vehicle traffic affects dunes more than grasslands with respect to vegetation cover (Hosier & Eaton, 1980). No significant differences in vulnerability were found between the artificial dunes of Køge Bay Seaside Park and the natural dunes of Ølsemagle Revle. In both sites the trampled area was characterized by geophytes typical of the embryonic or mobile dunes. In contrast the surrounding stabilized dunes had a more dense vegetation cover, many annual species, and a similar low percentage of open ground as in the mown grassland. The vegetation of embryonic and mobile dunes consists primarily of geophytes, able to regenerate after natural erosion processes as well as after trampling, in contrast to other pioneer communities where the vegetation normally consists of annuals. The number of therophytes and 'others' is larger in stabilized dunes (Raunkiær, 1934). The man-made dunes of Køge Bay Seaside Park, which contains a higher number of annuals and woody species, are in a more advanced stage of succession compared with the natural dunes. Even if Ølsemagle Revle is considerably older than the Seaside Park the latter appears to have a higher 'ecological age'. Stabilized dunes are considerably more vulnerable to trampling than mobile dunes (Hylgaard, 1981; Johnsen & Søchting, 1993).

The dunes of NW-Europe are in some places threatened by eutrophication and afforestation leading to undesired stabilization (van der Laan, 1985). Efforts such as grazing are made to reverse vegetation succession, to stimulate sand movement and to secure the dynamic dune processes (van Dijk, 1992). The impact of human trampling in the sites studied helps to keep the dunes in a young, non-stabilized stage and can be used for the conservation of mobile dunes.

Mobile dunes can easily regenerate after disturbance as no changes are induced in the basic soil conditions. In the grasslands and salt marsh, where soil moisture levels are higher, trampling may result in irreversible changes in the soil, and there may be problems for regeneration of the vegetation cover on compacted soil after heavy trampling (Beeftink, 1979).

CONCLUSION

Light trampling is beneficial to seashore communities, because it keeps the vegetation in an immature, dynamic stage, even if it also changes the vegetation composition and decreases the species diversity in the more vulnerable communities. In the artificial coastal area the landscape configurations are square, linear and straight, and creation of paths has provided a more natural appearance to the landscape. A controlled, light trampling impact, of for instance 5–10 visitors per day, may contribute to securing the continuation of an open vegetation.

Human trampling at the present levels involves no serious detrimental effects on the five communities studied. If, however, the number of visitors should increase, a loss of important species, destruction of vegetation cover and erosion are likely, and impoverishment of the landscape and recreational values may result. Management can improve the recreational carrying capacity of the area, but even low-intensity management can change the original vegetation and landscape morphology.

Artificial coastal areas may relieve some of the pressure on the natural beaches, but creation of man-made coastal ecosystems cannot solve the problems of wear. Building of artificial coastal areas is rarely possible, and can never of course compensate for the reduction of natural areas caused by human disturbance. Plant communities created on an artificial basis can be equally vulnerable to the impact of human trampling as those created through natural processes.

ACKNOWLEDGEMENTS

I would like to thank Gitte Calov, Jørgen Jensen, and Kjeld Hansen for critical and constructive comments on the manuscript. Appreciation is extended to Køge City municipal authorities for providing mapping material and to the park headquarters of Køge Bay Seaside Park for information on management, visitors numbers, etc. This research was funded by a grant from the Royal Veterinary and Agricultural University.

REFERENCES

Bakker, J. P. (1985). The impact of grazing on plant communities, plant populations and soil conditions on salt marshes. *Vegetatio*, **62**, 391–8.

Bates, G. H. (1935). The vegetation of footpaths, sidewalks, cart-tracks and gateways. *J. Ecol.*, **23**, 470–87.

Bayfield, N. G. (1973). Use and deterioration of some Scottish hill paths. *J. Appl. Ecol.*, **10**, 635–44.

Beeftink, W. G. (1979). The structure of salt marsh communities in relation to environmental disturbances. In *Ecological processes in coastal environments*, ed. R. L. Jefferies & A. J. Davy. Blackwell Scientific Publications, Oxford. pp. 77–93.

Boorman, L. A. & Fuller, R. M. (1977). Studies on the impact of paths on the dune vegetation at Winterton, Norfolk, England. *Biol. Conserv.*, **12**, 203–16.

Bowles, J. M. & Maun, M. A. (1982). A study of the effects of trampling on the vegetation of Lake Huron sand dunes at Provincial Park. *Biol. Conserv.*, **24**, 273–83.

Burden, R. F. & Randerson, P. F. (1972). Quantitative studies of the effects of human trampling on vegetation as an aid to the management of semi-natural areas. *J. Appl. Ecol.*, **9**, 439–57.

Carlson, L. H. & Godfrey, P. J. (1989). Human impact management in a coastal recreation and natural area. *Biol. Conserv.*, **49**, 141–56.

Chappell, H. G., Ainsworth, J. F., Cameron, R. A. D. & Redfern, M. (1971). The effect of trampling on a chalk grassland ecosystem. *J. Appl. Ecol.*, **8**, 869–82.

Edmond, D. B. (1962). Effects of treading pasture in summer under different soil moisture levels. *N.Z. J. Agric. Res.*, **5**, 389–95.

Frederiksen, P. (1977). Turistslitage i et klitlandskab, Skallingen 1976. *Geogr. Tidsskr.*, **76**, 68–77.

Goldsmith, F. B., Munton, R. J. C. & Warren, A. (1970). The impact of recreation on the ecology and amenity of semi-natural areas: methods of investigation used in the Isles of Scilly. *Biol. J. Linn. Soc.*, **2**, 287–306.

Gravesen, P. & Vestergaard, P. (1969). Vegetation of a Danish off-shore barrier island. *Bot. Tidsskr.*, **65**, 44–69.

Grime, J. P. (1979). *Plant strategies and vegetation processes.* J. Wiley, Chichester.

Hansen, K. (1981). *Dansk feltflora.* Gyldendal, Copenhagen.

Hansen, K & Jensen, J. (1972). The vegetation on roadsides in Denmark. Qualitative and quantitative composition. *Dansk Bot. Ark.*, **28**, 1–61.

Hansen, K. & Vestergaard, P. (1986). Initial establishment of vegetation in a man-made coastal area in Denmark. *Nord. J. Bot.*, **6**, 479–95.

Hosier, P. E. & Eaton, T. E. (1980). The impact of vehicles on dune and grassland vegetation on a south-eastern North Carolina barrier beach. *J. Appl. Ecol.*, **17**, 173–82.

Hylgaard, T. (1980). Recovery of plant communities on coastal sand-dunes disturbed by human trampling. *Biol. Conserv.*, **19**, 15–25.

Hylgaard, T. & Liddle M. J. (1981). The effect of human trampling on a sand dune ecosystem dominated by *Empetrum nigrum. J. Appl. Ecol.*, **18**, 559–69.

Jensen, F. (1993). Dunes — managements and threats. In *Danske klitter — overvågning, forvaltning og forskning*, ed. C. H. Ovesen & P. Vestergaard. Skov-og Naturstyrelsen, Copenhagen, pp. 25–31 (English summary).

Johnsen, I. & Søchting, U. (1993). Lichens dominated heathlands — dynamics and vulnerability. In *Danske klitter — overvågning, forvaltning og forskning*, ed. C. H. Ovesen & P. Vestergaard. Skov-og Naturstyrelsen, Copenhagen, pp. 58–63 (English summary).

Kardell, L. (1978). Vegetationsslitage — Katastrof eller bara olågenhet? *Sveriges Lantbruks Universitet, Avdelningen för Landskapsv ård, Rap.*, No. 12.

Liddle, M. J. & Greig-Smith, P. (1975*a*). A survey of tracks and paths in a sand dune ecosystem, I. Soils. *J. Appl. Ecol.*, **12**, 893–908.

Liddle, M. J. & Greig-Smith, P. (1975*b*). A survey of tracks and paths in a sand dune ecosystem, II. Vegetation. *J. Appl. Ecol.*, **12**, 908–30.

McDonell, M. J. (1981). Trampling effects on coastal dune vegetation in the Parker River National Wildlife Refuge, Massachusetts, USA. *Biol. Conserv.*, **21**, 289–301.

Magnusson, M. (1986). Månniskans påverkan på Sandhammerens dynområde i sydöstra Skåne. *Sv. Bot. Tidskr.*, **80**, 81–93 (English summary).

Malmer, N. (1974). Scandinavian approach to vegetation science. *Medd. Avd. Ekol. Bot., Univ. Lund*, **2**.

Meijer, L. W. (1992). Recreation in the Dutch Wadden dune areas, a curse or a blessing. In *Dune management in the Wadden Sea area. Proc. Trilateral Working Conference*, 3rd, ed. G. Hilgerloh. Nordeney, Germany 8–12 September 1991, pp. 55–61.

Page, R. R., da Vinha, S. G. & Agnew, A. D. Q. (1985). The reaction of some sand-dune plant species to experimentally imposed environmental change: a reductionist approach to stability. *Vegetatio*, **61**, 105–14.

Raunkiær, C. (1934). *The lifeforms of plants and statistical plant geography.* Clarendon Press, Oxford.

Sousa, W. P. (1984). The role of disturbance in natural communities. *Ann. Rev. Ecol. Syst.*, **15**, 353–91.

van der Laanl, D. (1985). Changes in the flora of the coastal dunes of Voorne (The Netherlands) in relation to environmental changes. *Vegetatio*, **61**, 87–95.

van Dijk, H. W. J. (1992). Grazing domestic livestock in Dutch coastal dunes: experiments, experiences and perspectives. In *Coastal dunes*, ed. Carter, R. G. W., Curtis, T. G. F. & Sheehy-Skeffington, M. J. Balkema, Rotterdam. pp. 235–50.