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Author(s): T. Hylgaard and M. J. Liddle
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THE EFFECT OF HUMAN TRAMPLING ON A SAND DUNE ECOSYSTEM DOMINATED BY *EMPETRUM NIGRUM*

By T. HYLGAARD AND M. J. LIDDLE*

Botanical Institute, University of Aarhus, 68, Nordlandsvej, DK—8240 Risskov, Denmark

SUMMARY

(1) The influence of trampling was studied on the outer dune heath of Skallingen, southwest Jutland. The total number of passages and the period of time over which trampling occurred were varied independently, on areas that had either received fertilizer applications or were unfertilized. The depth and width of paths were measured and the relative cover of the vegetation and species frequency determined.

(2) There was a linear relationship between the depth of the paths and the number of passages. 2560 passes lowered the soil surface by 28 mm. The width of paths increased with increasing numbers of passages. The paths were slightly deeper when trampled on a single day as opposed to the effect of trampling over a period of 4 months.

(3) Relative cover was reduced with increasing numbers of passages; after 200 passages cover was only 50%. This low carrying capacity is suggested to be the consequence of reduced vigour of the dominant species *Empetrum nigrum*, although it is not reflected in frequency measurements of this species. The frequency of four species *E. nigrum*, *Festuca rubra*, *Ammophila arenaria* and *Veronica officinalis* was largely unaffected by 150 passages but only two species, *Empetrum nigrum* and *Hypnum cupressiforme* survived 2560 passages.

(4) Addition of fertilizer only slightly increased plant cover on the paths but tended to produce a vegetation dominated by grasses.

(5) It is emphasized that all the consequences of a management operation need to be considered before it is carried out.

INTRODUCTION

The accelerating use of coastal zones for recreation has had a many-faceted effect on the ecology of natural and semi-natural areas. For example, the floristic composition of North European sand dune communities is affected by human trampling (Leney 1974; Liddle 1973; Westhoff 1967) and so is the productivity and growth form of the individual species occurring within it (Liddle & Greig-Smith 1975b). The vulnerability of different habitats depends, in part, on their species composition because plant species differ in their ability to tolerate trampling. Plants with therophytic and cryptophytic life forms are generally the least vulnerable to treading (Bates 1938) and morphological features like folded leaves and low growth also offer some protection against damage (Leney 1974; Liddle 1973; Streeter 1971). The effects of trampling also depend on the intensity of use, the time of year at which the use takes place and on the topography of the area (Bayfield 1971, 1973; Burden & Randerson 1972; Edmond 1962). A relationship between the vulnerability of vegetation and the primary productivity has been suggested, according to which, highly productive vegetation should be the most tolerant to trampling (Liddle 1975). It has not been shown

* Present address: The School of Australian Environmental Studies, Griffith University, Nathan, Brisbane, Queensland.

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whether the addition of fertilizers can raise the primary productivity of sand dune communities, and thereby increase their carrying capacity for recreational use.

This paper describes the results of two linked experiments carried out in a Danish sand dune community dominated by *Empetrum nigrum**. One examines the effects of two different distributions of use in time and the other examines the interaction of the consequences of the addition of fertilizers with this use.

SITE DESCRIPTION

General

The investigation was carried out in the coastal sand dunes of Skallingen, a peninsula situated on the southwest coast of Jutland, Denmark. The dune system, which is about 8 km long and 200–800 m wide, runs in a northwest to southeast direction, with the prevailing winds coming from west to northwest. According to early maps the dune development started 300 to 400 yr ago and at present the system consists of five to ten more or less coherent rows of sand dunes with a maximum height of about 15 m.

The area investigated is part of the outer dune heath (Böcher 1954) dominated by *Empetrum nigrum* and *Hypnum cupressiforme**. Here, the ground water table is always situated at least 2 m below the soil surface. The water content of the top soil (0–5 cm) was 10·5% (vol : wt.) in late August 1976, and the field capacity 32·5% (vol : wt.). pH of the top soil was 6·3 and the grain size distribution was 2·00–0·60 mm, 0·1%; 0·60–0·20 mm, 72·5%; 0·20–0·06 mm, 27·2%; and <0·06 mm, 0·2% (Hylgaard 1976).

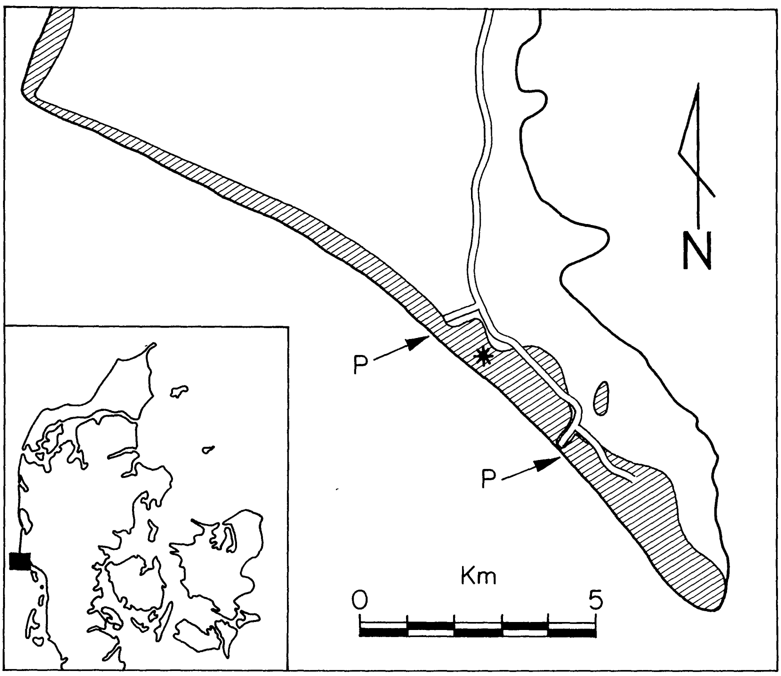

FIG. 1. The penisula of Skallingen showing concrete roads (—); parking places, (P); the experimental area (*), and sand dunes ▨. Inset: Jutland showing peninsula of Skallingen ■.

* The nomenclature of higher plants follows Rostrup (1973) and of bryophytes Anderson *et al.* (1976).

Reaction impact

Skallingen has been conserved as a nature reserve since 1938 (Mentz 1940). Walking is permitted throughout the reserve but use of cars and horses is restricted to a concrete road which runs through the peninsula, and the two side roads to a northern and a southern car park respectively (Fig. 1). During the last 5–10 yr the number of visitors to Skallingen has increased considerably and parts of the dune system, especially those around the two car parks, are now suffering considerable damage through wear of the vegetation and subsequent increased erosion. In June, July and August 1976, when the greatest part of recreation activities normally takes place, the extent and pattern of recreation on the peninsula was recorded (Hylgaard 1977). During these 3 months Skallingen was visited by a total of 180 000 persons. Eighty-four thousand of these visitors stayed in a rather restricted area close to the northern car park, an average of about 1000 persons per day. Only 0·5% or an average of five persons per day, spent time in the outer dune heath where the present investigations were carried out. The rest went directly to the sparsely vegetated white dunes and the beach. The damage to the outer dune heath associated with the northern car park is therefore mainly due to the passage of users to the neighbouring white dune and beach areas.

METHODS

Layout of the experiments

Trampling experiment

The effect of human trampling was studied on the outer dune heath near the northern car park. In April 1976 a visually homogeneous unworn area of 20 × 20 m was selected and fenced to prevent any uncontrolled trampling. This area was appropriate for eight 20 m long simulated footpaths with intervening control strips, perpendicular to the coastline. On 7 May 1976 trampling was initiated on the first four of these paths. The total number of passes (40, 160, 640 and 2560) were based on those used by Liddle (1973) so that a direct comparison could be made. The highest number of passages is also in the order of magnitude of the average daily impact on the area in the previous year. The passes on the four footpaths were distributed through the summer and fitted to the actual time distribution of visitors recorded by automatic counters in the area (Hylgaard 1977), thus simulating the intensity of recreational use of the area during that period (Table 1). During the treatment the proportion of wear between the four paths was kept constant.

TABLE 1. The cumulative number of passages on the experimental footpaths. 7 May to 22 August 1976

Date	Cumulative no. of visitors to the northern parking area	Footpath 1	2	3	4	5	6	7	8
7 May		–	2	–	8	–	32	–	128
30 May		–	10	–	40	–	160	–	640
3 July	27 790	–	12	–	48	–	192	–	768
7 July	34 940	–	18	–	72	–	288	–	1152
14 July	44 260	–	22	–	88	–	352	–	1408
21 July	55 180	–	24	–	96	–	384	–	1536
4 August	67 170	–	30	–	120	–	480	–	1920
11 August	73 760	–	34	–	136	–	544	–	2176
21 August		40	–	160	–	640	–	2560	–
22 August	84 250	–	40	–	160	–	640	–	2560

On 21 August 1976 four additional paths were created in the experimental area with the same total number of passes as the first four. These paths were completed on a single day (instantaneous) so that possible differences in effects of wear spread through a period of 4 months, and wear induced on a single day, could be examined. Single paths were used for each treatment partly to allow a realistic mode of walking and partly to reduce the time required for each treatment to a practicable level.

Treatment with mineral nutrients

The effects of fertilizers were investigated in the outer dune heath by applying mineral nutrients to 5 m at the south western end of the experimental area. This was done on three occasions during the summer, in late May, early July and mid-August. The quantities of salts were based on the levels used in agricultural practice for correcting deficiencies of nutrients in sandy soils (Table 2). The salts were evenly spread by hand in powder form.

TABLE 2. Composition of mineral nutrients g m^{-2}

NO_3	10·50	K	7·10
NH_4	3·30	Mg	0·65
PO_4	2·60	Br	0·05

Plus micro nutrients and 42·5 g of calcium.

Field records

One week after trampling on the simulated paths was finished, in late August 1976, the effects of the impact were recorded by the following methods.

Surface topography

This was only measured on that part of the experimental area which had had no additional fertilizers. Here three transects perpendicular to the eight footpaths were placed at random and along these a Zeiss Ni 2 levelling instrument was used for a geometric levelling with tacheometry (Møller 1977). On each path the height of the centre and the two edges were recorded. All sights were made at distances shorter than 50 m and the accuracy of the horizontal measurements was ± 10 cm and of the height measurements ± 1 mm. The relationship between surface levels of paths and $\log_{10}$ of the number of passes was examined by calculating lines to fit the two sets of data for trampling on a single day and trampling over a period of 4 months. A simple non-linear relationship $y = ax^2$ was found to give the best least squares fit for these data, where a is the fitted constant.

Width of the footpaths

The width of the eight footpaths to the nearest centimetre, was recorded in the part of the experimental area that had had no treatment with mineral nutrients. Twelve recordings were made on each footpath at intervals of 1 m. The edges of the footpaths were considered to be the points where clear changes in the vegetation cover, height or structure could be determined visually. However, as the edges of footpaths that had only forty passages were very diffuse, these were not measured. The line fitted to these data was based on the simple linear model $y = ax$, where a is the fitted constant.

Relative cover of the vegetation

The cover of live vegetation remaining after the various wear treatments was estimated visually and expressed as a percentage relative to the adjacent unworn vegetation. For that purpose a frame of 25 × 100 cm was placed continuously along the whole length of each of the eight footpaths in the fertilized as well as the unfertilized part of the fenced area. The value of percentage relative vegetation cover remaining after the various treatments (y) was fitted to ($\log_n + 1$) of the number of passages (x) by the logistic $Y = A + B/[1 + \exp(C + Dx)]$, and was constrained to pass through the point 0·100%.

Species frequency

The presence or absence of species was recorded using a circular sample area of 0·25 m^2 in the manner described by Raunkiaer (1918). The sampling was done both in natural unworn vegetation (−fertilizers) and on the footpaths that were created experimentally from May to August. On the unfertilized section of each of the four paths, fourteen records were made at intervals of 1 m and on each of the fertilized sections of the paths, seven records were made at intervals of 0·5 m. In natural unworn vegetation fourteen records were made at random. From these records the frequency of every species on each path (fertilized and unfertilized) and in natural vegetation was calculated as percent present out of the total number of records.

Standard errors were derived as follows. The variance of point p is given by the standard binomial theorem as $px(1-p)/n$, which has the maximum value of $0{\cdot}25/n$ when $p = 0{\cdot}5$ (or 50%), and the minimum value of 0 when $p = 1$ (100%) or 0. The standard errors shown for those observations where $p = 1$ or 0 are based on the conservative formula of $0{\cdot}25/n$.

RESULTS

Surface topography

There was evidence of a considerable lowering of the soil surface when subjected to trampling (Fig. 2). This lowering increased steadily in proportion to an increased number of passages. The rather high variation apparent in the figure is due to the very irregular surface morphology of the experimental area. The difference in height between the highest and the lowest points measured in the unworn vegetation is 94·4 cm and at distances of only 30 cm the height measurements sometimes diverged by as much as 13 cm. Two readings on the paths subject to wear over 3 months were omitted as one side of both paths was originally lower than the paths themselves. There was no significant difference in depth in response to the two types of wear treatment, although there was a tendency towards deeper footpaths being formed when the trampling was concentrated on one day.

Width of the footpaths

The width of the experimental footpaths increased considerably as the number of passages rose (Fig. 3). This relationship is statistically significant for both types of wear and the rate of widening appeared to be greater when paths were trodden for one day.

Relative cover of the vegetation

For all types of wear the relationship of the total number of passages to the relative cover of the vegetation can be approximated using a logistic model (Fig. 4).

Using this relationship it can be seen that in the unfertilized area relative cover was reduced to 50% after 200 passages and depressed below 2% after 2560 passages, which approximately corresponds to the daily number of passages by visitors in the remaining part of the dune system during the summer season. Impact concentrated in time tended to cause slightly less damage to the vegetation cover than an equivalent but prolonged impact

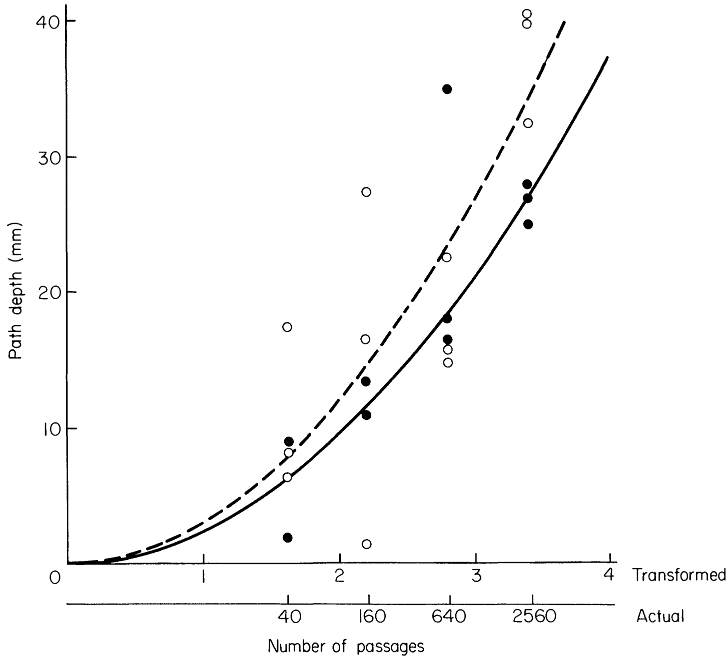

FIG. 2. The relationship between the number of passages and path depth for paths created over a period of 4 months (●—●: $y = 2{\cdot}36x^2$); and paths created in a single day (O---O: $y = 2{\cdot}99x^2$). $x = \log_{10}(n + 1)$ where n = number of passages. In both cases $r = 0{\cdot}91$. The null hypothesis that the two curves are statistically the same, just fails to be rejected ($P \simeq 0{\cdot}07$).

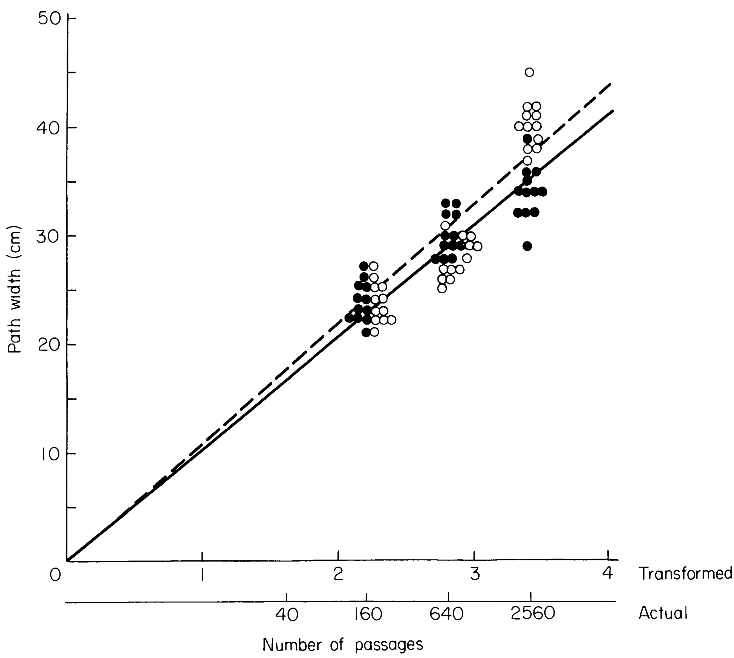

FIG. 3. The relationship between the number of passages and path width for paths created over a period of 4 months (●—●: $y = 10{\cdot}35x$); and paths created in a single day (O---O: $y = 10{\cdot}99x$); $x = \log_{10}(n + 1)$ where n = number of passages. There is no statistical difference between the two curves.

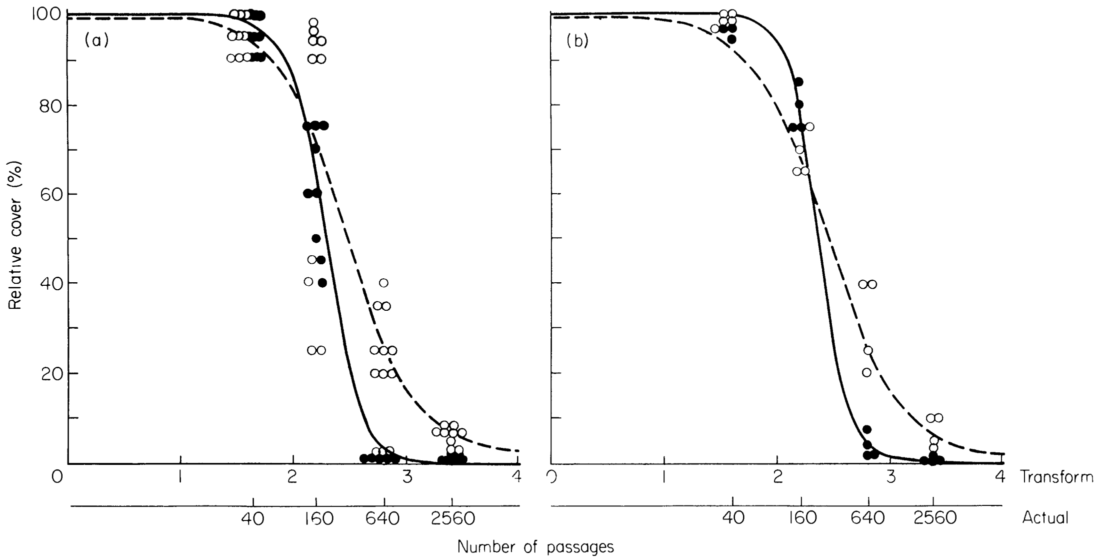

FIG. 4. The relationship between the number of passages and total relative cover of the vegetation for paths created over a period of 4 months (●——●); and paths created on a single day (O——O). (a) Paths on unfertilized area; (b) paths on fertilized area. Lines fitted by $y = A + B/[1 + \exp(C + Dx)]$. Where $x = \log_{10}(n + 1)$ and n = number of passages.

(Fig. 4(a) and (b)). Therefore, in terms of carrying capacity, paths of this type tolerated 116 passages more than paths when trampling was extended over four months, before cover was reduced to 50%.

Treatment with mineral nutrients had relatively little effect (Fig. 4(b)) and there is no significant difference in % cover between the paths treated with nutrient and the untreated paths subject to both types of wear treatment.

Species frequency

Of a total of nineteen species recorded, sixteen whose frequency exceeded 5% are discussed here (Fig. 5). It is evident that foot traffic had a profound effect on all the prominent species. This showed mainly as a reduction in frequency directly related to increased pedestrian impact as for example, for *Hypnum cupressiforme* and *Cerastium caespitosum* where the percentage drop after only forty passages amounted to 63% and 100% respectively. After 2560 passages, the approximate impact on an average summer day, only two species were still left in the unfertilized area, namely *Empetrum nigrum* (50%) and *Hypnum cupressiforme* (7%). In very few cases, moderate trampling tended to stimulate the plants to more vigorous growth such as was shown by *Carex arenaria* and *Polypodium vulgare* which exhibited a peak in frequency after forty passages and, in the case of *Polygala vulgaris* and *Veronica officinalis*, after 160 passages.

The effect of adding nutrients to the soil was apparently two-sided. It seems that when untrampled, a few of the species were able to use the extra nutrient supply for a more vigorous growth; these included *Dianthus deltoides*, *Poa pratensis*, *Cerastium semidecandrum*, *Polygala vulgaris* and *Veronica officinalis*. However, *Cerastium caespitosum*, *Carex arenaria* and *Polypodium vulgare* all had a considerably lower percentage frequency in the nutrient treated than in the untreated area, reflecting a less vigorous growth of these species when supplied with fertilizer. In untrampled areas nutrient addition

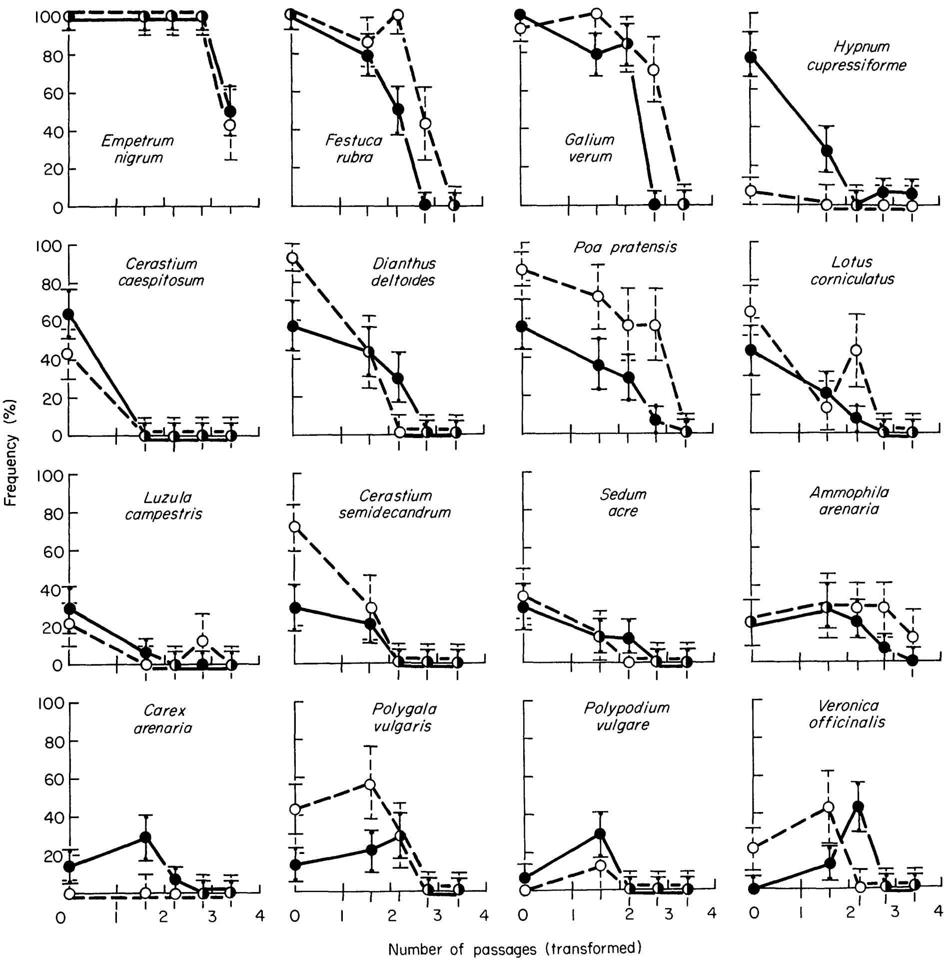

FIG. 5. The relationship between the number of passages and percentage frequency of the various species for unfertilized paths (●—●) and paths which had been fertilized (O---O). ± S.E. given.

tended to favour a few species at the expense of others; this led to a gradual change of the plant community. On the other hand, some species only responded to additional nutrients when wear was applied. The species in this group are *Festuca rubra*, *Galium verum*, *Lotus corniculatus* and *Ammophila arenaria*; the latter was the only species to benefit at the highest intensity of wear.

DISCUSSION

The successive lowering of the soil surface as a response to increased wear is likely to be, for the most part, a result of soil compaction. In the Aberffraw dune system Liddle & Greig-Smith (1975a) found a linear relationship between number of passages and the changes in bulk density, with a maximum recorded increase of 0·25 g cm^{-3}. An increase of 0·36 g cm^{-3} was reported in a sandy soil by Lutz (1945). The lowering of the soil surface can, however, only be due to soil compaction until the maximum value of bulk density is reached which, according to Liddle & Greig-Smith (1975a) may be expected after 1024 passages. In the present investigation, in a site where the largest proportion of sand grains is of a greater size than that of the Aberffraw sand (Liddle 1973), a continuous lowering of the surface was recorded from 40 to 2560 passages. As there was no decrease in the rate of lowering it may proceed even further, probably as an effect of soil erosion induced by trampling in which surface material is removed from the path by wind action. Surface lowering in sand dunes induced by trampling has been reported by Frederiksen (1977) who suggested the effect to be a response to a combination of factors including trampling intensity, a relief energy and elevation above the surrounding area. The present investigation, however, suggests that trampling intensity is the most important factor since the latter factors were of little prominence in the study area.

In addition to the general tendency towards deeper footpaths being formed when the number of passages was increased, there was clear evidence of a simultaneous widening effect. Bayfield (1973) demonstrated that path width can be related to features of the terrain such as wetness, roughness and slope as well as trampling intensity, whereas Frederiksen (1977) concluded that trampling intensity was the only causal factor. In the present investigation factors other than the number of passages seem to be involved in this widening process since the two types of wear show somewhat different results. One of these factors may be the specific response of the dominant species *Empetrum nigrum*. Microscopic examination of transverse leaf sections shows that the ericoid structure of leaves of *E. nigrum* is destroyed when they are subjected to trampling. In three to four days the colour of the leaves gradually changes from green to yellowish brown due to wilting, probably induced by increased transpiration losses. The leaves fall from the shoot approximately 1 week after trampling. On the footpaths that were trampled on a single day this wilting process did not have time to take place before completion of the trampling, in contrast to the footpaths where trampling was spread throughout the season. In the latter case the footpaths became very distinct a week after the first treatment so that they were easily followed when subsequent treatments were applied. When trampling was carried out on a single day the footpaths were much less distinct and consequently the chances of stepping aside greater, so that paths became broader. Bayfield (1973) has stressed that pedestrians tend to stay on the paths where it is easier to walk, and this is most probably an additional reason why the rate of widening eventually decreased when the treatment was spread over 4 months.

The reduction of vegetation cover induced by trampling reflects, for the most part, a reduction of *Empetrum nigrum* as this was the dominant species. The cover was reduced to 50% after 316 passages by the instantaneous treatment and after 200 passages when the trampling was spread over 4 months. Compared with the reports of Liddle (1973) from the Aberffraw dune system, where a 50% reduction was reached after 1828 passages, the vulnerability of the Skallingen dune system is rather high. The reason for this difference is probably that the dominant species in the Aberffraw experiments were various grasses which, according to Bates (1935, 1938), tolerate trampling better than most other plants. Furthermore, visual inspection showed that *Empetrum nigrum* was greatly reduced in vigour although this is not evident from the frequency records. *Empetrum nigrum* appears to be especially vulnerable because the leaves offer no protection to the other morphological structures, except when trampling stops before wilting occurs. This may also be the reason why the cover is slightly higher on the paths made on one day than on those made throughout the whole season.

A logistic relationship between total relative cover and log (number of passages + 1) was found to be adequate for all treatments. Similar results have been reported by Leney (1974) in terms of a reduction of height and dry weight of tillers and by Edmond (1962) for a reduction in biomass. Other authors report a peak of biomass in marginal areas, suggesting that low levels of trampling may stimulate greater production (Kellomäki 1973; Liddle & Greig-Smith 1975b), or an enhanced growth of a few species (Streeter 1971). In this case no increase in cover was recorded but the frequency records to some extent support the observations of Streeter since at least some species tend to occur more frequently when subjected to light trampling (*Carex arenaria*, *Polypodium vulgare*, *Polygala vulgaris* and *Veronica officinalis*). It was suggested by Streeter (1971) that growth stimulation could be related to the higher concentrations of phosphorous which were recorded in the trampled zones and which have also been demonstrated by Chappel *et al.* (1971). The results of the fertilizer experiment suggest that the growth of *Polygala vulgaris* and *Veronica officinalis* may be stimulated by the addition of nutrients.

The use of fertilizers in management to increase the 'carrying capacity' (or total cover on paths) seems inappropriate as a strategy on the outer dune heath that was studied as they had almost no effect on the total relative cover. These observations contradict the general assumption (Bayfield 1971; Speight 1973; Liddle 1975), but this may be due to the fact that most earlier experiments have been made in ecosystems dominated by grasses. This conclusion, however, depends on the assumption that an increase in productivity will be reflected in the measurement of relative cover. On the outer dune heath of Skallingen the consequence of adding mineral nutrients was a considerable increase in the relative cover of some species, particularly of the grasses *Poa pratensis* and *Ammophila arenaria*, and a marked decline of other species especially the bryophyte *Hypnum cupressiforme*. These effects are very similar to the observations of Willis (1963) at Braunton Burrows, U.K., where addition of fertilizers gradually changed the flora towards a grass dominated pasture. It is likely that adding fertilizers will eventually increase the resilience of the ecosystem but it is important to emphasize that the species composition will also be completely changed.

The results of the present investigation have emphasized the importance of human trampling as an environmental factor. Although the outer dune heath of Skallingen has no particular recreational interest, as judged from the behaviour of visitors, approximately 1000 persons per day passed through to the beach and back again in the summer of 1976. Eight-four thousand persons or approximately 168 000 passages spread over 3–4 months on an area about 100 m wide, is a large number when compared with the observations that 200 passages by one person in the same period may create a new footpath 24 cm wide and 15 mm deep, reducing vegetation cover by about 50% and the number of species by approximately 75%. The results also indicate that sustained use may cause a greater reduction in cover than instantaneous use. Addition of fertilizers may raise the carrying capacity a little, but it must be emphasized that an intervention such as this involves a complete alteration of the biotic environment initiated by floristic change towards a grass sward, presumably followed by a change in the fauna. The willingness to accept the secondary effects that are inevitably connected with all management techniques is, in the end, dependent on the declared objectives of the management programme and the final administrative decisions should always be taken on the basis of all available information that bears upon these objectives.

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