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The effect of recreational impacts on soil and vegetation of stabilised Coastal Dunes in the Sharon Park, Israel

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Abstract

Coastal sand dunes are considered among the most susceptible habitats to recreational use. The aim of this study was to monitor the impact of visitor use on soil and annual plants on long-established trails in the stabilised coastal dunes of the Sharon Park, Israel. The results indicate that:

1. The vegetation cover, height and species richness and diversity, as well as soil organic matter content were lower on trails subjected to high visitor use than that on trails under low use. However, soil compaction and moisture on high-use trails were higher than that on low use.
2. The rate of change in each of the vegetation properties moving outwards from the centre of the trail towards the undamaged area on its margins and beyond, was higher on trails under high visitor use than on low-use trails.
3. The impact of high visitor use is localised and limited to the trail boundaries and their immediate surroundings (6 m axis perpendicular to the trails), while the effect on low-use trails is dispersed over a larger area, apparently because the trail borders are less visually defined to the visitor.

The conclusion derived from this study is that the spatial damage caused to the park by the numerous low-use trails is higher than that caused by the trails under high visitor use. Thus, there is an immediate need to reduce the number of this type of trails and to rehabilitate them. © 2000 Elsevier Science Ltd. All rights reserved.

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1. Introduction

The demands of ecotourism have been increasing steadily for some years now. To meet these demands with the limited supply of open spaces with high landscape, faunal and floral values, ecological management must be taken into consideration so that the damage caused will be minimal and remediable. Among the extremely vital factors to decision making in determining the policy of their management are the soil and vegetation responses to various levels of recreational use.

Soil is the environmental factor that is stressed most immediately by the level of recreational activity, while sand soils react rapidly and more strongly than clay soils [1–4]. Visitor traffic and other recreational activities cause soil compression, the reduction in soil volume resulting from a loss of natural porosity, as well as a drop in the infiltration/percolation ratio which causes increased overland flow and erosion [2,3,5–9]. Cole [2], for instance, found that the soil bulk density was 20% higher and the infiltration percentage 80% lower in a camping area of the Grand Canyon in Arizona than in inaccessible parts of the same area. A decrease in the soil porosity volume also causes a reduction in the soil moisture [2,3,10]. The extent of this effect depends on the soil structure and texture. In sand soils, for instance, which are characterised by high porosity and low field capacity, trampling results surprisingly in increased soil moisture because of compaction and reduction in porosity volume. All of this is, of course, true only as far as the threshold of the carrying capacity for trampling and travel, beyond which threshold the moisture level decreases as it does for clay soils [3,4]. A high positive correlation has been reported between the intensity of visitor use and trail attributes (width, depth from the surface level and the degree of soil compaction) [4,11,12].

Recreational stress also reduces the amount of litter and organic matter in the upper layer of the soil [2,4,10]. This layer is of the greatest importance since it forms a buffer that protects the mineral soil beneath it from the stresses imposed from above. The organic matter also contributes nutrients to the soil, and is responsible to a considerable measure for soil stability [13,14]. Soils rich in organic matter and containing a thick layer of litter are more resistant to recreational stress than infertile soils that are poor in litter and organic matter content [10,11].

Vegetation is also affected by recreational activities. Several studies informed a negative correlation between recreational intensity and plant cover, plant height, species richness and species diversity. The species composition and the dominant life forms also vary with time [1,2,4,15–17]. Many studies have pointed out that the herbaceous plants, and particularly annuals, are more resistant than other life forms to recreational stresses [2,3,10,18,19].

Of all habitats, sandy ones are the most sensitive to any disturbance (including recreational use) [1,20]. Moreover, stabilised sand dunes that carry a climax vegetation community have been found to respond more strongly to any disturbance as compared with shifting and semi-stabilised sand dunes [21].

The studies on recreational impact on soil and vegetation are based on two different approaches. The first is the experimental approach in which controlled levels of recreational use are applied to previously undisturbed sites, usually on small plots.

Many investigators have taken this experimental approach in different vegetation types [11,17,21–23]. The second approach is based on observations on long established trails, assuming that the soil and vegetation, particularly the annual plants, whose life cycle is short, adapted themselves over time to recreational stresses imposed upon them over the years. Thus, the trails are in dynamic equilibrium with the interfering factor whose intensity varies during the year as well as from year to year [1,2,9,12,18,19,24,25]. Hall and Kuss [19] stated that such approach lead to a better understanding of the soil response and the relative tolerance of plant communities to human use and the displacement of native flora by species better adapted to withstand use pressures.

The aim of the present study was to monitor the effect of visitor traffic on soil and annual plant properties on long-established trails in the stabilised coastal dunes in the Sharon Park. The central questions in this study were, is the effect of visitors limited to the area within the boundaries of the trails, or does it extend further, and how far? In other words, is the effect localised on a micro scale or on a meso- and macro scales? Assuming that the level of visitor use in this area increases from the end of summer to the beginning of winter (the start of the growing season) and into spring (peak of flowering and visitors' and hikers' season), do the plants' attributes change during the growing season as a result of visitors' use, and if so in which manner?

2. Study area

The study was carried out in the woodland of the Sharon Park, which is scheduled to be declared a national park in the near future. The overall coastal woodland area is 104 ha. This woodland stretch from the Hadera planted forest in the north to the industrial Emek Hefer area in the south. Its eastern border is the old Haifa–Tel Aviv road (Highway No. 4), and its western border is the main Haifa–Tel Aviv road (Highway No. 2) (Fig. 1a). The climate is Mediterranean. The average annual rainfall ranges from 500 to 600 mm, and the average annual temperature is 16°C. The soil in the research area has been defined as a sandy regosol (A–C profile) [26]. The plant cover comprises scattered trees such as carobs (*Ceratonia siliqua)* and oaks (*Quercus ithaburensis*), and shrubs such as *Pistacia lentiscus*, surrounded by a wealth of about 70 different annual species, some of which are typical of sandy habitats (for example, *Aegilops sharonensis*, *Cutandia philistaea*, and *Trifolium palaestinum*, species which are endemic to the coastal plain in Israel) [27,28].

There is a trail network system in the woodland park that has been created spontaneously by passers-by and visitors (Fig. 1b). The number of trails has risen exponentially over recent years because the place still lacks statutory acknowledgement as a protected open area. The trails differ in length, in width, and in the traffic stresses to which they are subjected [29].

3. Methods

Eight different trails in the coastal woodland were randomly selected in September 1997. Four of them are subject to a high visitor use, and the other four to a lower use.

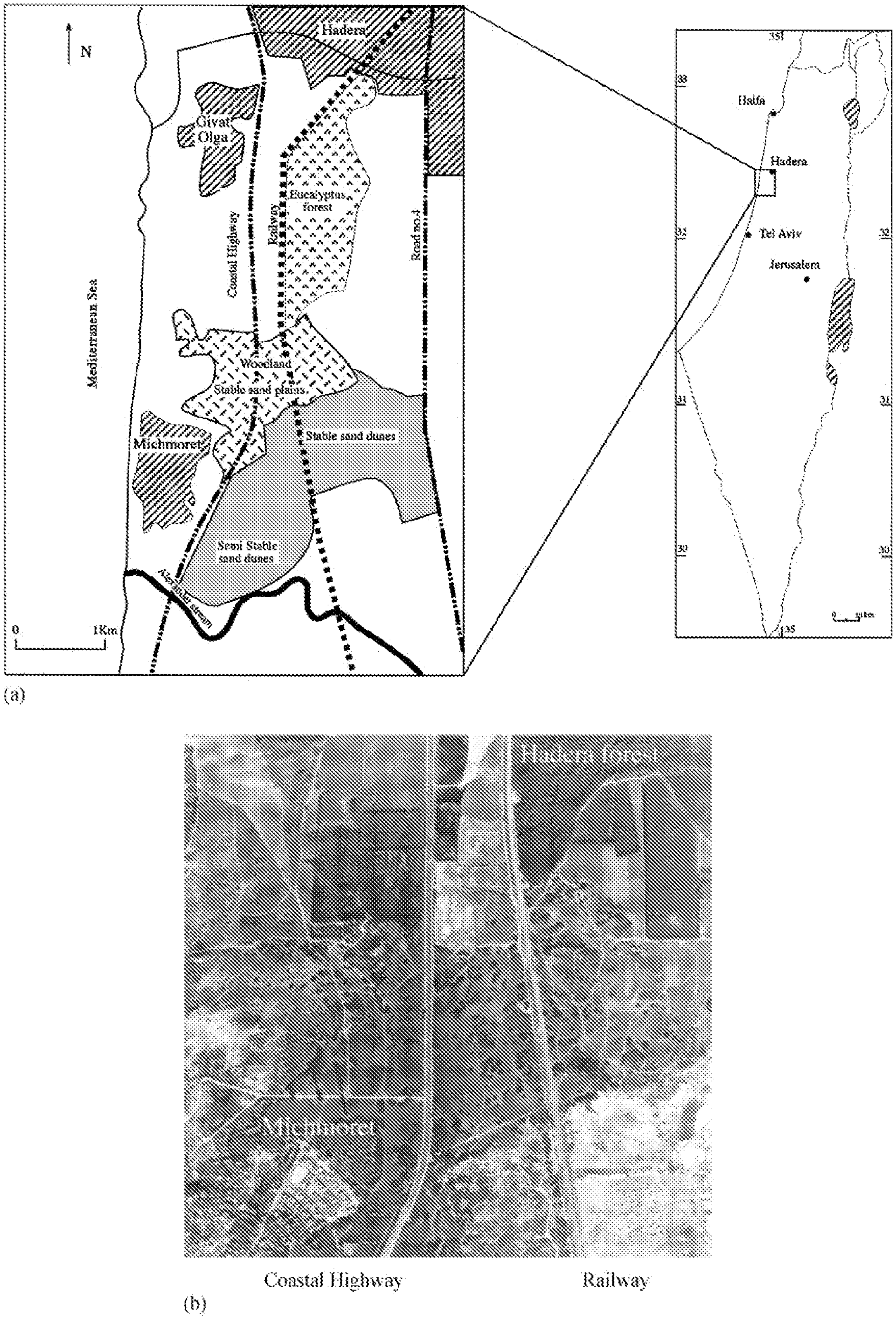

Fig. 1. The study area; (a) a scheme, (b) an air photo.

The level of use was defined on the basis of familiarity with the area, observation of visitors, and the properties of the trails. Observation of visitors was done on weekends and holidays from December 1997 to April 1998 inclusive. Observations included counting the hikers and the vehicular at parts of the trail where the plant and soil attributes were also examined (Table 1). Observations were done simultaneously between the hours of 11:00 and 14:00 on all the trails. The trail properties included width and depth relative to the surrounding area (height of edges) (Table 1).

Two perpendicular sections, 5 m from each other, were marked on each trail. Each section was 10 m in total length, 5 m in each direction from the centre of the trail, and 1 m wide. The centre of the trail was fixed as the centre of the visible lane within which the plant cover was at least 50% lower than that of the undisturbed surroundings.

Each section was divided into ten equal squares 1 m × 1 m in size. Observations of the plants were done during December and January (the start of the growing season), the middle of February (the peak flowering season of most of the herbaceous plants) and at the end of April (the end of the growing season and the ripening of fruits). For each square, the overall percentage cover and the overall average height, as well as the relative percentage cover for each species, were recorded. From these data we determined the species richness (the overall number of species) and calculated the species diversity based on the Shannon–Wiener Index, which takes into account the number of species and the relative contribution of each species to the overall plant cover [27].

The following soil attributes were monitored: the compaction level, the organic matter content, and the soil moisture. The compaction level was measured by a penetrometer with stick length 50 cm, and with a 235 g weight that is cast from the head of the stick towards its base. The depth to which the stick penetrates the soil is the measure of its level of compaction [30]. Measurements of the penetration depth were made in December 1997 after a light rain (6 mm) had fallen. Data were taken

Table 1
Number of visitors and attributes of high- and low use trails in the Sharon Park

Visitor use	Trail number	Average number of vehicles per hour	Average number of hikers per hour	Depth of trail (cm)	Width of trail (cm)
High	1	5	24	27	252
	2	4	6	21	263
	3	16	38	22	345
	4	7	7	15	236
	Mean	8	19	21	274
	Standard deviation	5	15	5	49
Low	1	4	5	5	218
	2	3	6	3	247
	3	5	2	6	270
	4	1	3	10	234
	Mean	3	4	6	242
	Standard deviation	2	2	3	22

continuously at constant distances of 50 cm along the length of the 10 m sections, 20 observations being included in each section. This penetrometer is simple to use and enables the collection of a large amount of data in a limited time. Liddle and Greig-Smith [4] pointed out that in sandy soils the depth of penetration is a more reliable and efficient measure than the apparent soil density, which is also more awkward to measure.

Soil samples for estimation of the organic matter content were taken in April, at a time of maximum soil decomposers activity [13]. Three samples were taken from a depth of 0–2 cm after removal of the plant cover and litter layer, from three sites along each section: the centre of the trail, the peripheral part of the section (henceforth the "control area") and 10 cm outwards from the visible boundaries of the trail (henceforth the "edge"). The analysis was based on wet combustion with dichromate at 450°C [31] after the samples had been air dried and cleaned from undecomposed organic residues.

Soil samples for estimation of soil moisture were taken once a month from December 1997 to April 1998. From April to May, at the end of the rainy season, the samples were taken once in two weeks. Four soil samples were taken from the centre of the trail and from the control area in each section. The moisture was measured gravimetrically: two weightings, one at the time of sampling and the second after drying at 105°C [31].

The data were processed and the results were analysed statistically to determine the significant differences by non-parametric Duncan's test [32] at the $\alpha = 0.05$ level of significance.

4. Results

4.1. Vegetation

The plant cover on the trails under high visitor use varied from the centre of the trail outwards. In the two squares flanking the centre of the trail (henceforth "trail"), the plant cover approached zero. In the next two squares, those flanking the previous ones (henceforth "edges"), the plant cover increased to 50%. The third pair of squares, identified as the control squares, showed an 80% plant cover (Fig. 2). The differences between the trail, the edges, and the controls were significantly preserved throughout the entire studied period (Fig. 3). The plant cover of these trails, in each of the sectors (trail, edge and control) described, did not change significantly during all of the growing season (Fig. 3, Table 2). On the other hand, in trails where the level of visitor use was low the plant cover in the centre of the trail reached 20–30% and was significantly lower than its control (60–70% cover). In this type of trail we could not clearly demarcate the edge areas (Figs. 2 and 3). The plant cover on the trails increased significantly from December to February by 37%. On the other hand, in the control areas the increase was smaller and not significant (Fig. 3, Table 2).

The difference in plant cover between the trails under high use and those under low-use was expressed in the percentage cover in the centre of the trail and in the rate

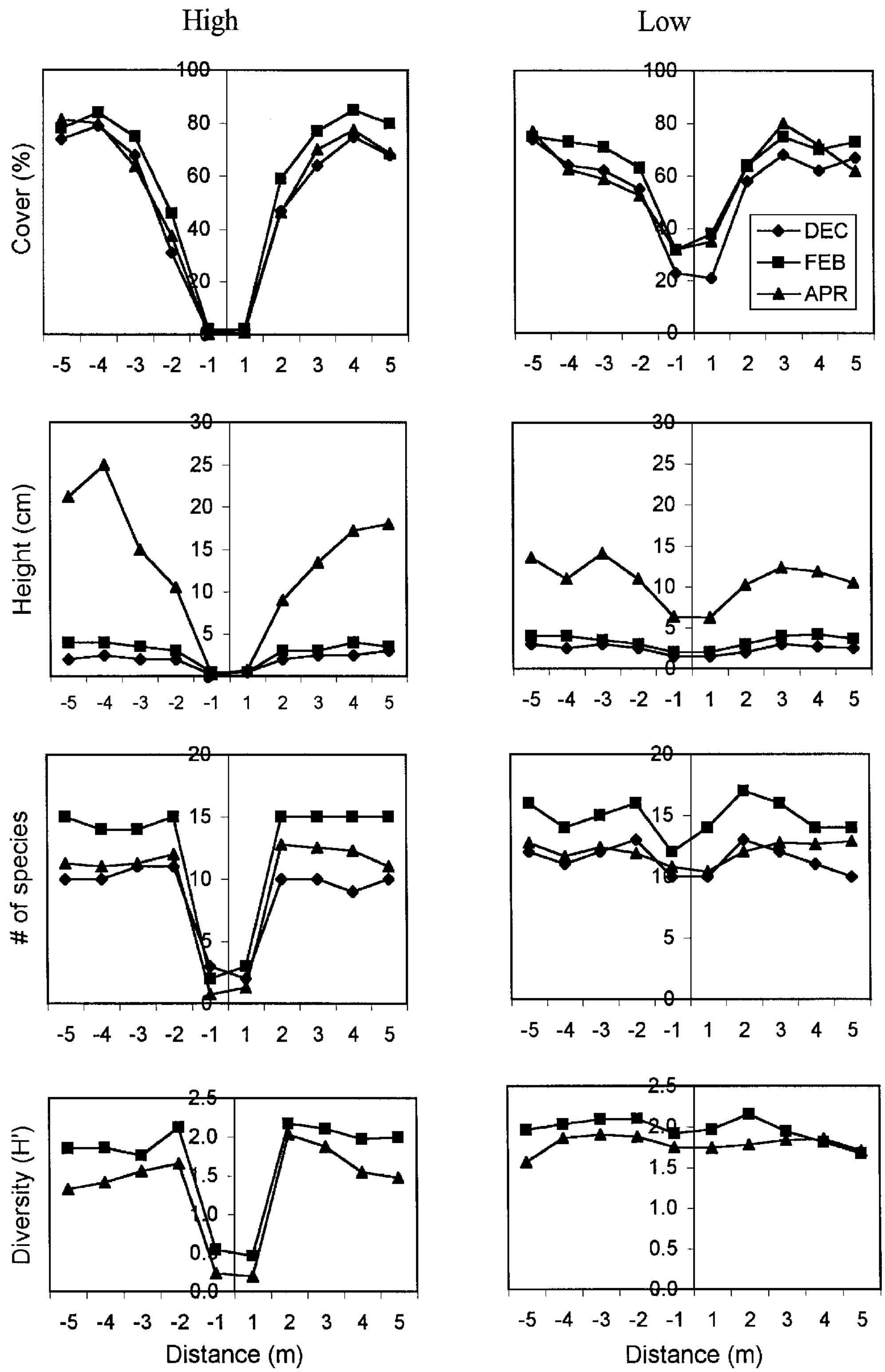

Fig. 2. Changes in the plant cover, average height of plants, and the number and diversity of species along a 10 m section perpendicular to the trail (0 = the centre of the trail) during the growing season in trails subject to high and low levels of visitor use (each point is an average of 8 squares).

changes in the cover from the centre of the trail to the control. The cover at the centre of the low-use trails was significantly higher as compared with high-use trails (Fig. 3). A tendency, although not a significant one, was also noted towards a lower cover in control areas of trails under low-use than in control areas of high-use trails. The

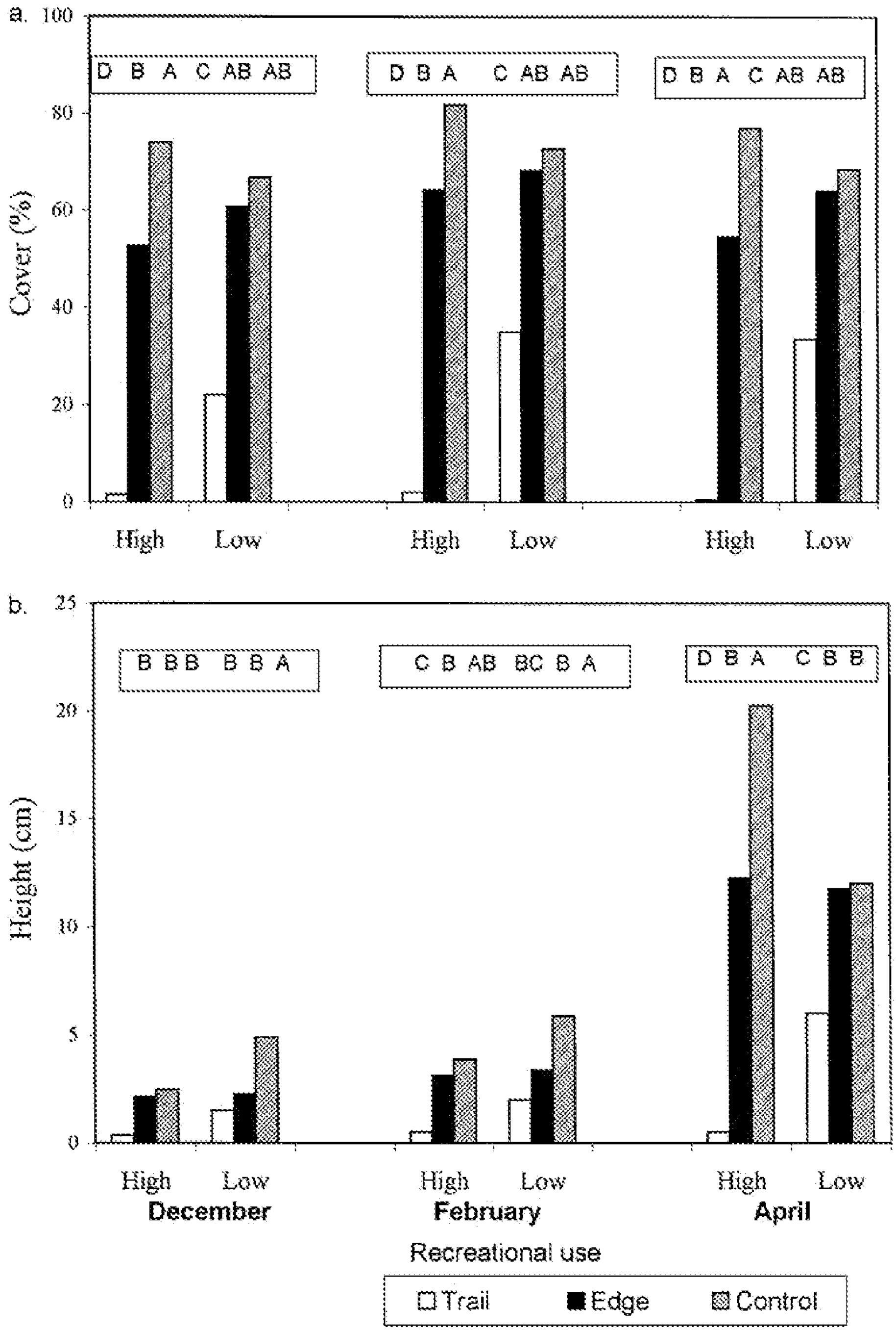

Fig. 3. Differences in plant cover, average height of plants, and the number and diversity of species between the centre of the trail, its margins, and the control areas during the growing season in trails subject to high and low levels of visitor use (the letters mark the significant of the differences between groups — high or low — at each date. Identical letters = not significant. Different letters = significant. Each point for the control and the margin averages 32 observations, and for the centre of trail $n = 16$).

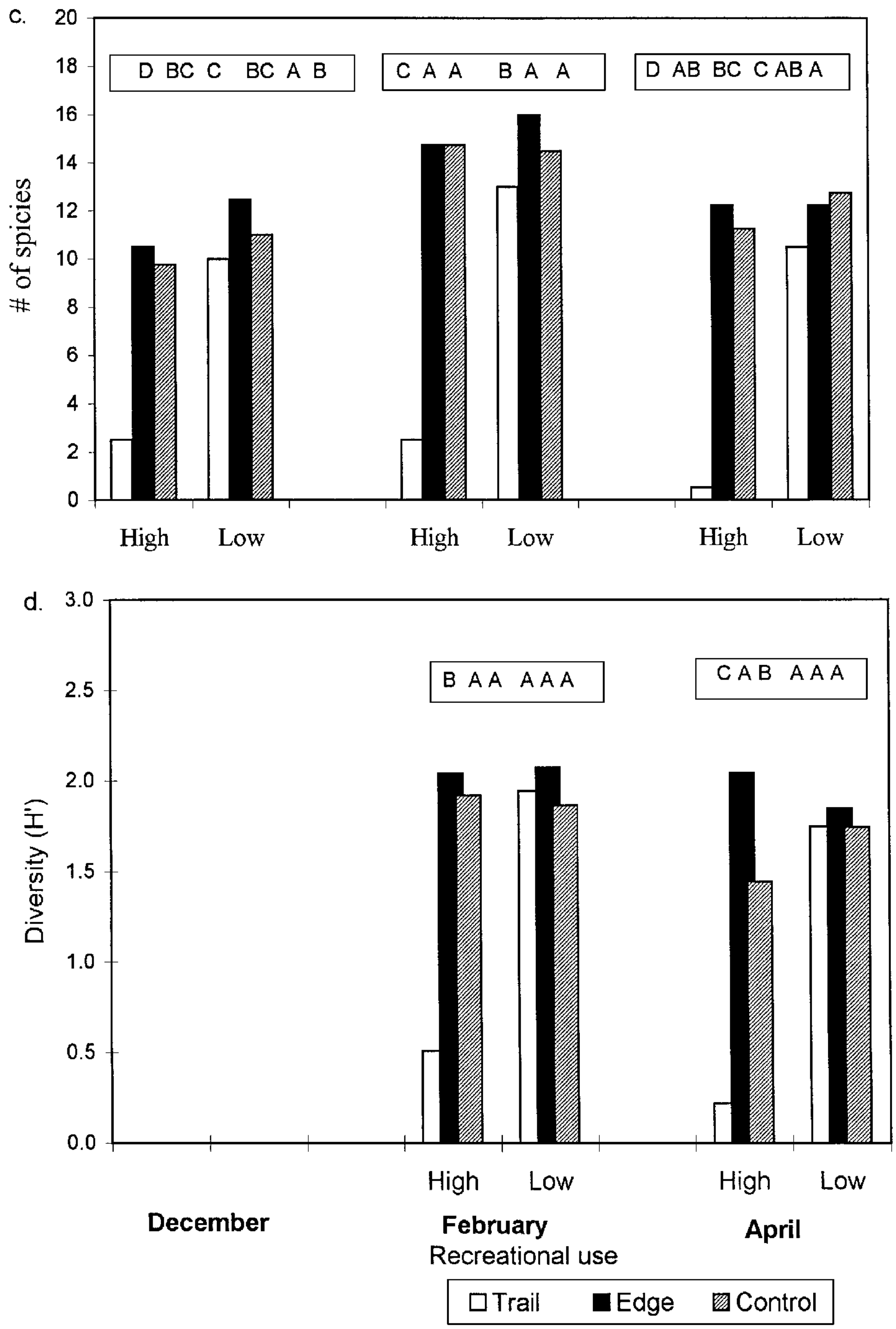

Fig. 3 (*continued*)

change rate in the plant cover from the centre of the trail towards the control was almost twice as great in high-use trails than in low-use trails. This trend was noted in all the dates studied during the growing season (Fig. 4).

The average height of the plants also increased from the centre of the trail towards the control area. In the centre of the high-use trails we found that the average plant height approached zero as compared with the edge and the control areas (Fig. 2). The differences between the centre of the trail, the edges and the control become gradually sharper during the growing season, while at the end of this season (the end of April)

Table 2
The significance of differences among the months on all trails sectors (centre of trail, edges and control) on trails with high and low visitor uses

Feature	December			February			April		
	Trail	Edges	Control	Trail	Edges	Control	Trail	Edges	Control
High level of visitor use									
Cover	D	C	AB	D	BC	A	D	C	AB
Height	D	CD	CD	D	CD	C	D	B	A
No. of species	E	CD	D	E	A	A	F	B	BC
Species diversity				D	A	AB	E	B	C
Low level of visitor use									
Cover	C	A	A	B	A	A	B	A	A
Height	D	CD	BC	CD	BCD	B	B	A	A
No. of species	D	C	D	C	A	B	D	C	C
Species diversity				AB	A	BC	C	BC	C

the differences between the three sectors (trail, edge and control) became significant (Fig. 3). The plant height in the centre of the trails did not change during the growing season, as compared to the changes that took place in the edges and the control areas. In the edges the average plant height increased significantly, by a factor of 4, from February to April (from 3 to about 12 cm) while in the control the increase was by a factor of 7 (from 3 cm in February to 20 cm in April) (Fig. 3, Table 2). In low-use trails, clear differences in the average height were also found between the low heights at the centre of the trail and the greater heights in the control areas. In this case too, as well as in the case of vegetation cover, we could not definitely demarcate the edges of the low-use trails (Figs. 2 and 3). The plant height in the centre of the low-use trails and in their control areas increased during the growing season in the same proportion, while the increase from February to April was greater by a factor of 3. The differences between the studied dates were significant (Fig. 3, Table 2).

The differences in plant height between the high-use trails and the low-use trails were mainly expressed in the centre of the trail, which was significantly less in high-use trails during the whole growing season, and in the controls. The average plant height in the control of high-use trails at the end of the growing season was twice that in low-use trails (Fig. 3). Moreover, in April, the rate of change in the average height of the plants from the centre of the trail towards the control was 3.5-fold higher in high-use trails than in low-use trails. No significant differences were found in this context between the two types of trails in the other two periods studied (December and February) (Fig. 4).

The change in the number of species from the centre of high-use trails towards the control was very sharp. Two species on the average were found in the range of the trail boundaries, while 12 species were observed in the control area. No significant differences were found between the edges and the control sectors, although there was a tendency for the number of species on the edges to be higher than in the control (Figs. 2 and 3). The number of species in the edges and the control areas of the high-use trails increased significantly from December to February and dropped

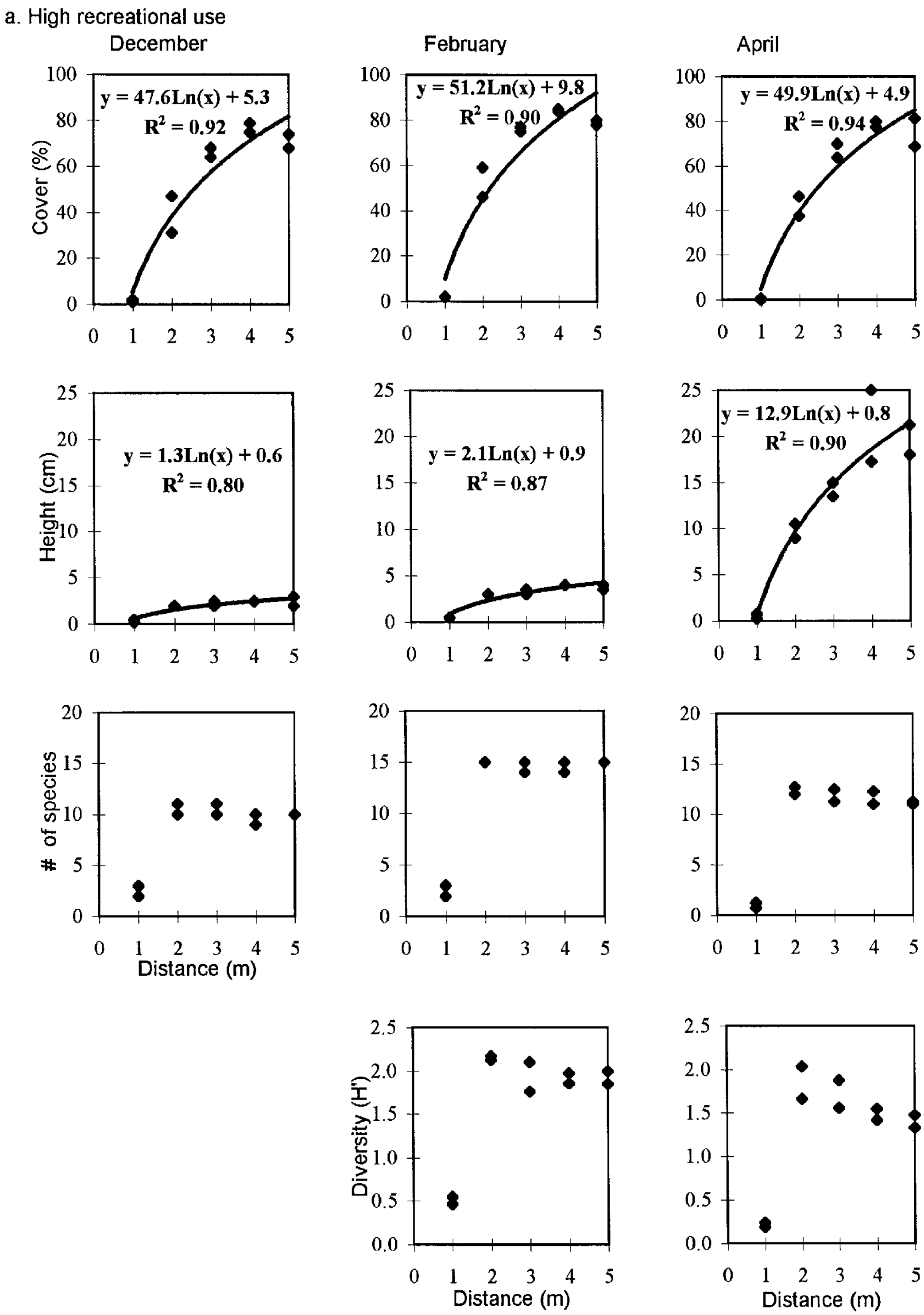

Fig. 4. Rate of change in plant cover, average height of plants, and the number and diversity of species from the centre of the trail towards the control area in trails subject to high (a) and low (b) levels of visitor use (each point is an average of 8 values. It is assumed that the changes from the centre of the trail outwards are similar in the two directions).

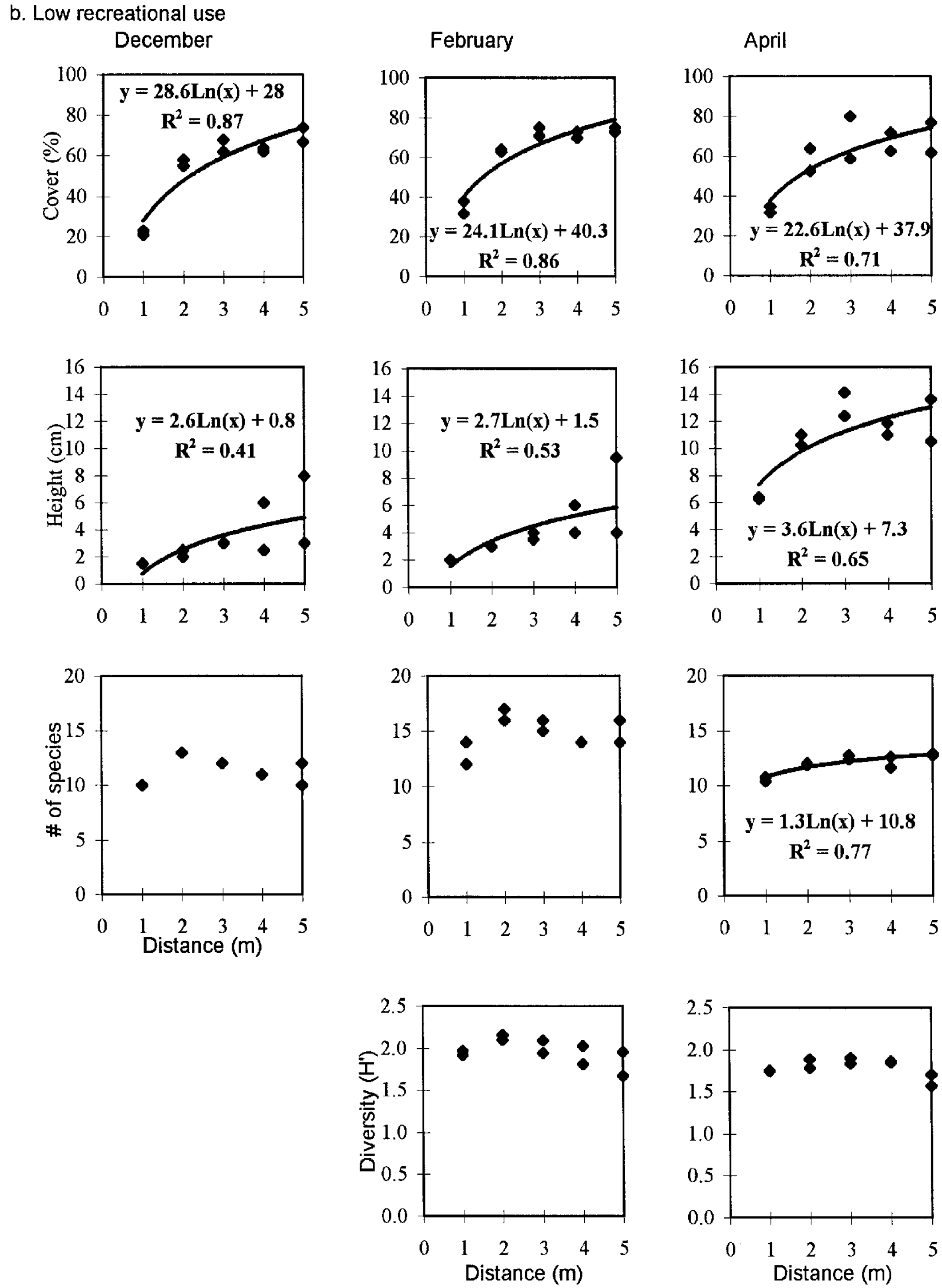

Fig. 4 (*continued*)

significantly in April. In the centre of the trail there were no differences between December and February. In April the number of species in the centre of the trail was significantly lower than in February (Table 2). A similar trend was obtained for low-use trails, where the average number of species in the centre of the trail reached 13, and in the control it reached 15 (Figs. 2 and 3, Table 2).

The difference in number of species between the two types of trail (high and low use) was expressed in the centre of the trails and in the rate change from the centre of the trail towards the control areas. The number of species in the low-use trails was 7 times greater than that in the high-use trails (Fig. 3). The rate of change in the number of species along the section in high-use trails was also very sharp while in low-use trails the changes were very gradual (Figs. 2–4).

The species diversity in high-use trails was low in the centre of the trail (0.3 on an average) and high in the edges and the control (1.8 on an average). The differences between the centre of the trail, the edges and the control were found to be significant only in April, when the species diversity was the highest in the edges. The differences between the three studied dates were found to be significant (Fig. 3, Table 2). In low-use trails, no significant differences were found in the species diversity between the various sectors, although there is a trend towards higher species diversity in the edges. The species diversity in the centre of the trail reached an average of 1.9 and 2.0 in the control. The differences between the three studied dates are significant, except for the control area (Fig. 3, Table 2). The differences in the species diversity between the two types of trails is similar to the differences found for the number of species (Figs. 2–4).

4.2. Soil

The degree of soil compaction on the trails subject to high use, as well as their nearby surroundings, was significantly higher than the low-use trails. The differences in compaction level along the section across each type of trail vary (Fig. 5).

On the low-use trails the depth of penetration increased gradually from the outside edges of the section and reached a maximum at the centre of the trail. The depth of penetration in the outermost meter to 1.5 m of the section reached 3 cm. In the next 2 m on each side towards the centre of the trail, the depth of penetration increased to 3.5 cm, and in the next 3.5 m, the visible range of the trail, the depth of penetration rised above 3.5 cm. In contrast, high-use trails showed a very slight rise in the depth of penetration, up to 2.5 cm from the end of the section and as far as 2.5 m from it in the direction of the centre of the trail. In the following 1 meter, the depth of penetration increased sharply to a maximum of 3.2 cm, and from here on there was a very sharp drop in the depth of penetration to 1.5 cm (Fig. 5). The differences in the depth of penetration to the soil between the two types of trail were significant only in the range of the central 3.5 m of the sections.

The amount of organic matter in the centre of the trails and in the edges of the two types of trails, high and low visitor activity levels, was significantly lower by a factor of almost 2 from the control areas (Fig. 6). However, there were no significant differences between the centre of the trails and the edges nor between the two types of trail except for the control area. Unexpectedly, the amount of organic matter in the control area of the high-use trails was significantly greater than that of the low-use trails. The edges and the centres of the trails also showed this tendency, while it is not significant (Fig. 6).

The soil moisture in the centre of the high-use trails at both depths, 0–2 and 5–10 cm, was higher than that found in the centre of the low-use trails. This finding

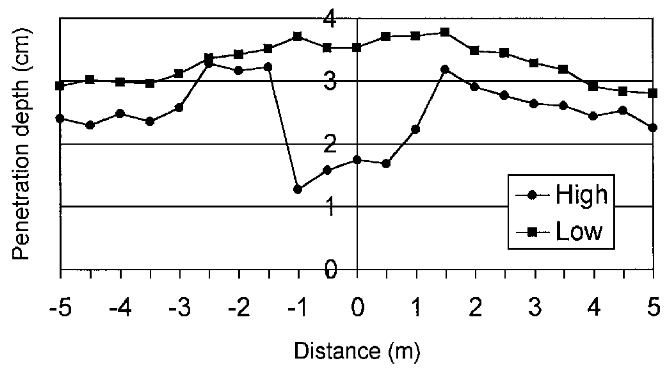

Fig. 5. Soil penetrable depth along a section perpendicular to the trail vs. high- and low-use trails (each point is an average of 8 values).

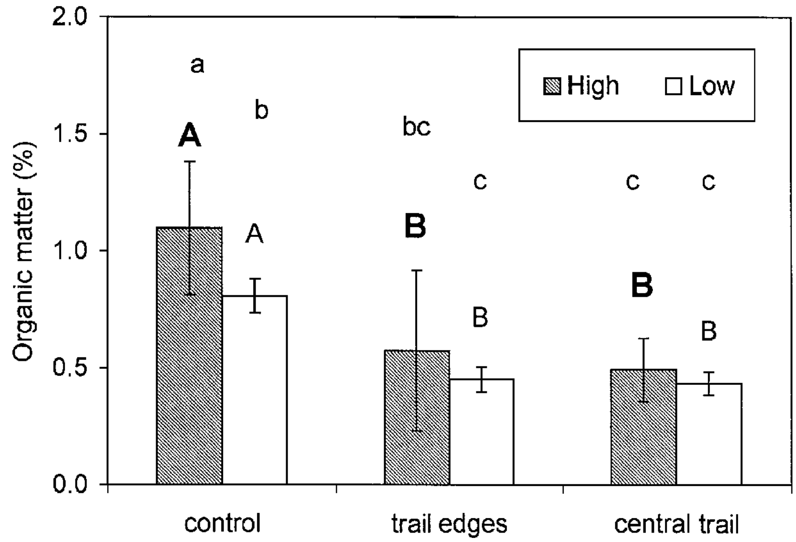

Fig. 6. Organic matter content in the upper soil layer in high- and low-use trails (I — standard deviation; capital letters denote the level of significance of the differences between the various parts of the trail for each use level; small letters denote the level of significance of the differences between high- and low-use trails at each section of the trail (each point is an average of 8 values).

was observed during the whole of the study period, but it was significant only during periods of relatively low rainfall or during dry spells (Fig. 7). There is also a generally insignificant tendency, during the whole research period, for the soil moisture in control areas adjacent to the high-use trails to be higher than in the control areas near low-use trials.

5. Discussion

Several studies have pointed out that recreational uses change the attributes of the soil and vegetation, although the effect is very local, extending in some cases beyond the boundaries of the trail by about 1 m on each side [3,10,15,19,22,33]. This is not the case in our research area: recreational use extends several meters beyond the trails

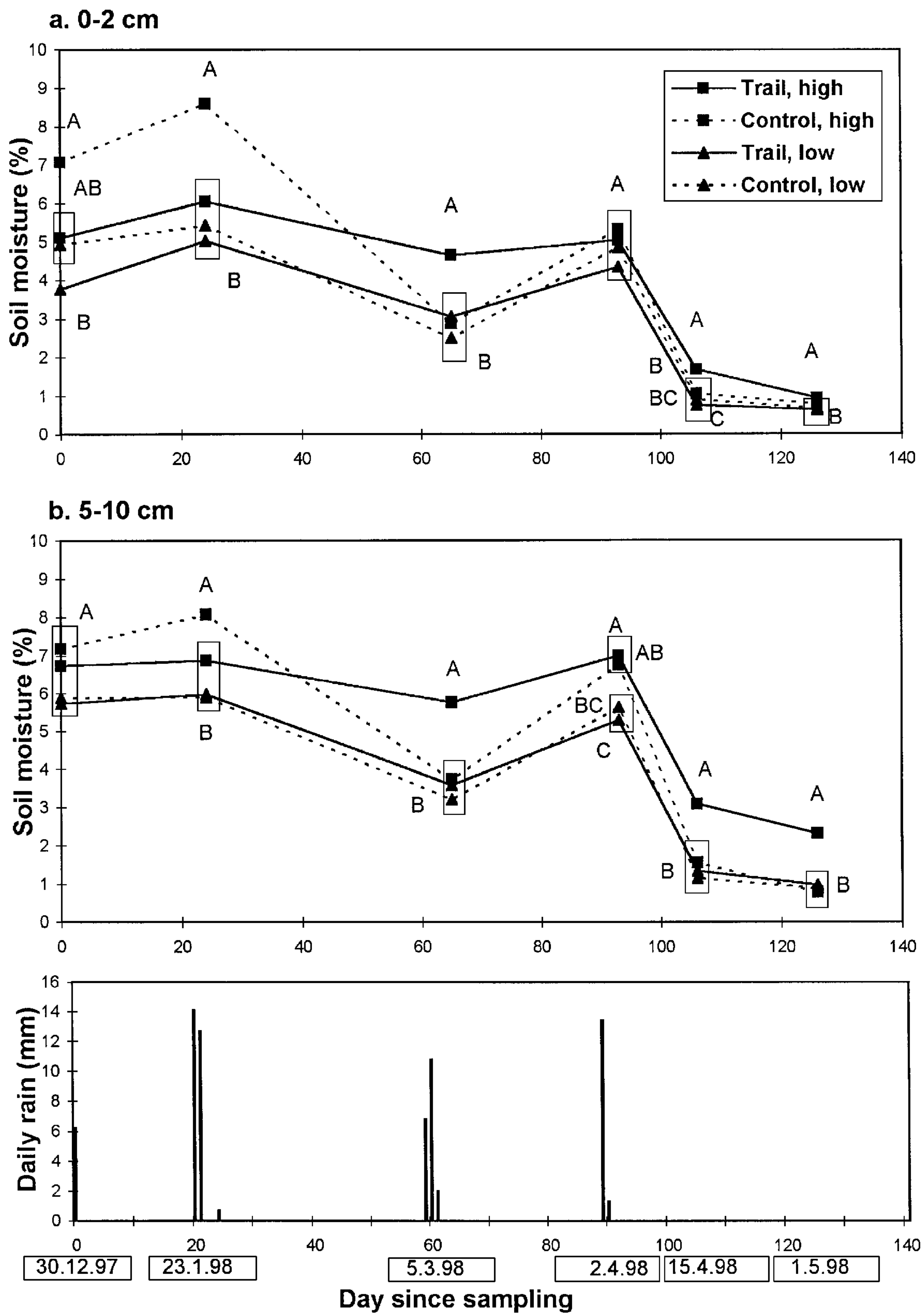

Fig. 7. Changes in soil moisture at depths of 0–2 and 5–10 cm in the centre of the trail and in controls in high- and low-use trails (each point is an average of 8 values).

boundaries. The average width of the trails in the coastal woodland where the visitor use is high reaches about 2.7 m. This area is almost devoid of plants and its soil is compressed. Moreover, the vegetation cover and its average height at the edges of this type of trails at a distance of 2 m on each side from the apparent trail boundaries is low as compared with areas that are not affected by the visitors in the park. Although the visitors' impact on the trail edges is indirect, it is significant for plants and soil in the micro- and meso scales, and for the whole area in general.

In a survey conducted in the winter of 1997 in the woodland area we counted and measured the number of trails and their length [29]. We found their overall length to be 22 km in the entire 104 ha within which the woodland is concentrated. One-third of this length is subjected to a high level of visitor use, while the remaining two-thirds of the trails are classified as medium to low use. This indicates that, if the range of visitor traffic impact on high-use trails covers a width of about 6 m (including the visible trail and its edges), about 4.2 ha (7 km of trail × 6 m), which is about 5% of the overall area of the park, is affected by high visitor use. The influence of visitors also extends, of course, to the area covered by the medium- and low-use trails.

On lower use trails we found that there is a clear difference between the trail itself, where the plant cover and average plant height are low, and its surroundings, where the plant cover and height is higher. However, when we compared the plant cover and height five meters outwards the visible trail centre (what we defined as "control" area) with that of high-use trails, we found the former areas to have a lower plant cover and height. Furthermore, the rate of change of plant height during the growing season near to high-use trails was higher than that adjacent to low-use trails. A similar trend was found regarding the soil parameters: the quantity of organic soil matter and the moisture content were lower in "control" areas of low-use trails than in those of high-use trails. On the face of it there is no explanation of these findings, unless we assume that in low-use trails the hikers and the travellers use at least the entire 10 meters within which we measured the effect of visitor traffic (5 m in each direction from the centre of the trail). In high-use trails, on the other hand, the visitors keep to the plant-free part of the trail. It seems that the fact that a trail and its edges are clearly demarcated cause the visitor to stay within the 2.5 m width of the trail. On the other hand, on low-use trails the trail is not clearly defined, its profile is planar and covered with plants. Thus, when a "clear direction" to the visitor's perception is lacking he walks all over the area. Although low-use affects the plant cover less that does high-use, we cannot ignore the damage caused to low-use trails as compared to areas that visitors do not reach. Hylgaard and Liddle [11], in their work on coastal sands in Denmark, noted that the trails were defined by obvious differences in plant cover, the height or structure of the vegetation as visually discernible. At low stress levels, they claim that borders of the trails are not clear — "diffuse" according to their definition.

If we pay attention also to the total area of the park that is affected by visitor use, we should add to the 4.2 ha calculated for the high-use trails another 14 ha for the low-use trails (10 m of affected area × 14 km of trails). This brings us to the conclusion that about 18% of the total area of the park is affected by visitor traffic. There is no doubt that the greatest effect on the area is caused to the trails. Cole [24] found that only 0.5% of the area of a nature reserve in Oregon was affected by trampling and overnight camping.

The effect of vehicular and pedestrian traffic on species richness and species diversity is limited mainly to the range of the apparent trails. However, we did find some trend for the number of species and the species diversity in the edges of the two types of trails to be greater than that for control areas. This is particularly obvious at the peak of the growing season in the vicinity of the low-use trails. This area, which can be regarded as a transitional area, is subject to low trampling stresses as compared to the centre of the trail. This fact alone can explain the relationships among the species. Many studies have reported that trampling limits the competition between dominant species and the rest of the species, resulting in a larger number of species that are able to share the space among them [2,15,23,25]. The edges are the most dynamic areas. In the course of time, as the impact level increases on what are now low-use trails, they will change gradually and acquire the characteristics typical of high-use trails.

The end of February in this habitat marks the peak of the growing season, and by the end of April the number of species had decreased. There was, however, a significant increase in the average plant height. Some of the species, such as *Medicago litoralis*, *Trigonella maritima*, *Hippocrepis unisiliquosa*, and *Anthemis leucanthemifolia*, which are prostrate and typical of the trail area, ended their growing season in February, while *Aegilops sharonensis* and *Crepis aculeata* continued to grow in height and ripen their seeds with the approach of May. It may be that the differences in behaviour of different species during the growing season is correlated with the seasonal distribution of trampling stresses in this area.

The changes in soil properties observed along the sections of high-use trails were quite different from those described for the low-use trails. The differences between these two types of trails also enable us to understand better the evolution of the trails from low- to high-use trail.

The sandy soil within the visible boundaries of the high-use trail is very compacted due to traffic pressures. Many studies reported that soil compaction increases with the increase of recreational activity [2–4,10]. However, the compaction level in the additional meter of the high-use trail on each side of the trail boundaries is the lowest, even compared with the undamaged soil. This 1 m lane is very dynamic and separates the visible trail from the undamaged area. The sand that is removed from the trail due to vehicle traffic is piled here causing a decrease in the compaction level, hence a decrease in soil moisture content. From here towards to the end of the section identified as control, the compaction level increases presumably as a result of extensive annual plant root systems concentrated in the upper 5 cm of the soil. The undamaged areas together with the trails (the area with the maximum impact) are in equilibrium with the surroundings, while the edges are subjected to continuous changes. However, on the low-use trails the compaction level is the lowest within the boundaries of the trail (in contrast to what has been reported in the studies cited above, and the results obtained for the high-use trails in the present study) and increases as we move through the margins and the controls. In general, the compaction level along the 10 m section is lower than that along the high-use trails (including the areas that were identified as controls).

Visitor use also reduces the soil organic matter content. This process is very crucial for stabilised sand soils because the amount of organic matter is very low and all soil properties are depended on this organic layer [27,28,34]. This layer in soil defined as a sandy regosol, that is, a soil with an A–C profile, is concentrated in the upper 0–3 cm, and it is this layer that contributes the soil its relative stability and fertility. The moment that this layer is destroyed, the transition to an unstable sand (profile C — the parent soil material), is more rapid. This process was already observed on low-use trails along the entire section examined in this study. Likewise, the soil moisture values received for the centre of the low-use trails and for the control areas were very similar. These facts reinforce the assumption that area affected by low visitor use is larger than the affected area of high-use trails. In the latter, there is a significant difference in soil moisture between the centre of the trail and the control area.

In the first stage of the trail evolution the organic layer is destroyed. This process is followed by a decrease in soil compaction level, organic matter and moisture contents. As the level of use on low stress trails increases, the surface in the central part of these trails becomes more compressed and denuded from plant cover [11]. In this stage the trail significantly differs from the surrounding area and is clearly visible to the visitor. The visitor use is more and more directed within the trail boundaries, so at the end of this process the centre of the trail and the control area reach an equilibrium condition with the environment, where only the remaining margins testify to this development.

The effect of visitors on soils and plants is immediate and localised in the short term, but in the long term traffic stresses affect the whole area. The effects may be expressed in geomorphic processes (overland flow and erosion) [2,18,35], and in biotic processes such as fragmentation. Spatial fragmentation by trails and roads causes an increase in the number of natural spaces with a marginal effects, and a decrease in the process continuity in the overall area by creating “ecological islands” separated by trails [36]. An increase in trails in open spaces and an application of high-use stresses upon them is liable to damage the landscape, the soil, the plant population, and the animals [25,37].

The sandy woodland area of the Sharon Park has been defined as having a high ecological value [35], comprising as it does about 90 different perennial and annual plant species, some of which are endemic or unique to the area [27]. This study has shown that recreational use in the herbaceous areas of the stabilised coastal sand dunes affects the plant cover on the micro level (the area within the visible boundaries of the trail), the meso level (the margins of the trail) and the macro level (the park as a whole). About 18% of the coastal woodland area are affected by the visitor use. It is therefore urgent that we reduce the extent of the trails, especially those where activity is low, and which constitute the major part of the total length of trails in the park woodland, and to leave a number of trails where the activity is high. These trails will cover the park from side to side.

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