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TRAMPLING DISTURBANCE AND RECOVERY OF CRYPTOGAMIC SOIL CRUSTS IN GRAND CANYON NATIONAL PARK

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ABSTRACT.—Cryptogamic soil crusts in Grand Canyon National Park were trampled by hikers, under controlled conditions, to determine how rapidly they were pulverized and how rapidly they recovered. Only 15 trampling passes were required to destroy the structure of the crusts; visual evidence of bacteria and cryptogam cover was reduced to near zero after 50 passes. Soil crusts redeveloped in just one to three years, and after five years the extensive bacteria and cryptogam cover left little visual evidence of disturbance. Surface irregularity remained low after five years, however, suggesting that recovery was incomplete.

Cryptogamic soil crusts are common and functionally significant features of arid ecosystems. Bacteria, algae, fungi, lichens, and mosses bind surface soil particles together, creating a highly irregular surface crust of raised pedestals (typically black and several cm tall) and intervening cracks. Crusts provide favorable sites for the germination of vascular plants (St. Clair et al. 1984) and play important roles in water conservation (Brotherson and Rushforth 1983) and nitrogen fixation (Snyder and Wullstein 1973). These crusts are particularly significant in reducing soil erosion. Soil aggregation raises the wind and water velocities required to detach soil particles, while the irregular soil surface tends to reduce wind and soil velocities (Brotherson and Rushforth 1983). Increased water infiltration in crusted soils also reduces runoff and erosion. Increased soil stability is highly significant in arid environments where sparse vegetation and surface soil organic matter as well as sporadic torrential rainfall contribute to a high erosion hazard.

A number of recent studies have examined the response of cryptogamic soil crusts to disturbance by grazing and by fire (Anderson et al. 1982, Johansen et al. 1984, Johansen and St. Clair 1986, Marble and Harper 1989). The results of these studies suggest that crusts are unusually fragile and can be seriously disrupted by low levels of disturbance that have no noticeable effect on vascular plants (Kleiner and Harper 1972).

The fragility of crusts presents unique challenges to land managers attempting to avoid adverse impacts on desert lands. This is particularly true in the many national parks located in the arid lands of the southwestern United States. The popularity of these desert parks has made it increasingly difficult for managers to meet management objectives that stress the maintenance of natural conditions and processes. Many hikers now visit places that a decade or two ago had few visitors. These backcountry users can significantly impact cryptogamic soil crusts if they wander off the trail or set up camp in crusted areas.

The purpose of this study was to examine the effect of trampling disturbance on soil crusts to better understand how rapidly they are disturbed and how quickly they can recover. It was conducted in the backcountry of Grand Canyon National Park on a study site located close to the Bass Trail, at an elevation of about 1,650 m. The site is flat, and during the study the soil crusts exhibited well-developed pinnacles and were conspicuously blackened with lichens. The vegetation type is a *Coleogyne ramosissima–Pinus edulis–Juniperus osteosperma* woodland (Warren et al. 1982). Soils, derived from sandstones of the Supai Group, are shallow and highly sandy. The climate can be characterized as that of a cold desert; annual precipitation is about 25 cm with a bimodal occurrence in winter and summer.

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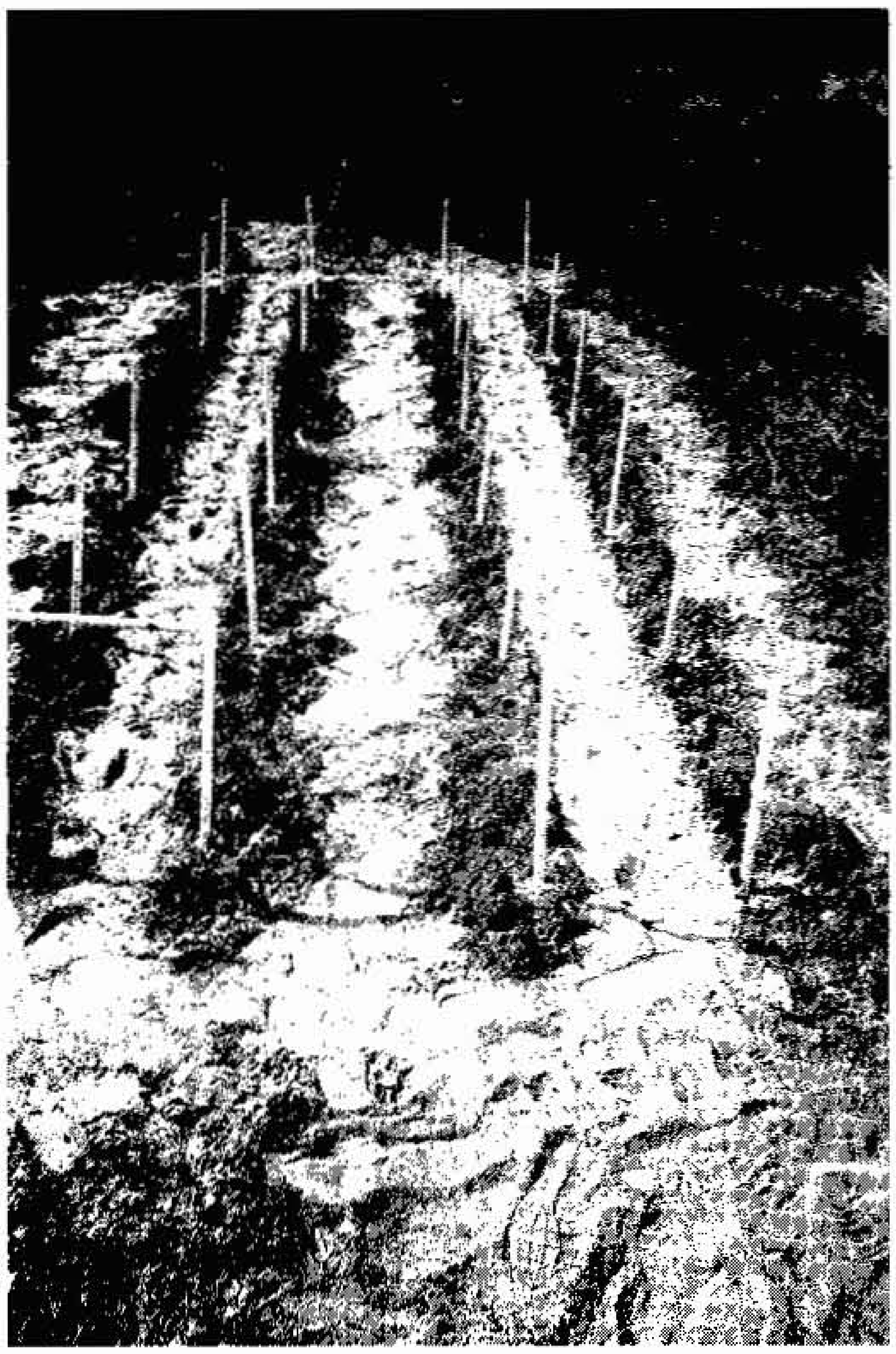

Fig. 1. The two trampling lanes immediately after 50 passes in tennis shoes (left) and 250 passes in lug-soled boots (right). Note horizontal bar for measuring vertical distances.

METHODS

Two lanes about 6 m long and 0.4 m wide were delineated with lengths of PVC pipe in an area of well-developed, undisturbed soil crust (Fig. 1). The lanes were separated by a path that was trampled during the period when the treatments were applied and then allowed to recover afterward. One lane was trampled by a 75-kg person in tennis shoes, the other by an 86-kg person in lug-soled boots. Measurements were taken prior to trampling and after 5, 15, 25, and 50 passes, a pass being one walk down the lane at a normal gait. The lane trampled with lug-soled boots was trampled another 200 times, for a total of 250 passes. Subsequent measurements were taken one, three, and five years after the treatments were administered. Treatments and measurements occurred in late spring—April or May 1984.

Each lane was sampled along five transects oriented perpendicular to the lane and located 1 m apart. Each transect consisted of 10 measurement points 2 cm apart in the central part of the lane. At each point along the transect the vertical distance between a horizontal pipe, temporarily connecting the pipe at each end of the transect, and the ground surface was measured. Then the ground surface at that point was categorized as either bare soil or cryptogam.

These data provide three measures to evaluate disturbance. First, the vertical distances, a mean of 50 observations per lane, provide a measure of the degree to which crusts have been compressed by trampling. The variability of vertical distances across each transect provides an indication of surface roughness, which should decline with trampling. Roughness increases with crustal development and is important in reducing soil erosion. The measure used is the coefficient of variation of the vertical distances. Coefficients were calculated for each of the five transects across each lane and then averaged. The third measure is cryptogam cover, expressed as a percentage of the 50 ground surface observations for each lane. The significance of differences, between treatments and between years, was tested with analysis of variance and Duncan's multiple range test.

TABLE 1. Changes in the cryptogam cover, vertical distance, and coefficient of variation of vertical distance in response to different levels of trampling.[a]

Number of passes	Cryptogam cover (%)	Vertical distance (mm)	Coefficient of variation (%)
0	89 a	492 a	2.7 a
5	69 b	497 ab	1.9 b
15	45 c	505 bc	1.5 b
25	36 c	502 abc	1.4 b
50	9 d	511 c	1.4 b
250	0 d	511 c	1.4 b

[a]Any two values in the same column followed by the same letter are not significantly different (Duncan's multiple range test, $p = .05$).

RESULTS

Cryptogamic crusts were immediately pulverized by trampling. Pedestals were flattened, and the black veneer of bacteria and cryptogams was obliterated. Changes in cryptogam cover, vertical distance, and the index of surface roughness were all statistically significant (Table 1). Differences between the effects of trampling with tennis shoes and boots were not significant, however.

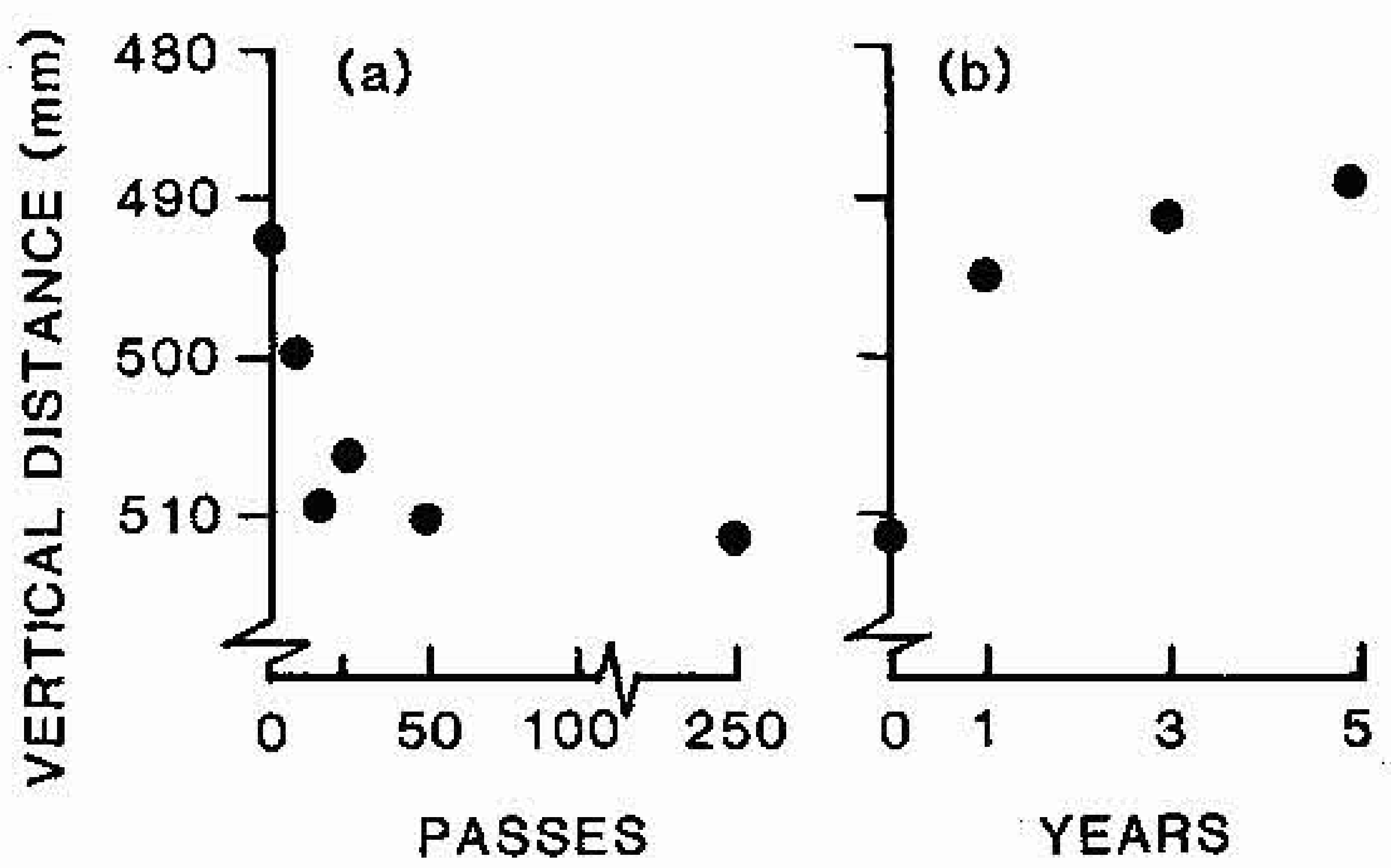

Fig. 2. Mean vertical distance from a horizontal transect to the ground surface (a) after different levels of trampling in lug-soled boots and (b) after one, three, and five years of recovery. Standards errors were all 2.2–2.8 mm.

TABLE 2. Cryptogam cover, vertical distance, and coefficient of variation of vertical distance 0, 1, 3, and 5 years following trampling.[a]

Years since trampling	Cryptogam cover (%)	Vertical distance (mm)	Coefficient of variation (%)
0	3 a	511 a	1.3 ab
1	20 b	499 b	1.0 a
3	71 c	491 c	1.9 b
5	85 d	490 c	1.9 b
Pre-trampling	89 d	492 c	2.7 c

[a]Any two values in the same column followed by the same letter are not significantly different (Duncan's multiple range test, $p = .05$).

Cryptogam cover was reduced by 50% after 15 passes and was reduced to zero after 250 passes (Table 1). At this point the organisms were so widely dispersed that all visual evidence of their existence disappeared (Fig. 1). Destruction of pedestals also occurred rapidly (Fig. 2a). The vertical distance below the transect increased 13 mm following 15 passes. Additional trampling caused no significant further compression; the pedestals were already destroyed. Surface roughness, as measured by the mean coefficient of variation of the vertical distances, declined as the pedestals were pulverized (Table 1). All treatments were significantly different from the control, but not from each other. A blackened, irregular, aggregated soil surface was replaced after trampling by a flat surface of unconsolidated sands, which was much more vulnerable to erosion.

Substantial recovery occurred in the first year after trampling ceased. After one year of recovery, cryptogam cover had increased significantly (Table 2), and vertical distance had decreased significantly (Fig. 2b); however, surface roughness had not increased (Table 2). The unconsolidated sands left by trampling had reaggregated into a smooth, raised crust, but neither pedestals nor the blackened veneer of organisms had reformed. After three years of recovery, vertical distances were similar to pre-trampling levels. Cryptogam cover had increased dramatically, as had surface roughness, although both were still below pre-trampling values (Table 2). After five years of recovery, cryptogam cover had returned to pre-trampling levels. At this point all visual evidence of damage was gone (Fig. 3). Surface roughness values remained depressed (Table 2), however, suggesting that pedestals had not redeveloped fully.

Fig. 3. The lane that received 250 passes in lug-soled boots after five years of recovery. View is from the end opposite that in Figure 1.

The typical pattern of structural destruction and recovery is illustrated in Figure 4, which

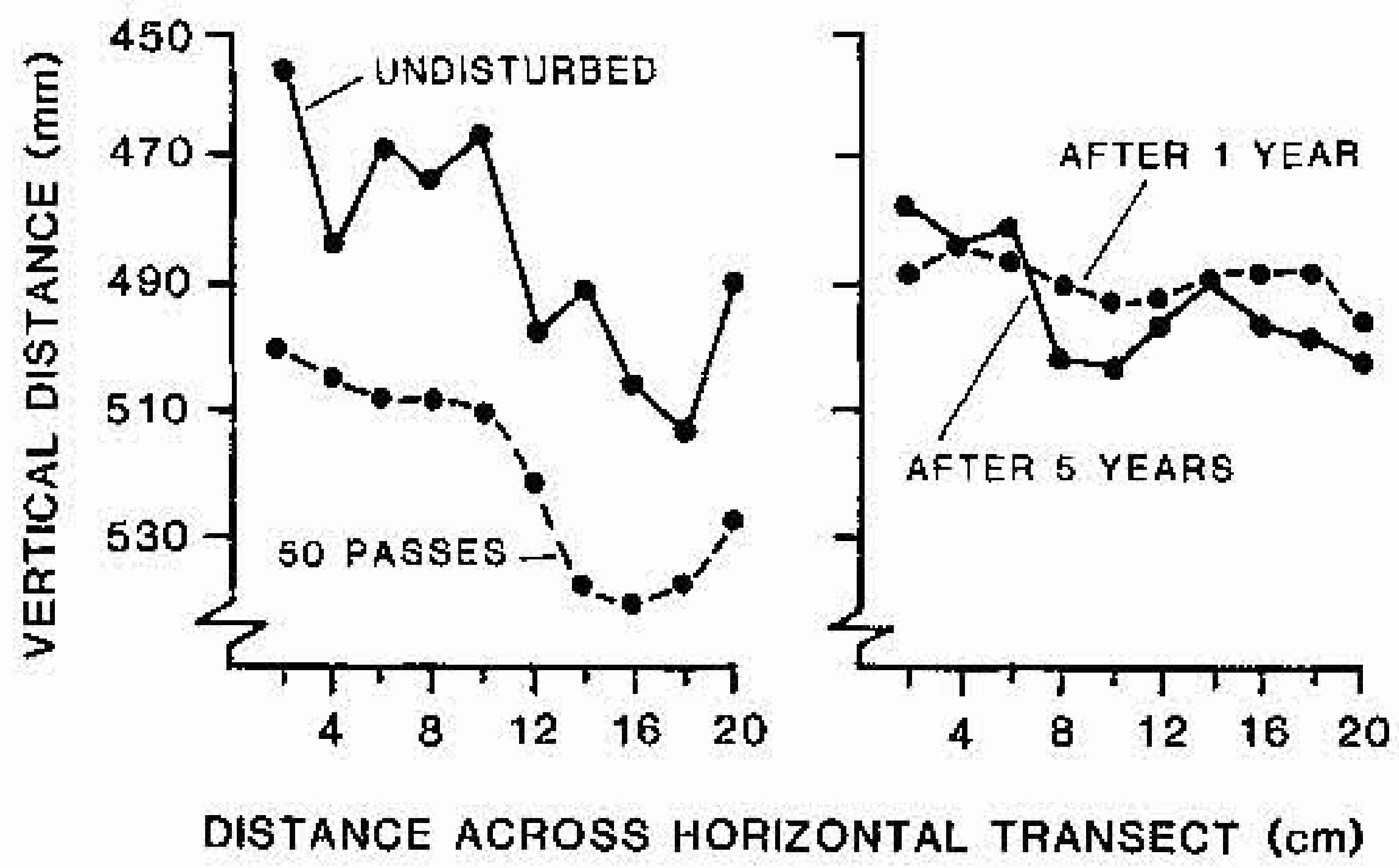

Fig. 4. Vertical distance from a horizontal transect to the ground surface (a) before trampling, (b) after 50 passes, (c) after one year of recovery, and (d) after five years of recovery. Data are for one of five transects across the lane trampled in tennis shoes.

shows the changes that occurred under one of the transects. Fifty passes with tennis shoes increased mean vertical distance and decreased variations between adjacent sample points. The redevelopment of a soil crust during the first year of recovery reduced vertical distance (i.e., the ground surface apparently rose), but surface irregularity remained low. After five years of recovery, the surface was more irregular than after trampling, but less irregular than before trampling.

Discussion

These results illustrate the damage hikers can do to cryptogamic soil. The structure of these crusts was destroyed by only 15 passes, and cryptogam cover was negligible after only 50 passes. Compared with the response of vascular plants to similar levels of trampling disturbance, cryptogamic crusts are highly fragile but moderately resilient (Cole 1985, 1988). No other experimentally trampled vegetated surfaces have been denuded by such low levels of trampling.

Recovery was surprisingly rapid, however. This conclusion agrees with that of studies of recovery after grazing and fire (Johansen et al. 1984, Johansen and St. Clair 1986), which report more rapid and extensive recovery than anticipated. In this study recovery rates were probably increased by the close proximity of inoculum to the disturbed lanes and by the fact that disturbance occurred only once and was then removed. This study and previous ones rely primarily on visual criteria for evaluating recovery. The depressed surface roughness values five years after trampling suggest that complete recovery will take longer than five years. On disturbed sites at Canyonlands National Park such parameters as chlorophyll content, species diversity, and the thickness of the subsurface gelatinous sheaths that bind soil particles remain low even after crusts appear to have recovered (Belnap 1990).

The finding that the crustal surface rose during the first few years following the cessation of trampling is intriguing. The process by which pinnacled crusts develop is not well understood, but this result suggests that they may develop through accretion rather than erosion. If they were erosional features, the undisturbed strips should have remained conspicuously higher than the treatment lanes. This was not the case.

Given the fragility of these crusts, random trampling by backcountry recreationists is capable of seriously impacting large areas. Very low levels of ongoing use will maintain high levels of disturbance. This shows up most commonly as webs of trails that surround trail junctions, camping areas, and points of interest. In arid parks of the southwestern United States it is important to educate visitors about the nature, importance, and fragility of cryptogamic crusts. With this knowledge, visitors are more likely to voluntarily minimize trampling of crusts and support management actions taken to protect areas of crust. Most visitors neither recognize cryptogams as fragile vegetation nor realize their importance to site stability. It is also important to locate trails, camping areas, and other activity sites away from places with well-developed crust and, where this is not possible, to try to confine traffic to one well-developed route.

The one positive management implication of this research lies in the finding of relatively fast visual recovery. Where it is possible to eliminate trampling, crusts can quickly reestablish themselves. In this experiment trampling left an apparently sterile surface of sand that, in reality, was heavily inoculated with crustal organisms. Managers can speed recovery of disturbed areas by inoculating them (St. Clair et al. 1986). Moreover, even though complete recovery may take much more than five years, the rapid elimination of the visual evidence of damage is helpful. This makes it easier for managers to keep visitors off certain trails and campsites.

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