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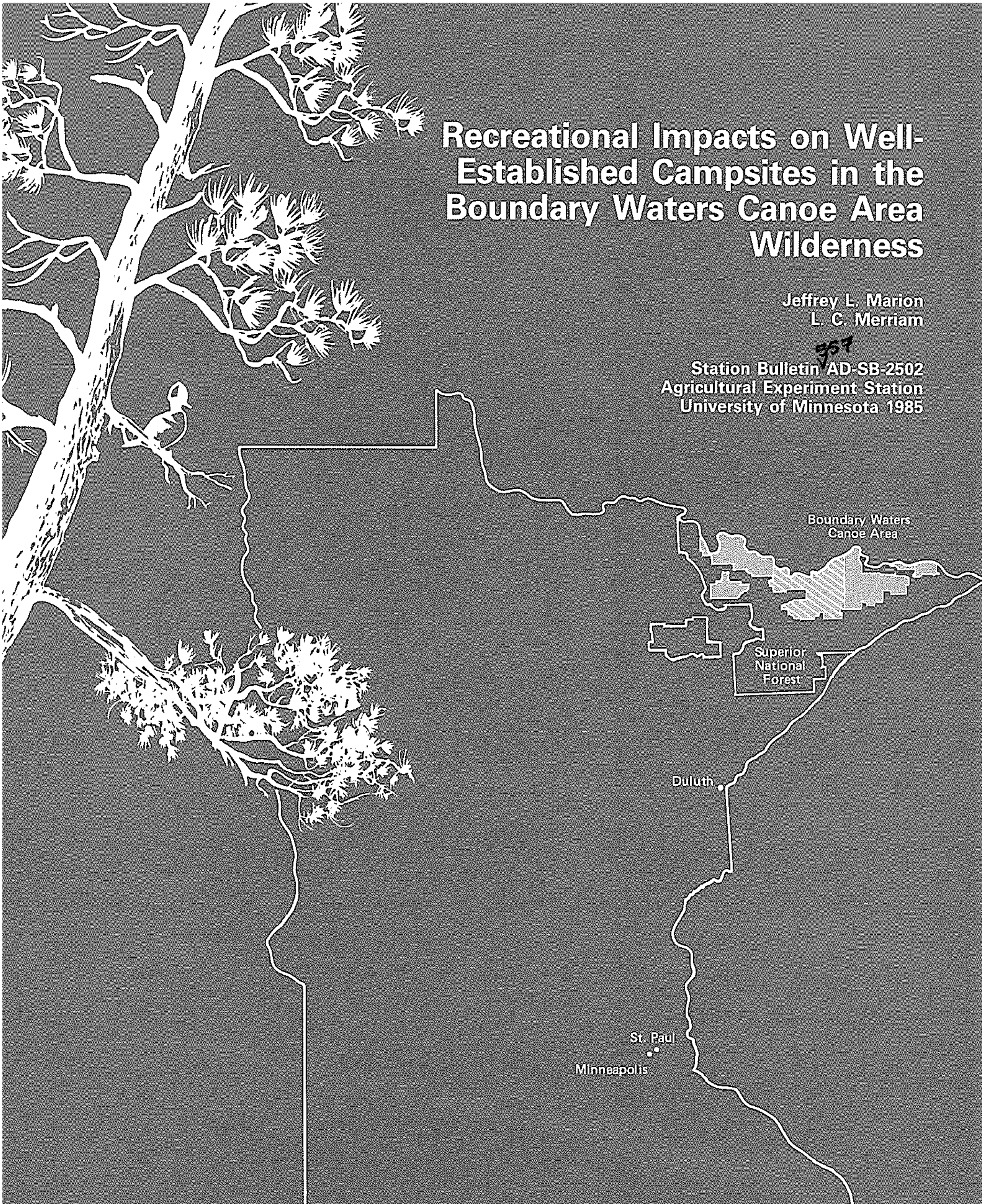

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RECREATIONAL IMPACTS ON WELL-ESTABLISHED CAMPSITES IN THE BOUNDARY WATERS CANOE AREA WILDERNESS

Jeffrey L. Marion and L. C. Merriam[1]

SUMMARY

This study examined recreationally related changes on 96 well-established campsites in the Boundary Waters Canoe Area Wilderness (BWCA), Minnesota. Biophysical measurements taken on campsites and adjacent, environmentally similar but undisturbed control sites were compared in an effort to identify and assess the extent of vegetative, soil, and physical site changes.

Vegetation

Shallow soils and high use contributed to root exposure in approximately 84 percent of the trees on the average BWCA campsite. Severe root exposure results in increased moisture stress, particularly during drought years, and can also contribute to increased susceptibility to windthrow. Ninety-six percent of all trees on the average campsite had significant damage, consisting of large branches cut or broken off, trunk scars from axes or hatchets, bark stripping, and tree girdling. The number of campsite trees with reduced vigor and crown dieback increased significantly with increasing level of tree damage, indicating that this may be an important factor in increased tree mortality on campsites.

Tree seedlings and saplings were virtually eliminated on campsites. Most of the seedlings and saplings were lost during campsite construction and initial use; those that survived did so only in protected locations. Mortality rates of mature trees were found to be significantly higher on campsites than in undisturbed offsite areas.

Vegetative ground cover declined from an average of 94 percent on control sites to approximately 36 percent on the average campsite. This was accompanied by significant increases in exposed litter cover, root area, soil, and bedrock. The amount and durability and/or recoverability of vegetative ground cover increased significantly with increasing sunlight penetration. The broad-spreading leaves and tall flimsy stature of forest herbaceous vegetation, adaptations to better compete for sunlight, make forest understories particularly susceptible to trampling damage.

The composition of campsite vegetation is highly different from that of undisturbed offsite vegetation. Much of the original campsite vegetation is replaced by more trampling-resistant species, many of which are not native to northeastern Minnesota. Twenty-two non-native species were identified; 62 percent of all campsites had at least one non-native species. These "invader" species have evolved growth forms, life histories, and physiologies that enable them to survive and reproduce under highly disturbed conditions. Grasses and some sedges were found to be trampling resistant and often comprised the majority of vegetative cover on campsites.

Soils and Site Size

Soil compaction, as measured by both bulk density and penetration resistance, was significantly higher on campsites than on control sites. Compaction can have pervasive long-term ecological effects such as reduced soil, water, and air infiltration capacity, obstruction of plant roots, and an increase in water runoff and erosional rates. The potential for soil compaction was found to decrease substantially with increasing organic content. Soil organic horizon layers were significantly reduced on campsites, with much of the organic material broken down and compacted through trampling or blown and eroded away.

Campsites varied considerably in size (42 to 576 square meters) with an average of 220 square meters. Landform, local topography, and offsite vegetation density all influence campsite size.

Level of Use

The impact variables exposed soil, bulk density, penetration resistance, organic horizon thickness, number of tree seedlings, campsite size, floristic dissimilarity, and tree damage were significantly related to amount of use. The proportionately greatest impact occurred on lightly used sites. Overall, sites used only 1 to 12 nights/season were approximately two-thirds as impacted as sites used more than 60 nights/season. More heavily used sites were more highly impacted, but the rate of increase in impact diminished as use increased. However, this relationship varied among impact parameters, and for some important variables such as exposed soil and campsite size, little leveling off occurs at higher use levels.

Campsite Age

The impact variables exposed soil, bulk density, organic horizon thickness, campsite size, floristic dissimilarity, tree damage, and root exposure were significantly related to campsite age. Overall, sites 5 to 10 years old were approximately three-quarters as impacted as sites over 14 years old. Although most impact occurred with site establishment and initial use, ongoing damage was also evident. For well-established campsites the annual deterioration was apparently small, but due to the cumulative nature of many impacts, the deterioration can be substantial over longer periods.

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INTRODUCTION

The goals set forth in the Wilderness Act of 1964 (P.L. 88-577) are becoming increasingly difficult for wilderness managers to achieve. According to the Act, wilderness lands are to retain their "primeval character and influence" and are to be "protected and managed so as to preserve (their) natural conditions." Congress intended wilderness to be managed in such a way that human use would not significantly impair the resource. However, marked increases in wilderness recreational use have resulted in environmental impacts that threaten both the primitive character of these areas and the quality of wilderness experiences for the visitor.

Wilderness managers faced with the dual objectives of preserving the natural integrity of these resources and providing for their continued recreational use are confronted with a paradox requiring difficult decisions and innovative management. Physical and biological changes resulting from recreational use of wilderness areas therefore present a dilemma for managers. A solid information base concerning these changes will be required by managers seeking to develop and refine visitor and resource management policies and techniques. Nowhere is this of greater concern than in Minnesota's Boundary Waters Canoe Area Wilderness (BWCA), which receives approximately 150,000 visits annually.

This study examines the nature and extent of biophysical changes that have occurred on well-established designated BWCA campsites. Physical and biological measurements were taken on 96 campsites and on adjacent, environmentally similar but undisturbed, control sites. Campsite and control measurements were compared in an effort to: (1) identify and measure the extent of vegetative, soil, and physical site changes, (2) evaluate and identify factors relating to differences in the extent of these changes, and (3) assess the relative recreational durability of various vegetation and soil types.

The BWCA, established by the Wilderness Act of 1964, is currently the most intensively used unit in the National Wilderness Preservation System. Located in northeastern Minnesota, it comprises 435,200 hectares of land and water with over 2,000 kilometers of canoe routes. Although 67 percent of the visitors are Minnesota state residents, the BWCA is truly a national asset, drawing 22 percent of its visitors from neighboring states and 11 percent from more distant areas. Visitor use of the BWCA is predominantly by paddle canoe, which accounted for 75 percent of the 1983 visitation.

The BWCA is managed by the Superior National Forest, U.S. Forest Service. The 1964 Wilderness Act and 1978 BWCA Act, together with previous legislation and administrative policies, provide management direction for the area. A number of visitor management policies restricting and regulating recreational use have been adopted in an effort to control resource degradation and to preserve the quality of recreational experiences. For example, to limit unnecessary and/or poorly located campsites, wilderness managers have carefully selected and developed approximately 2,000 campsites. Visitors are required to use designated sites for overnight camping. Each designated campsite consists of a steel fire grate, tenting areas, a canoe/boat landing, and a small box latrine. Managers have found such regulations to be the only realistic means of reducing resource damage and visitor crowding given the extremely heavy use the wilderness receives.

PREVIOUS STUDIES

A number of important physical and biological changes occur when a previously undisturbed area is subjected to recreational use. Recreational impact research has shown that even low levels of use often result in considerable change, particularly on forested sites. Taller herbaceous vegetation, mosses, and lichens are particularly susceptible to trampling damage and are quickly reduced or eliminated on campsites (Cole 1979, Leonard et al. 1983). Further use results in reductions in the thickness of litter and organic soil horizons, which are pulverized by foot traffic, compacted, and eroded (Monti and Mackintosh 1979). Subsequent soil and tree root exposure indicates further deterioration in site conditions.

Many studies have documented a nearly-complete elimination of tree seedlings and saplings on campsites (Magill and Nord 1963, Bratton and Stromberg 1980, Cole 1983b). Tree seedlings are very susceptible to trampling damage, and along with saplings, are often removed by visitors in tenting areas. Mortality rates for mature campsite trees are also much higher than in undisturbed areas because of removal for firewood, damage inflicted by axes and knives, root exposure, and compacted soils. Shrubs are also greatly reduced in cover and number on campsites (Dawson et al. 1978, Cole 1982).

The compaction of campsite soils by foot traffic can have pervasive long-term effects, including a reduction in the movement of water and air through the soil, obstruction of plant roots, and accelerated water runoff resulting in increased erosional rates (Legg and Schneider 1977, Monti and Mackintosh 1979, James et al. 1979). In regions with thin soils, such as northeastern Minnesota, severe soil erosion can lead to increased windthrow, physical root damage, and reduced drought resistance of vegetation.

The balancing of recreational impacts and use is particularly difficult because of the relationship between the two. In an earlier study of BWCAW campsites, Frissell and Duncan (1965) found that over 80 percent of ground cover is lost with light use (0 to 30 days use/season), with little additional change from heavier use (up to 90 days use/season). Merriam et al. (1973), in a five-year study of newly developed BWCA campsites, reported that campsites are highly affected by initial use and that further use has less and less effect on the site's physical character. However, subsequent studies have revealed that a number of impacts increase over time and with increasing use levels (Merriam and Smith 1975, Legg and Schneider 1977, Dunn et al. 1980, Merriam and Peterson 1983).

The general research finding that the majority of change occurs with initial and low levels of campsite use supports the current BWCA designated campsite policy. However, long-term management of the designated campsites will require more specific information on use/impact relationships and the effects of long-term camping use. This study provides such information for BWCA managers and others responsible for site protection.

METHODS

Physical and biological measurements were taken on 96 back country campsites and on adjacent undisturbed control plots. Control plots, each with an area of 50 square meters, were chosen on the basis of similarity of environmental conditions such as soil and vegetation type, depth to bedrock, and slope. All campsites were located within the Kawishiwi Ranger District in the vicinity of Ely, Minnesota, and had been in use for at least five years.

Campsite areas were determined by first identifying campsite boundaries on the basis of pronounced changes in vegetative cover or composition. Campsites were then measured with steel tapes and areas were calculated, excluding the area of any undisturbed "islands" of vegetation within the boundaries.

A variety of vegetative measurements were taken on campsites and control plots. The number and species of tree seedlings, (height 15 to 140 centimeters), tree saplings (height greater than 140 centimeters but diameter less than 2 centimeters), standing dead trees, and stumps were tallied. The extent of damage and root exposure was also assessed for each campsite tree. Four categories of root exposure and tree damage were utilized: none, slight, moderate, and severe (Figures 1 and 2). Six categories of ground cover were also assessed as percentages of the total campsite or control area: 1) dense ground cover—ground which has 50 to 100 percent vegetative cover (less than 0.5 meters in height); 2) sparse ground cover—ground which has 5 to 50 percent vegetative cover (less than 0.5 meters in height); 3) exposed bedrock—ground where bedrock is largely exposed; 4) exposed root area—ground where tree roots are moderately or severely exposed (Figure 1) and the immediately adjacent areas; 5) exposed soil—ground where soil is largely exposed with little or no litter cover, excluding exposed root area; and 6) litter cover—ground where vegetative cover (less than 0.5 meters in height) is less than 5 percent and which is not exposed soil, bedrock, or root area. Separate cover estimates were made for trees, shrubs, herbs, mosses and lichens, and for each vegetative species relative to the total campsite or control area.

Soil samples were taken from four primary campsite use areas and from four control plot locations. These samples were from the surface 8 centimeters of mineral soil, following removal of surface organic horizons. The irregular hole method for determining bulk density (a measure of soil compaction) was used due to the large number of coarse fragments present in some of the soils encountered (Howard and Singer 1981). Soil samples were analyzed for moisture content, bulk density, particle size, and organic content. Organic horizon thickness and penetration resistance (another measure of soil compaction) were measured at 12 points around the primary campsite use area and in the control plots. Penetration resistance was measured with a Soiltest pocket penetrometer at the top of the mineral soil horizon.

Use level estimates for each campsite studied were obtained from the previous five years of BWCA travel zone permit data and an experienced back country manager. Three discontinuous classes of use were defined: 1) light use (less than 12 nights per season); 2) moderate use (20 to 40 nights per season); and 3) heavy use (greater than 60 nights per season). An effort was made to ensure that only sites with a consistent level of use for the previous five years were measured. Campsite age was determined from U.S. Forest Service records dating back to 1968.

To assess the impacts of recreational use, measurements taken on campsites and undisturbed control sites were compared, presuming that any differences were due to recreational use. Environmental variability was minimized through the use of absolute difference (Cole 1982) as the principal measure for comparison. (Absolute difference is the difference between campsite and control site values, on a site-specific basis). Control values were subtracted from campsite values so that the sign of the absolute difference values indicates the direction of change. For example, if litter depth is 2 cm on a campsite and 5 cm on its paired control site, the absolute difference of −3 cm indicates a reduction in litter depth on the campsite.

Two impact assessment systems designed for use by managers were also applied on each campsite. These standardized systems were designed to objectively assess the extent of change on campsites for the purpose of monitoring impacts over time. The first system, developed by Frissell (1978), has five condition classes describing the relative extent of change in ground cover, soil exposure and erosion, and tree damage. The second system, developed by Cole (1983b), is based on assessments for nine parameters: vegetative cover, mineral soil exposure, tree damage, root exposure, extent of user-constructed developments, cleanliness, number of trails, camp area, and barren core area. Each parameter was given a rating from 1 to 3 based on three quantitatively defined categories describing the range of conditions. Individual parameter ratings for each campsite were averaged to determine an overall summary impact rating.

Finally, a multiple-item impact scale was constructed using the standardized measures of eight important impact variables from this study: root exposure index, tree damage index, floristic dissimilarity, campsite size, and absolute difference values for exposed soil, organic horizon thickness, bulk density, and dense ground cover (Marion 1984).

RESULTS AND DISCUSSION

Tree Damage and Root Exposure

On the average campsite approximately eight trees (84 percent of all campsite trees) had exposed roots (Table 1). This is considerably higher than values reported by Cole (1982, 1983a) of 30 percent in the Eagle Cap Wilderness of Oregon and 54 percent in the Bob Marshall Wilderness of Montana. Over one-fifth of all trees fell into the severe root exposure category (Table 1, Figure 1c). This excessive root exposure may be due to the shallow soils common throughout much of the BWCA, as well as to higher use levels.

Approximately nine trees per campsite (96 percent of all campsite trees)

Table 1. Number and percent of trees in four categories of tree root exposure and tree damage.[1]

Category	Number/ Site[2]	Number/ Hectare[2]	Percent of All Trees	Number of Trees With Crown Dieback
Root Exposure				
None	1.5	68	16	23
Slight	3.4	197	32	26
Moderate	3.1	147	30	24
Severe	1.8	93	22	23
Tree Damage				
None	0.2	36	4	1
Slight	2.3	170	33	25
Moderate	4.2	241	39	29
Severe	2.3	109	25	41

[1]N = 92 (campsites without trees are not included).
[2]Due to a moderately skewed distribution, median values are reported.

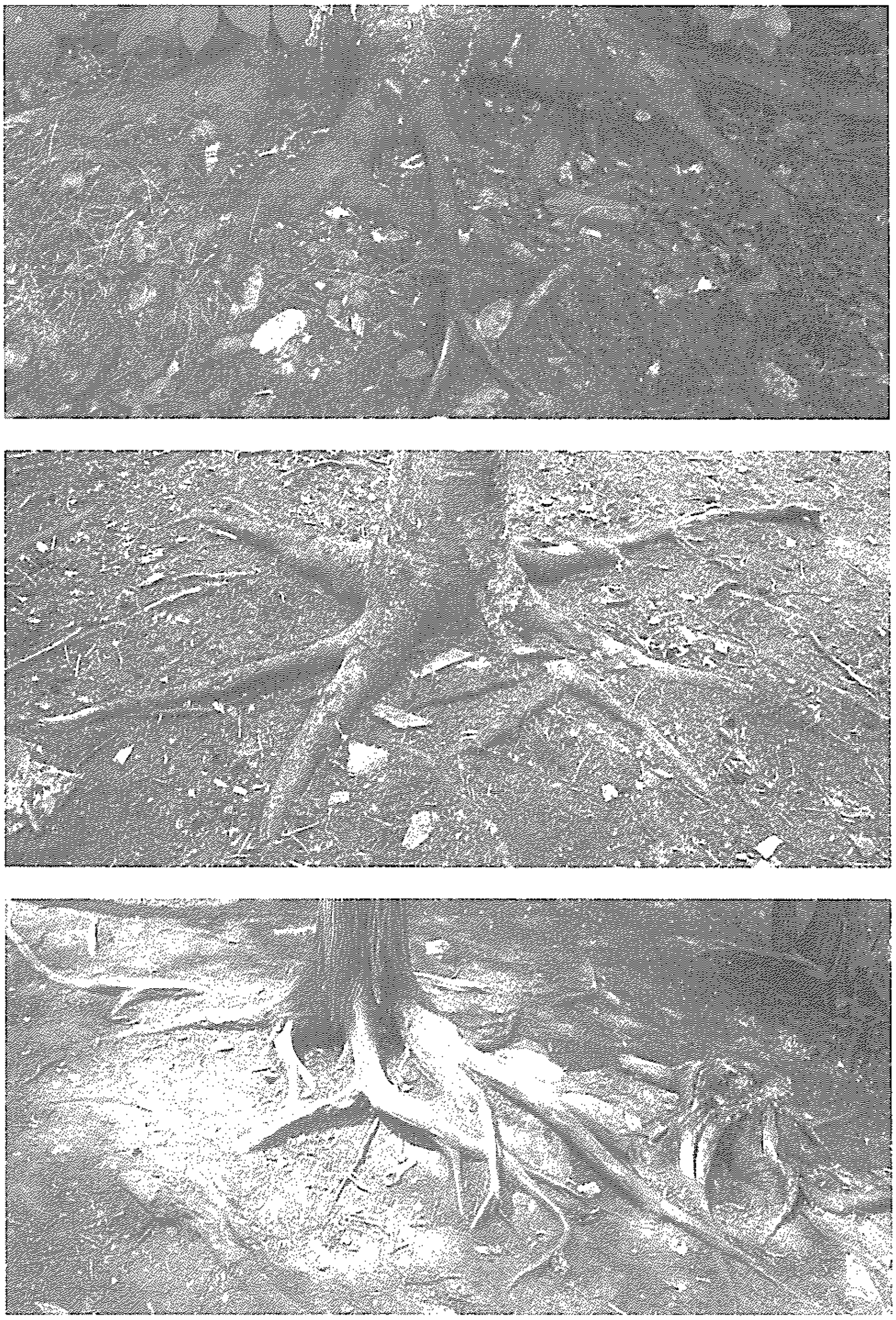

Figure 1. Typical examples of three root exposure ratings: slight (a), moderate (b), and severe (c).

were damaged by recreationists (Table 1). Over half of all campsite trees had moderate to severe levels of tree damage (Figure 2b, c) consisting of large branches cut or broken off, extensive trunk scars, bark stripping, and tree girdling. In a previous study of BWCA campsites, McCool et al. (1969) reported that 64 percent of main travel route sites and 60 percent of off-route sites had trees with mechanical damage.

Several researchers have documented reductions in tree foliage characteristics, tree vigor, and diameter growth for trees on recreation sites (James et al. 1979; LaPage 1962; Magill and Nord 1963). Some authors (Settergren and Cole 1970) attribute these findings to reduced soil moisture caused by soil compaction and loss of organic duff layers (which expose tree roots, increase water runoff, and reduce moisture retention). Others (Merriam et al. 1973, DeVos and Baily 1970) contend that trunk damage is a more important factor.

The relative importance of tree root exposure and damage in reducing tree vigor and increasing mortality was assessed by stratifying campsite trees exhibiting visibly reduced vigor and crown dieback by the root exposure and tree damage categories. Approximately equal numbers of these "dying" trees fell into each of the four classes of root exposure (Table 1). This suggests that root exposure is not causally related to reduced vigor and tree mortality, at least in the BWCA.

In some instances severe root exposure undoubtedly contributes to increased windthrow susceptibility. This is particularly true in canoe landing areas (Figure 3). Erosional rates in these areas are high as a result of concentrated use, steep slopes, and wave action on shorelines lacking vegetative cover.

Number of "dying" trees shows a very strong correlation with increasing degree of tree damage (Table 1). Only one of these trees had no damage, while 41 such trees showed severe damage. The strength of this relationship supports the hypothesis that tree damage is causally related to reduced tree vigor and perhaps also to increased tree mortality.

Many of the "dying" trees, particularly in the severe damage class, were *Betula papyrifera* (paper birch) whose outer bark had been extensively peeled. This practice is fairly common in spite of strong visitor education efforts.

Tree Mortality and Regeneration

There were 95 percent fewer tree seedlings on campsites than on control sites, with only two seedlings on the typical campsite (Table 2). Seedlings were found only in protected locations, near large rocks and shrubs, or close to campsite boundaries. Tree regeneration was considerably higher for species with suckering and stump sprouting ability (ability to send up new shoots following damage) such as *Populus tremuloides* (trembling aspen), *Betula papyrifera* (paper birch), and *Acer rubrum* (red maple), than for species lacking these abilities.

Tree saplings were virtually eliminated from campsites, declining from 836 per hectare on control sites to less than one per hectare on campsites. Many saplings were removed with initial campsite construction and use, others have grown into tree classes (greater than 2 centimeters dbh), and

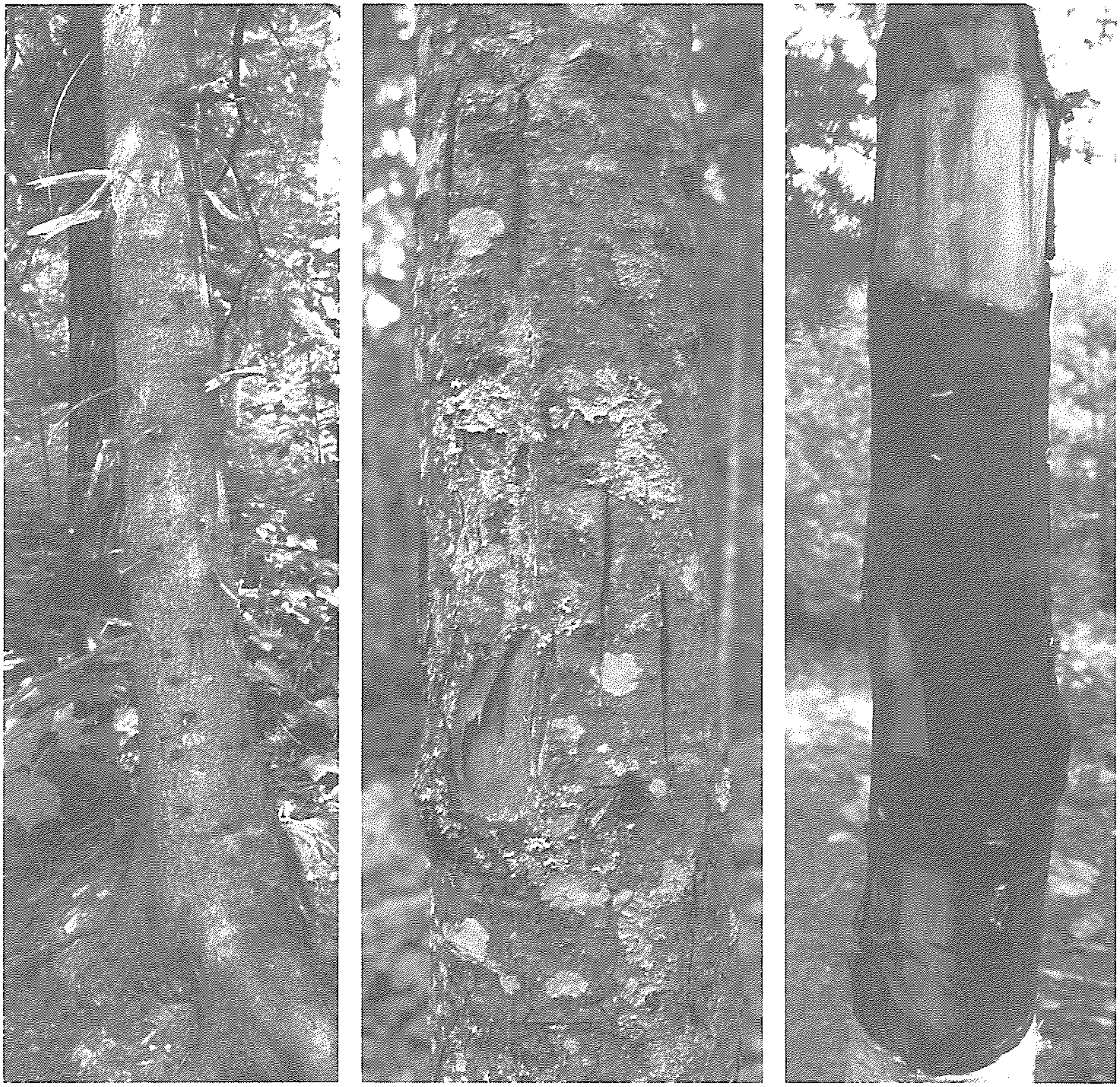

Figure 2. Typical examples of three three damage ratings: slight (a), moderate (b), and severe (c).

present replacement rates (from seedling classes) are extremely low.

The number of standing dead trees and stumps on campsites (185 per hectare) is significantly greater than the number found on control sites (66 per hectare), indicating that tree mortality rates are considerably higher on campsites. This finding, combined with the near-complete lack of tree regeneration on campsites, forecasts potentially major problems for long-term campsite management unless campsite tree planting and protection efforts are intensified and expanded.

Ground Cover

Significant differences occurred between campsites and controls for all six categories of ground cover. The most notable difference was a 76 percent reduction in dense ground cover, from 87 percent on control sites to 22 percent on campsites (Figure 4). Sparse vegetative cover increased to 14 percent on campsites. Combining dense and sparse ground cover categories reveals that vegetative cover has been lost from approximately 58 percent of the average campsite.

Vegetative reductions resulted in a 280 percent increase in the exposure of litter cover on campsites, from 5 percent to 36 percent, making it the largest ground cover category on campsites. In primary use areas the litter cover was largely absent due to pulverization from trampling. This resulted in the exposure of mineral soil, tree roots, and bedrock.

Because of its ecological and aesthetic importance, the variable "percent dense ground cover" was subjected to more comprehensive analysis to identify and assess the importance of influencing factors. Durability and/or resilience of ground cover was found to be directly related to sunlight intensity. This was revealed by analysis of variance results of absolute difference dense ground cover values for four categories of tree cover (Table 3). Mean absolute difference dense ground cover values diminish significantly with decreasing campsite tree cover (which permits greater sunlight penetration). The actual amount of dense ground cover on campsites was also directly related to sunlight intensity, ranging from 52 percent on campsites with less than 25 percent tree cover to only 4 percent on campsites with greater than 75 percent tree cover (Table 3).

These results support the findings of Cole (1979), who reported that open forest and meadow vegetation types lost less than 38 percent of their undercover while over 53 percent of the undercover was lost in more densely forested vegetation types. Natural selection favors a small investment in above-ground supporting structure in conditions of low light intensity (Whittaker 1975). Therefore, forest floor herbaceous vegetation has developed life forms characterized by tall but flimsy stature with broad spreading photosynthetic leaves. These morphological characteristics make forest herbaceous vegetation particularly susceptible to trampling damage (Cole 1979).

There was no apparent relationship between amount of dense ground cover and soil texture, moisture, or bulk density in campsites. In particular, the lack of a relationship between campsite dense ground cover and soil bulk density was unexpected. These findings suggest that plant species, which have adapted to high levels of disturbance and account for much of the cover on campsites (primarily grasses), have also developed adaptations for coping with compacted soils.

Vegetative Composition

Plant composition is affected by human trampling through direct mechanical damage, and through indirect effects such as changes in soil bulk density, moisture, and possibly nutrients. Floristic dissimilarity (Cole 1979), a relative measure of vegetative compositional change, ranged from 40 percent (nearly natural) to 100 percent (no species in common between campsite

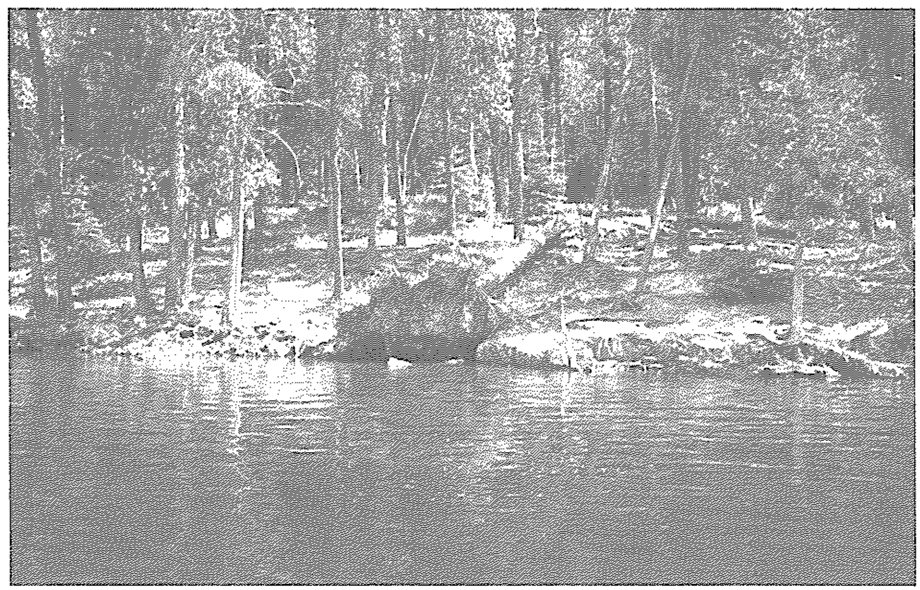

Figure 3. Severe root exposure in canoe landing areas (a) causes greater susceptibility to windthrow (b).

Table 2. Selected statistics for four tree-related impact variables for campsites and controls.[1]

Impact Variable	Campsite (N = 96)		Control (N = 96)		Absolute Difference	Z Value
	No./site	No./ha	No./site	No./ha	(No./ha)	
Tree Seedlings Median	1.8	104.5	9.2	1823.7	−1760.0	−8.4**
Tree Saplings Median	0.1	0.3	4.2	835.6	−797.4	−6.0**
Standing Dead Median	0.2	0.1	0.1	23.0	−0.01	−2.0*
Stumps Median	3.3	184.7	0.2	43.1	139.2	−6.1**

[1]Due to a highly skewed distribution of cases for these variables the median is the best measure of central tendency and the Wilcoxon matched-pairs ranked-signs test was used to test differences between paired observations.
*Significant at p = 0.05.
**Significant at p = 0.01.

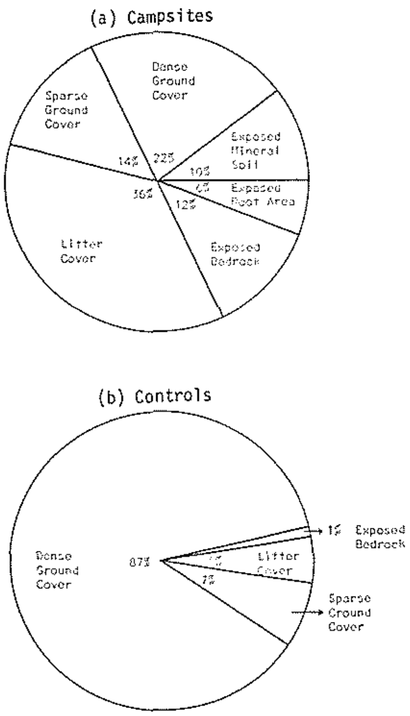

Figure 4. Average ground cover conditions on campsites (a) and controls (b).

and control sites), with an average of 88 percent. Natural variation among the undisturbed control sites accounts for 10 to 30 percent of the floristic dissimilarity. In spite of this it is clearly evident that significant changes in understory composition have occurred on campsites.

The floristic dissimilarity average of 88 percent is considerably higher than the values of 59 percent reported by Cole in the Eagle Cap Wilderness (Cole 1982) and 63 percent in the Bob Marshall Wilderness (Cole 1983a). This difference may be due to the greater susceptibility to trampling damage of the deeper forest herbaceous vegetation or to the higher use levels present in the BWCA.

Highly disturbed environments support only plant species that have evolved highly specific adaptations for coping with repeated disturbance. Species that are successful in these environments have growth forms, life histories, and physiologies which enable them to survive and reproduce under disturbed conditions. Worldwide, relatively few species exhibit these adaptations, and the same ones are repeatedly found on disturbed recreation sites (Speight 1973). These species are typically not native to the surrounding undisturbed vegetation.

Table 3. The relationship between dense ground cover and tree cover on campsites.

Percent Tree Cover	N	Dense Ground Cover: Mean	Dense Ground Cover: Absolute Difference
		Percent	Percent
0-25	18	52 ± 16	−44 ± 14 (a)[1]
25-50	19	26 ± 12	−61 ± 11 (ab)
50-75	37	15 ± 8	−70 ± 9 (b)
75-100	21	4 ± 5	−77 ± 14 (b)
			F Value = 5.4
			p = .01

[1] Mean values reported, including 95% confidence intervals. Means with the same letter were not significantly different; Duncan's Multiple Range test (p<.05).

Twenty-two non-native species were identified on BWCA campsites and 62 percent of the sites had at least one non-native species. The most abundant non-natives are common weedy species characteristic of disturbed soils: *Trifolium repens* (white clover), *Taraxacum officinale* (dandelion), *Phleum pratense* (timothy), *Cerastium vulgatum* (mouse-ear chickweed), and *Plantago major* (plantain) (Figure 5). Ahlgren and Ahlgren (1984) report that 92 species, over 11 percent of the 817 known BWCA flowering plant species, have been introduced from outside the area. Only 8 of the invading species are natives of other North American regions; the remaining introduced species came from Europe.

Currently, non-native species in the BWCA are restricted primarily to portage trails, campsites, and the sites of former logging camps, homes, and resorts. However, Ahlgren and Ahlgren (1984) found an aggressive non-native species, *Aegopodium podagraria var. variegatum* (goutweed), which has been spreading vigorously on a former resort site, eliminating native plants as it spreads. This species is known to produce substances toxic (allelopathic) to many native species and grows well in sun or shade (Ahlgren and Ahlgren 1984).

The presence of non-native species on campsites and portage trails is inevitable and there is little that managers can or perhaps should do to eliminate them. However, the unchecked spread of species such as goutweed is more serious and could eventually compromise wilderness values, particularly the scientific value of wilderness as a naturally functioning ecosystem.

Trampling-resistant native plant species were identified through quantitative differences in frequency, mean cover, and mean relative cover between campsites and controls. Grasses were the most successful of these species because of their unique growth form. Grass cover was directly related to sunlight intensity, increasing from an average of 5 percent on shaded sites to 52 percent on sunny sites.

Soils

Several significant soil-related changes have occurred on campsites. Soil compaction, as indicated by changes in bulk density and penetration resistance, was significantly higher on campsites than on control sites. Campsites had an average bulk density of 1.3 g/cm^3, 29 percent more dense than control sites (Table 4). This is comparable to increases of 23 percent, 30 percent, and 34 percent found on campsites in some other studies (Settergren and Cole 1970, Dawson et al. 1978, Monti and Mackintosh 1979). Bulk densities exceeding 1.3 g/cm^3 have been shown to significantly reduce vegetative growth (Barton et al. 1966, Halverson and Zisa 1982). Penetration resistance increased 214 percent, from 1.4 kg/cm^2 on control sites to 3.7 kg/cm^2 on campsites.

Multiple regression analysis revealed that the extent of change in bulk density was primarily related to the initial soil bulk density (control bulk density) and to soil organic content. Low initial bulk densities make possible larger potential increases in bulk density following recreational use. The compactability of soils was found to decrease markedly with increasing organic content.

Organic horizon thickness decreased 66 percent, from average values of 5.6 centimeters on controls to 1.9 centimeters on campsites (Table 4). Much of the organic material was broken down through trampling and blown or eroded away. The remainder was most likely decomposed, compacted, and intermixed with or leached into the mineral horizon. This accounts for the significant increase in organic content in the upper mineral horizon on campsites (Table 4).

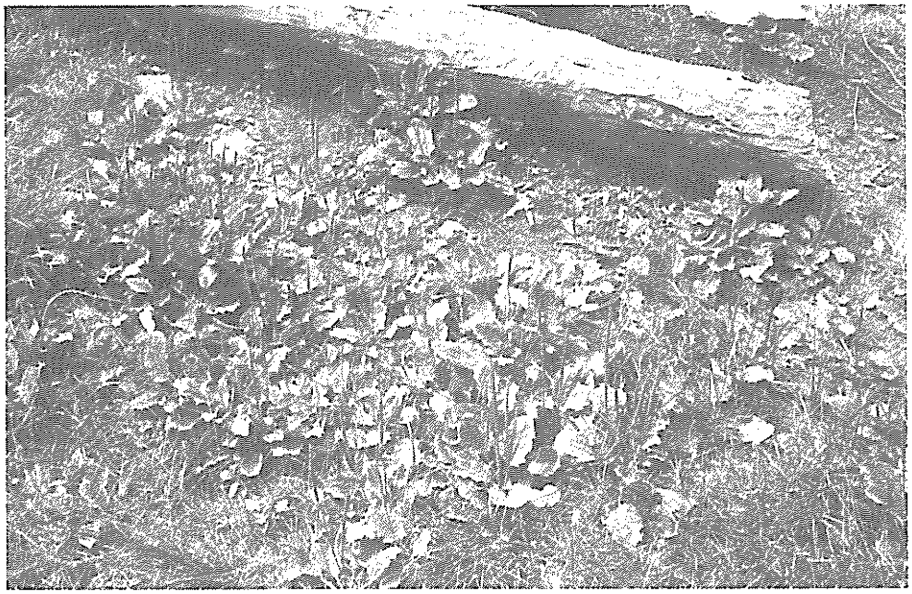

Figure 5. Species such as *Plantago major* have evolved many adaptations that enable them to survive and reproduce under conditions of high disturbance.

Table 4. Selected statistics for five soil impact variables for camp-sites and controls.

Impact Variable	Campsite Mean (N=96)	Control Mean (N=96)	Absolute Difference	T Value[1]
Stone-free Bulk Density (g/cm^3)	1.3 ± 0.1[2]	1.0 ± 0.1	0.3 ± 0.1	12.3**
Penetration Resistance (kg/cm^2)	3.7 ± 0.2	1.4 ± 0.1	2.4 ± 0.2	26.2**
Organic Horizon Thickness (cm)	1.9 ± 0.3	5.6 ± 0.4	−3.7 ± 0.4	−19.1**
Organic Content (% dry wt.)	6.2 ± 0.7	5.5 ± 0.6	0.7 ± 0.5	2.5**
Moisture Content (% dry wt.)	15.8 ± 2.1	16.4 ± 2.0	0.6 ± 0.3	− 0.8

[1] Significance was tested with paired sample one-tailed t-tests. A two-tailed test was used for organic and moisture content as the direction of change was unknown prior to testing.
[2] Mean values reported, including 95% confidence intervals.
*Significant at p = 0.05.
**Significant at p = 0.01.

Soil moisture was lower on campsites than on controls but the difference was not statistically significant. Reduced soil moisture would be expected on campsites due to reduced water infiltration and the reduction or loss of insulating vegetative and litter cover. The increased water holding capacity of moderately compacted soils and the incorporation of soil organic matter into the mineral soil may be responsible for offsetting the expected reduction.

Campsite Size

Campsites ranged in size from 42 to 576 square meters with an average size of 220 square meters. Satellite sites (tenting areas erected outside of a campsite's primary boundary) ranged in size from 4 to 97 square meters with an average size of 13 square meters. Forty-two percent of the campsites measured had at least one satellite site.

Landform, local topography, and vegetation density affect campsite sizes and expansion potential. Campsites established in fairly open vegetation with relatively level offsite areas free of large rocks were larger on the average (295 square meters) than campsites established in areas characterized by dense vegetation, steep slopes, rockiness, or poor drainage (188 square meters).

Impact Variation With Level of Use

As previously discussed, earlier studies have generally found the relationship between impact and amount of use to be curvilinear. All studies reveal significant biophysical changes with initial or low use. As use increases, most impacts continue to worsen but at significantly reduced rates. A smaller number of impacts show little evidence of leveling off and increase steadily with increasing use. Furthermore, research has shown that the impact/use relationship varies with respect to both environmental and use-related factors. For these reasons the impact/use relationship was examined in detail for BWCA campsites.

The impact/use relationships for the important impact variables in this study were assessed by stratifying the absolute difference values for the variables by the three levels of use and applying appropriate statistical tests. These results are presented in Table 5 and discussed below. The actual mean values for the controls and the three campsite use levels are graphically presented in Figure 6.

Vegetation Changes

Weighted root exposure and tree damage indexes were created using the number of trees in each of the four categories for each variable. On a four-point scale, root exposure ranged from index values of 2.4 for low-use sites to 2.7 for high-use sites (Table 5). These differences, however, were not statistically significant. A typical low-use campsite had one tree with severe root exposure (17 percent of all campsite trees), compared to three trees (27 percent) for high-use sites. In contrast, tree damage did increase significantly with increasing use, from index values of 2.6 to 3.0 on a four-point scale (Table 5). A typical low-use campsite had no severely damaged trees while a typical high-use site had five severely damaged trees (32 percent of all campsite trees).

The number of surviving tree seedlings decreased significantly with increasing use level (Figure 6a). Of the total reduction in tree seedlings, from 1824 seedlings per hectare on control sites to 55 per hectare on high use sites, 94% occurred with only low use (Figure 6a). These values emphasize the extremely low trampling resistance of tree seedlings, which survive only in protected locations on campsites. Campsite tree mortality, as indicated by the number of tree stumps on campsites, was also related to level of use (Figure 6b). The lack of statistical significance for the test of tree stump

Table 5. The relationship between level of use and important indicators of campsite condition.

Impact Variable	Level of Use: Low (N=28)	Moderate (N=38)	High (N=32)	F Value
Root exposure index	2.4 ± 0.2 (a)[1]	2.6 ± 0.2 (ab)	2.7 ± 0.2 (b)	2.3
Tree damage index	2.6 ± 0.2 (a)[1]	2.9 ± 0.2 (b)	3.0 ± 0.2 (b)	4.3*
Tree seedlings[3] (no/ha)	−799	−2000	−1799	7.9*
Tree stumps[3] (no/ha)	82	131	187	1.1
Dense ground cover[2] (%)	−56 ± 11 (a)	−65 ± 10 (a)	−70 ± 11 (a)	1.5
Floristic dissimilarity (%)	79 ± 7 (a)	90 ± 3 (b)	93 ± 3 (b)	10.8**
Exposed soil[2] (%)	3 ± 2 (a)	9 ± 3 (b)	18 ± 5 (c)	19.5**
Bulk density[2] (g/cm^3)	0.2 ± 0.1 (a)	0.3 ± 0.1 (b)	0.3 ± 0.1 (b)	3.0*
Penetration resistance[2] (Kg/cm^2)	1.7 ± 0.3 (a)	2.5 ± 0.3 (b)	2.9 ± 0.2 (c)	22.6**
Organic horizon thickness[2] (cm)	−2.6 ± 0.8 (a)	−4.0 ± 0.5 (b)	−4.4 ± 0.6 (b)	8.8**
Campsite size (m^2)	104 ± 18 (a)	198 ± 29 (b)	347 ± 39 (c)	63.2**
Condition class	2.1 ± 0.2 (a)	2.8 ± 0.2 (b)	3.5 ± 0.3 (c)	34.0**
Impact rating	1.5 ± 0.1 (a)	2.0 ± 0.1 (b)	2.5 ± 0.1 (c)	77.8**
Impact scale	−0.54 ± 0.14 (a)	0.09 ± 0.14 (b)	0.39 ± 0.15 (c)	44.2**

[1]Means include a 95% confidence interval. Means with the same letter for each impact variable were not significantly different; Duncan's Multiple Range test ($p<.05$).
[2]Absolute difference values reported and used in statistical tests. Absolute difference is the campsite value minus the control value, on a case-specific basis. Negative values indicate a decrease in that measure on campsites.
[3]Due to a highly skewed distribution of cases median values are reported and the Kruskal-Wallis one-way analysis was used to test statistical significance.
*Significant at p = 0.05.
**Significant at p = 0.01.

absolute difference values (Table 5) is primarily due to high site-to-site variability in the number of campsite trees and, subsequently, tree stumps. Nevertheless, the number of stumps increased directly with increasing levels of use, with no apparent leveling-off trend (Figure 6b).

The amount of dense vegetative cover on campsites ranged from 35 percent on low-use sites to 24 and 10 percent on moderate- and high-use sites (Figure 6c). However, differences in the absolute amount of change for the three use levels were not statistically significant (Table 5). The lack of a stronger relationship between level of use and loss of vegetative cover may be due to the greater loss of trees on more heavily used sites, which permits increased sunlight penetration. Regression analysis revealed that sunlight penetration to the ground surface was the most important factor influencing the extent of campsite vegetative cover, followed by use level.

Sixty-eight percent of the total reduction in dense ground cover occurred with just low use, but reductions continued with increasing use level (Figure 6c). The strength of these further reductions is more apparent than in other studies. Frissell and Duncan (1965) found changes in ground cover between use levels to be relatively minor. Cole (1982), LaPage (1967), and Young (1978) also found no strong relationship between level of use and reductions in vegetative cover on campsites.

Vegetative composition, as measured by floristic dissimilarity, changed significantly with increasing level of use (Table 5). Most change in vegetative composition occurred with just low use (79 percent). Increasing use to 20-40 nights/season significantly increased floristic dissimilarity to 90 percent, but additional increases in use resulted in little additional compositional change (Figure 6d).

Soil and Physical Site Changes

A number of important soil changes were strongly related to amount of use. Bulk density increased significantly with increasing use level with the majority of change occurring between the low- to moderate-use levels (Table 5). Bulk density leveled off as amount of use increased, with 61 percent of the total change in bulk density occurring with just low use, diminishing to only 3 percent with high use (Figure 6e). Penetration resistance also increased significantly with increasing use level. However, in contrast to bulk density, significant increases occurred with each use level interval (Table 5, Figure 6f). The average penetration resistance on high-use sites of 4.3 kg/cm^2 is close to the instrument maximum of 4.5 kg/cm^2, which was obtained on 24 of the 96 campsites.

The amount of exposed soil on campsites was strongly related to level of use (Table 5). Furthermore, significant increases in exposed soil occurred with each rise in use level (Duncan's test, Table 5). These increases are illustrated in Figure 6g, where 38 percent of the total difference in exposed soil is associated with the low- to moderate-use interval, and 48 percent with the moderate- to high-use interval. No leveling-off trend is apparent. Cole and Fichtler (1983), working in three areas in the Rocky Mountains, found that exposed soil increased more than any other impact parameter with increasing use.

Organic horizon thickness decreased significantly with increasing use (Table 5) from 2.8 centimeters on low-use sites to 0.9 centimeters on high-use sites (Figure 6h). Sizable reductions occur with initial use (59 percent of the total change, Figure 6h), which pulverizes and compacts the loose organic material. With additional use the organic material is further compacted, intermixed with mineral soils, and eroded.

Campsite sizes expanded significantly with increasing level of use, ranging from an average of 104 square meters for low-use sites to 347 square meters for high-use sites (Figure 6i). Furthermore, the campsite size/use relationship was exceptionally strong, with significant size increases associated with each increase in use level (Table 5). Results from an earlier BWCA study of newly developed campsites (Merriam et al. 1973) also showed that campsite expansion is closely correlated with amount of use.

Summary Impact Ratings

Overall measures of campsite condition were provided by the two impact assessment systems and the standardized impact scale. Tests with these three impact variables indicate that the general condition of campsites signifi-

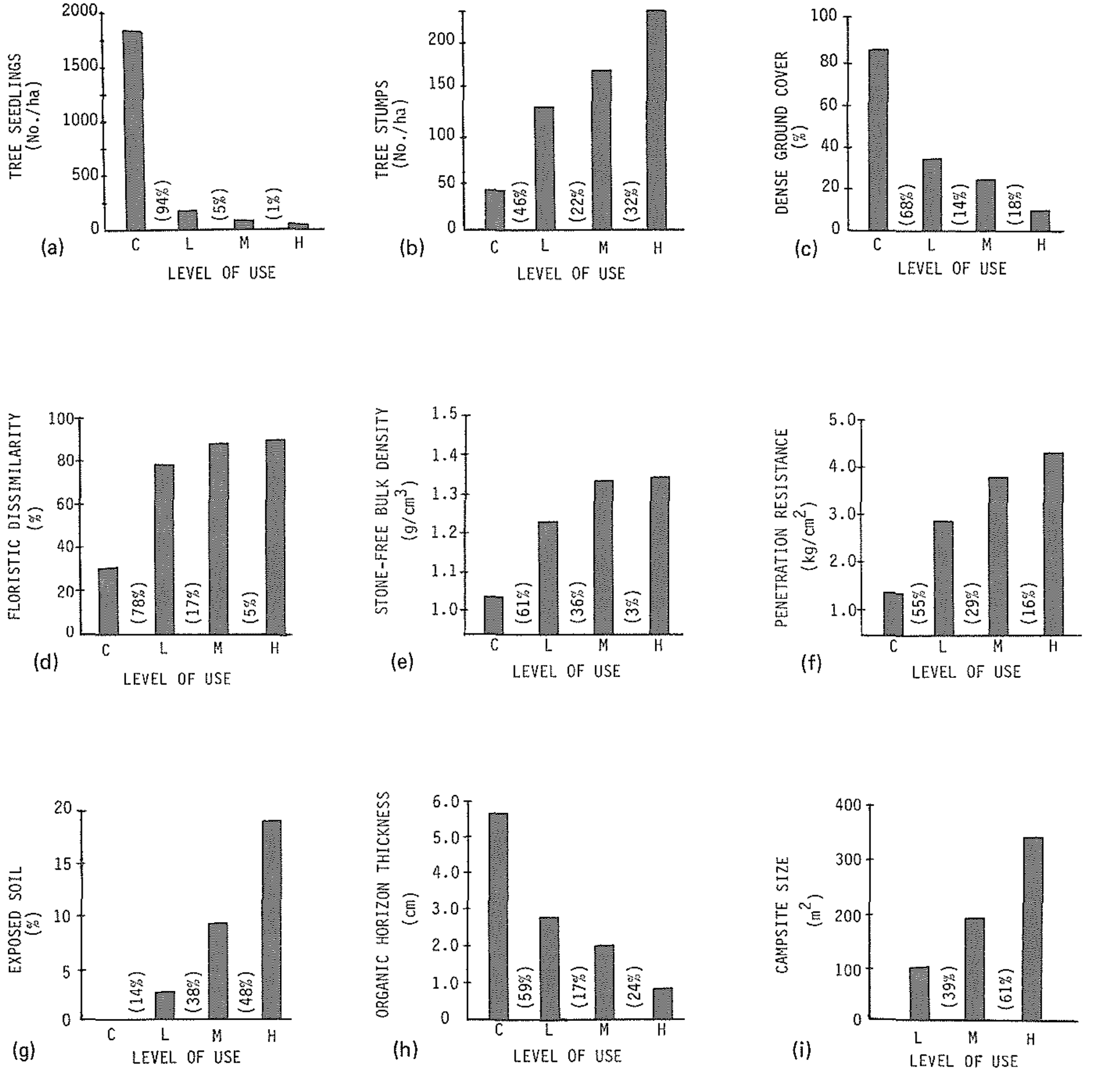

Figure 6. Median values for tree seedlings (a), tree stumps, (b), and mean values for dense ground cover (c), floristic dissimilarity (d), bulk density (e), penetration resistance (f), exposed soil (g), organic horizon thickness (h), and campsite size (i) on controls (C), low- (L), moderate- (M), and high- (H) use campsites. Percentages refer to the percent of total difference (high value minus low value) accounted for by the level of use interval. (For example, in (a) above, 94% of the total reduction in tree seedlings on campsites occurs with low use, 5% with moderate use, and 1% with high use).

cantly deteriorates with increasing use level (Table 5). Furthermore, tests of use level means for all three general impact variables found that each increase in use level results in a significant increase in the extent of impact (Duncan's test, Table 5).

This general use/impact relationship can be more easily interpreted when viewed graphically (Figure 7). Approximately 67 percent of the change occurred with just low use, even though this category represents less than 12 nights/season. A portion of this change is attributable to initial campsite development. Twenty-two percent of the total change is associated with the low- to moderate-use interval, followed by a smaller, yet statistically significant, 11 percent increase for the moderate- to high-use interval (Figure 7). Although the amount of change diminished with increasing use the impact/use relationship does not level off completely over this use range.

Other studies of wilderness campsite impacts generally have found fewer and less pronounced increases in impact associated with increases in use (Cole 1982, Cole and Fichtler 1983). The greater number of significant use/impact relationships found in this study may be attributable to several factors: 1) the BWCA is a very heavily used wilderness so the range in amount of use was greater than in other studies; 2) the widely separated, discontinuous use categories selected for this study helped to clearly differentiate existing use level differences; 3) a large sample size increased the power of statistical tests; and 4) the BWCA may be more resistant to impact than the high-elevation areas studied previously.

These results indicate that impacts could be reduced in BWCA campsites through reductions in use levels. However, for all but a few variables (exposed soil, penetration resistance, organic horizon thickness, and campsite size) the majority of change occurs with just low use. For most impact variables, differences between low- and high-use sites are still small compared to differences between undisturbed conditions and low-use sites. This suggests that reducing use on existing campsites would have little overall effect and would not justify the consequences of shifting use to additional sites. Cole (1981) reached similar conclusions from studies of western wildernesses.

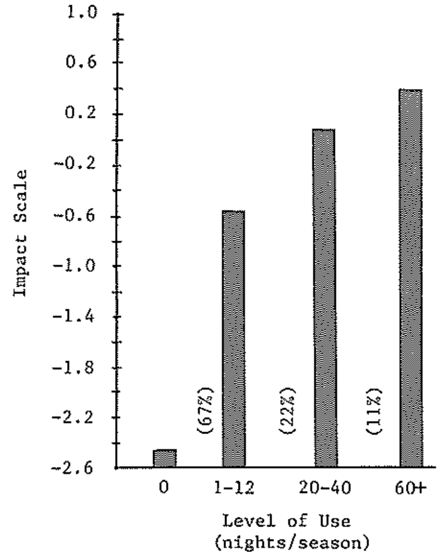

Figure 7. The general relationship between impact and amount of recreational use.

Impact Variation With Campsite Age

Accurate records of campsite age, particularly in wilderness areas, are often unavailable and few studies have examined this factor. Of the studies that have documented age-related changes, most have examined only initial changes on newly-developed campsites over short periods (1 to 5 years). To some extent the factors of amount of use and age are interrelated, particularly during initial use. When new sites are opened the amount of use increases directly with campsite age. However, after several years the cumulative amount of use can vary widely, depending upon average annual use levels, and the use/age relationship breaks down. With current visitor concentration policies, future emphasis and involvement in long-term campsite management will require a sound information base concerning the effects of extended camping use.

All campsites included in this study were at least five years old but ages for sites older than 14 years were unavailable. For the purpose of data analysis, three age categories were formed: 5 to 10 years (22 sites), 11 to 13 years (34 sites), and greater than 13 years (36 sites). Many of the campsites in the oldest category may date back to the post-World War II recreational boom or earlier; a few may have been used by Indians and voyageurs in the early 1800s.

Major impact variables that were significantly related to campsite age are presented in Table 6. For most of these variables conditions are significantly worse on the oldest campsites. With the exception of bulk density, the Duncan's test showed no significant differences between the 5- to 10-year and 11- to 13-year categories (Table 6). The significant increase in impact for these variables occurred on the sites more than 13 years old.

The significant relationship between these variables and campsite age was not entirely unexpected. For example, even low levels of campsite use undoubtedly result in erosional rates exceeding annual litter deposition rates. Over long periods of time organic layers would be reduced and lost, resulting in increasing amounts of exposed soil, greater tree root exposure, and an increase in campsite size. Increases in soil bulk density over time most likely are due to the loss of surface organic layers, which cushion compactive forces, and to the eventual breakdown, leaching and loss of organic material in the mineral soils. Soils then become significantly more compactable, often forming dense concentration layers.

A number of important vegetative changes also occur over time. The original understory plant species that are susceptible to trampling damage are gradually replaced by fewer but more trampling-resistant species. This process of compositional change is slow but inevitable given moderate, but consistent, levels of use. (Note floristic dissimilarity values, Table 6). As previously discussed, the invading species are often not native to the adjacent undisturbed vegetation and their success in these highly disturbed environments is due to very specialized evolutionary adaptations in their growth forms and life histories.

The summary ratings for the two impact assessment systems and the standardized impact scale ratings were also significantly related to campsite age (Table 6). As with the individual impact variables, significant differences in overall impact occurred only between the 11-to 13-year and greater-than-13-year categories. In the case of the impact scale ratings, approximately 22 percent of the total change occurred

Table 6. The relationship between campsite age and selected impact variables.

Impact Variable	Campsite Age: 5-10 yrs. (N=22)	11-13 yrs. (N=34)	7-13 yrs. (N=36)	F Value
Root exposure index	2.5 ± 0.2 (a)[1]	2.4 ± 0.2 (a)	2.8 ± 0.2 (b)	3.2*
Tree damage index	2.6 ± 0.2 (a)	2.7 ± 0.2 (a)	3.1 ± 0.2 (b)	6.7**
Floristic dissimilarity (%)	83 ± 7 (a)	85 ± 5 (a)	94 ± 2 (b)	6.8**
Bulk density[2] (g/cm^3)	0.1 ± 0.1 (a)	0.3 ± 0.1 (b)	0.4 ± 0.1 (c)	9.0**
Exposed soil[2] (%)	6.6 ± 3.4 (a)	5.8 ± 2.6 (a)	16.9 ± 4.3 (b)	13.3**
Organic horizon thickness[2] (cm)	3.4 ± 0.9 (a)	3.3 ± 0.6 (a)	4.4 ± 0.6 (b)	4.2*
Campsite size (m^2)	175 ± 54 (a)	178 ± 35 (a)	290 ± 44 (b)	10.0**
Condition class	2.5 ± 0.4 (a)	2.5 ± 0.2 (a)	3.3 ± 0.3 (b)	12.5**
Impact rating	1.8 ± 0.2 (a)	1.8 ± 0.2 (a)	2.4 ± 0.1 (b)	21.2**
Impact scale	−0.32 ± 0.17 (a)	−0.24 ± 0.18 (a)	0.41 ± 0.12 (b)	26.9**

[1]Means include a 95% confidence interval. Means with the same letter for each impact variable were not significantly different; Duncan's Multiple Range test (p<.05).
[2]Absolute difference values reported and used in statistical tests. Negative values indicate a decrease in that measure on campsites.
*Significant at p = 0.05.
** Significant at p = 0.01.

between the two categories (Figure 8). The majority of change (75 percent) still occurred within the first 5 to 10 years of campsite development. The annual deterioration for well-established campsites is apparently quite small, as indicated by the 3 percent increase in impact between the 5- to 10-year and 11- to 13-year categories (Figure 8).

These findings suggest that a number of important impacts are cumulative over time. However, improved campsite selection procedures, visitor education programs, and regulations concerning resource protection, and an expanding campsite rehabilitation program, have all proven effective in minimizing campsite impacts within the BWCA. These efforts may very well offset future age-related impacts. It is also possible that the age/impact relationships presented above have been affected by these programs. For example, due to extremely slow recovery rates the more severely impacted older sites may merely reflect earlier times when campsites were user-selected, parties were larger, and a visitor education program was not in place.

To some extent campsite age and use level are closely related. In the BWCA, high-use campsites are typically older, originally user-selected sites, while low-use campsites are primarily sites which have been established by the U.S. Forest Service in the last 13 years. However, a two-way analysis of variance between campsite age and level of use, with impact scale as the dependent variable, revealed that level of use explains more of the variation in impact. Nevertheless, campsite age remained highly significant and the interpretation of the results above remain unchanged.

CAMPSITE IMPACT MITIGATION

Research findings indicate that improved site selection in the future can aid in minimizing many biophysical impacts. A number of rehabilitation procedures have a high potential for minimizing both the area and extent of such impacts for existing campsites. Potential campsite selection criteria and rehabilitation procedures are presented and discussed below. A number of these criteria and procedures were developed by Paul Smith, wilderness manager, Superior National Forest, and are already being applied in the Kawishiwi Ranger District.

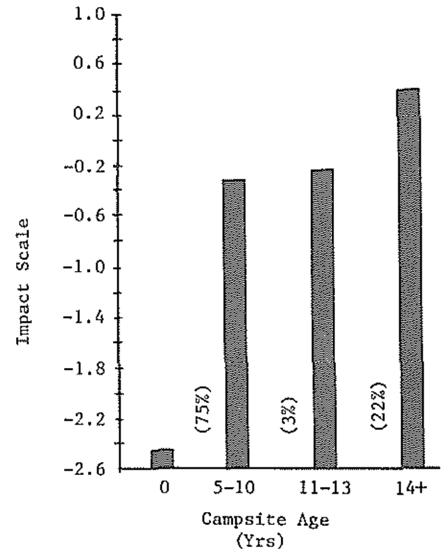

Figure 8. The relationship between standardized impact scale rating and campsite age.

Soil Erosion and Compaction

Shoreline soil erosion and tree root exposure can be substantially reduced by selecting sites with bedrock outcrops or cobbles at the shoreline and by avoiding steep shoreline slopes. Root exposure can be reduced by avoiding spruce, fir, and jack pine cover types, which have particularly shallow root systems. Soil compaction can be minimized by selecting sites with thick organic horizons (greater than 6 cm). Thick organic horizons resist soil compaction longer and provide more organic material (which reduces soil compactability) for incorporation into the underlying mineral soils.

Shoreline erosion can be minimized on existing campsites by placing rocks, gravel, and soil in the eroded areas. Additional, unnecessary landing areas should be closed off with large rocks, dead trees, or shrub and/or tree plantings. Tree root exposure can be amended by placing additional soil around the affected trees and planting small shrubs and grasses or sedges. Large rocks may also be placed to alter foot traffic patterns so that root exposure does not recur. General campsite soil erosion can best be minimized by transplanting and seeding native grasses and sedges. However, even grasses and sedges will generally not be successful in shaded locations and in primary use areas.

Vegetation

Open forest plant communities with high sunlight penetration support the most recreationally durable understory vegetation. Sites with closed overstory canopies should be avoided. Nutrient-rich soils with dense ground cover are also better able to support campsite vegetative cover and to resist continued expansion. Excessive tree damage can be minimized by avoiding paper birch, spruce, and fir cover types. The thin and easily damaged bark of these species is particularly susceptible.

Significant changes in vegetative composition on heavily used campsites are inevitable and must simply be accepted. However, if native grasses are seeded in the future, great care should be taken to insure that seed sources are completely free of extraneous non-native seeds. Due to high campsite tree mortality rates, long-term campsite management requires the planting of replacement trees. Tree seedlings similar in composition to the surrounding forest cover should be planted in protected sunny locations. Transplant stock or containerized seedlings are recommended and species which sucker or stump-sprout were found to be most successful on campsites.

Campsite Size and Visibility

Campsite size can best be minimized by placing the firegrate near the front of the site (on flat bedrock outcrops to minimize exposure of mineral soil) whenever possible. This tends to concentrate use and reduces the potential for campsite expansion. Site size can also be minimized by selecting areas surrounded by steep slopes, dense vegetation, boulders and rocks, or poor drainage.

Large rocks, dead trees, and plantings can be used to close off additional unnecessary campsite areas. Improvement of two or three tenting locations may help to minimize campsite expansion, tent ditching, and tree seedling, sapling, and shrub removal. Campsite visibility can be minimized by closing all additional unnecessary shoreline landing areas as described above. Plantings of shrubs and trees (particularly white cedar, which is very common along shorelines) will also reduce campsite visibility from the water.

CONCLUSION

Many of the benefits we seek from wilderness areas are derived from their primeval nature. Therefore, their ecological integrity and perceived naturalness are of primary importance. It is these qualities which differentiate wilderness from other natural resources. In particular, ecological changes resulting from recreational use have become a perplexing problem for managers charged with maintaining natural conditions.

This study identified and assessed the extent of a number of important biophysical impacts resulting from recreational use of campsites. In terms of an ideal wilderness, all of these changes are significant because they represent deviations from natural conditions (Cole 1982). However, many significant biophysical changes occur even at low use levels and are inevitable if use is to be accommodated. Cole (1982) suggests that a "significant" impact might best be defined as any change which reduces the future utility and desirability of a campsite.

Campsite utility is seriously diminished by changes such as the loss of campsite trees without replacement and the loss of campsite vegetative cover, which contributes to widespread soil exposure and erosion. Impacts which may indirectly influence these significant changes, such as tree root exposure, tree damage, and soil compaction, are also important. In addition, visitors spend a significant portion of their time in wilderness areas on campsites and their perception of the wilderness environment is therefore influenced by the conditions of these sites.

Increasing wilderness recreational pressures in the future will require managers to deal with the resulting changes. More objective and standardized impact assessment and management systems will be indispensible. Improved site selection criteria and limited resource manipulation in the form of rehabilitation programs may also aid in minimizing recreational impacts and restoring existing sites. Effective resource protection will involve careful integration of visitor and resource management policies and techniques. However, as use pressures increase, managers will be continually challenged to find new ways to manage wilderness resources so that human-induced changes remain substantially unnoticeable.

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