Thirty-Year Monitoring of Subalpine Meadow Vegetation Following a 1967 Trampling Experiment at Logan Pass, Glacier National Park, Montana

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Abstract—This long-term study, monitoring visitor impact on subalpine vegetation beginning in 1967, revealed that after 30 years all treatment plots had returned to pre-treatment ratios of vegetation (all species combined), organic litter and bare ground. Higher trampling intensities produced longer term impacts. Vegetation cover recovered in 19 to 25 years when trampled 15 times per week for six weeks in 1967 compared to 25 to 30 years where trampled 50 times per week. The long-term consequences of human trampling on dry meadow vegetation cannot be assessed from short-term observations.

Glacier National Park, like all sites in the National Park System, was set aside as a preserved area to be maintained "unimpaired for the enjoyment of future generations." In the words of the 1964 Wilderness Act, these "federally owned areas...shall be administered for the use and enjoyment of the American people in such manner as will leave them unimpaired for future use and enjoyment as wilderness…" The Wilderness Act goes on to define a wilderness as an area "where the earth and its community of life are untrammeled by man, where man himself is a visitor who does not remain."

The purpose of this 30-year research project was to ascertain any significant departure from unimpaired conditions triggered by human activities and to estimate the rate and direction of that change in the subalpine dry meadow vegetation at Logan Pass.

Study Area

Glacier National Park straddles the Continental Divide in northwestern Montana and includes over one million acres (approximately 424,000 hectares) of rugged, Rocky Mountain terrain. A visit to the Park usually includes a stop at Logan Pass, elevation 6,680 feet (2,036 meters), the highest point on the Going-to-the-Sun Road. Of the areas near treeline, Logan Pass receives by far the most visitors.

In the mid 1960s, while still a University of Montana undergraduate, I became concerned about the unrestrained activities of visitors at Logan Pass. Later, as a graduate student, I began studying human activities as an ecological factor. Field and laboratory work for the early part of this study are reported in Hartley (1976). I have returned to Logan Pass about every five years since the completion of that work to re-sample the permanent treatment plots established in 1967. Thus, sampling data are now available for the thirty year sequence from 1967 to 1997. Additional sampling is anticipated for the year 2002 (35th year).

Sixty-seven million people visited Glacier National Park in its first 89 years, 1910 to 1998 (Williams and others, 1999). Attendance has averaged 1.94 million visitors per year over the last 10 years (table 1). Heyward and others (1984)

Table 1—Glacier National Park, Montana, total annual visits: 1910-1998.

1910	4,000	
1911	4,000	
1912	6,257	
1913	12,138	
1914	12,168	
1915	13,465	
1916	12,839	
1917	15,050	
1918	9,086	
1919	18,956	107,959
1920	22,449	
1921	19,736	
1922	23,935	
1923	33,988	
1924	33,372	
1925	40,063	
1926	36,901	
1927	41,745	
1928	53,454	
1929	70,742	376,385
1930	73,783	
1931	59,846	
1932	53,202	
1933	76,615	
1934	116,965	
1935	143,240	
1936	210,072	
1937	194,522	
1938	153,528	
1939	170,073	1,251,846
1940	177,307	
1941	179,082	
1942	63,080	
1943	23,469	
1944	36,192	
1945	67,179	
1946	201,145	
1947	324,396	
1948	281,562	
1949	478,839	1,832,251
1950	485,950	
1951	500,125	
1952	630,949	
1953	633,480	
1954	608,230	
1955	674,004	
1956	718,938	
1957	759,161	
1958	706,841	
1959	722,338	6,440,016
1960	724,538	
1961	739,982	
1962	966,100	
1963	811,214	
1964	624,100	
1965	847,104	
1966	907,839	
1967	884,049	
1968	964,493	
1969	1,051,200	8,520,619
1970	1,241,603	
1971	1,303,073	
1972	1,392,145	
1973	1,398,958	
1974	1,406,643	
1975	1,571,393	
1976	1,662,678	
1977	1,656,212	
1978	1,601,131	
1979	1,446,236	14,680,072
1980	1,475,538	
1981	1,786,843	
1982	1,666,431	
1983	1,555,717	
1984	1,580,935	
1985	1,524,585	
1986	1,579,191	
1987	1,660,737	
1988	1,817,733	
1989	1,821,523	16,469,233
1990	1,987,000	
1991	2,096,966	
1992	2,199,767	
1993	2,141,704	
1994	2,152,989	
1995	1,839,518	
1996	1,720,805	
1997	1,708,877	
1998	1,830,944	17,678,570
1999		
2000		
	67,356,951	67,356,951

In: Cole, David N.; McCool, Stephen F.; Borrie, William T.; O'Loughlin, Jennifer, comps. 2000. Wilderness science in a time of change conference—Volume 5: Wilderness ecosystems, threats, and management; 1999 May 23–27; Missoula, MT. Proceedings RMRS-P-15-VOL-5. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

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estimated that 59% of total Park visitation crossed Logan Pass on the Going-to-the-Sun Road, and 36% of total Park visitation stopped at the Logan Pass Visitor Center. Recent estimates by Park officials indicate that nearly 80% of total Park visitors, or approximately 1,600,000 visitors, utilize the Logan Pass area each year: most of them during the brief, 100 day, vascular plant growing season between mid-June and mid-September. The inherent conflict between the photosynthetic and reproductive cycles of subalpine flora and the influx of several thousand visitors per day is most severe in July and August, on the weekends and at midday (fig. 1).

While the problems of recreational damage to high mountain vegetation have been recognized and described for over 85 years, detailed scientific research into these problems has been undertaken only during the past three to four decades (Price 1985; Hammitt and Cole 1998). Statistically quantified and designed visitor impact studies were rare when this study was initiated in 1967. More recently, a multitude of recreational impact studies have been conducted around the world, providing valuable baseline information geared to help resource managers evaluate carrying capacity and to establish the limits of acceptable change for many different ecosystems.

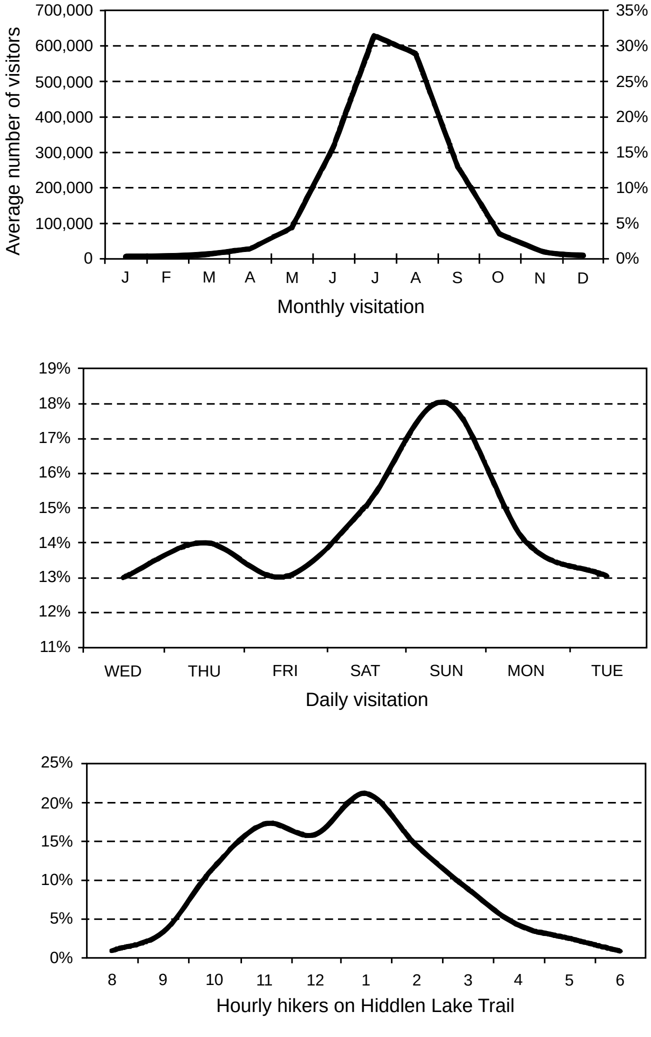


Figure 1—Glacier National Park visitation patterns. Top = monthly; middle = daily; bottom = hourly.

In reviewing visitor impact studies, particularly those involving trampling treatments, it was discovered that most described the initial rates of deterioration, but very few continued plant community analysis or monitored any kind of recovery beyond the first two or three years. Three European exceptions were studies continued for four to eight years (Bayfield 1979; Grabherr 1982; Lance and others 1989). Bayfield's (1979) trampling study recorded data for eight years, and the author concluded, "observation over a substantial period seems necessary to assess the responses of slow growing mountain vegetation to disturbance by trampling." Cole (1985) pointed out the inadequacies of applying only one year of trampling treatments and has initiated a long-term study, in which trampling and monitoring are being applied year after year until year-to-year change in vegetation and soil conditions becomes minimal.

Methods

The research design included experimental treatment plots and trail-side vegetation sampling using a point quadrat sampling method.

Experimental treatment plots were placed in plant communities similar to those found around the Logan Pass Visitor Center and along nearby trails to measure rates of vegetational change from *known quantities* of trampling treatments. During the 1967 growing season, the nine subplots (each one meter square) within the 3 x 3 meter plots were given nine combinations of treatments: three levels of trampling treatments per week [0-15-50] for six weeks, and three levels of clipping [0-1-2] (fig. 2). Plots were designed to separate the impact of trampling on plants and soil from the impact of removing or picking flowers and leaves without soil compaction. Four plots were placed on near level terrain on Caribou Ridge, south of the Logan Pass Visitor Center. Each plot was oriented in a different compass direction. In 1997, the plot locations were recorded by Global Positioning Systems. The plots were sampled using point-quadrats in a stratified random pattern. On each sampling date, 100 sampling points per subplot were recorded: a total of 900 sampling points per plot. Data from the replicated plots were pooled for analysis. The plot data reported herein represent 36,000 random point samples from the 3 x 3 meter plots from the years 1967 (5400), 1969 (8100), 1973 (2700), 1982 (4500), 1986 (5400) and 1997 (7200).

Vegetation of trail-side plant communities was sampled to determine changes in vegetation brought about by long-term, *unquantified*, off-trail trampling. Sampling was accomplished by a point-quadrat method at decimeter intervals along line transects running perpendicular to the trail axes. During the summers of 1967, 1968 and 1969, 40,000 points were sampled along the heavily used trails in the Logan Pass area (Hartley 1976). In 1997, one of those sites was revisited near the head of Highline Trail, just 20 meters north of the Going-to-the-Sun Road. This study consisted of 30 transects: 15 transects east of the trail and 15 transects west of the trail. Each transect was 3 meters long, and placed 0.5 meter apart, with sampling points each decimeter for a total of 900 sampling points in this study.

	T-0	T-15	T-50
C-0	Subplot 1 T-0 C-0	Subplot 2 T-15 C-0	Subplot 3 T-50 C-0
C-1	Subplot 4 T-0 C-1	Subplot 5 T-15 C-1	Subplot 6 T-50 C-1
C-2	Subplot 7 T-0 C-2	Subplot 8 T-15 C-2	Subplot 9 T-50 C-2

T = Number of trampling treatments per week (for 6 weeks), summer of 1967.
C = Number of clipping treatments, summer of 1967.

Plot sampling years and number of years since treatments.			
1968	1 year	1982	15 years
1969	2 years	1986	19 years
1973	6 years	1987	20 years
1976	9 years	1992	25 years
1977	10 years	1997	30 years

Figure 2—1967 Experimental plot design for trampling and clipping treatments.

Results: Plot Data

Analysis of pooled sampling data from individual subplots provides recovery data as a function of treatment intensity. Tables 2 to 4 and figure 3 illustrate ratios of living vegetation (VG), organic litter (LT) and bare ground (BG) in treatment subplots from 1967 through 1997. These ratios obtained from the point-quadrat sampling procedure present an overview of plant community status following trampling and clipping treatments.

1967—The First Year

Table 2 presents pooled data from three treatment plots sampled in 1967 before treatments commenced and again late in the season, after trampling and clipping treatments were completed. Total vegetation groundcover (VG) from all vascular plant species combined in all subplots and all plots averaged 78.2% at the first, pre-treatment sample. By the end of August, average groundcover had dropped to 23.6%: a conspicuous decrease in living vegetation with a corresponding increase in organic litter (LT-dead plant material) and bare ground (BG-soil surface). In the control Subplot 1 (T-0, C-0, upper left), the percentages of vegetation, litter and bare ground remained relatively constant through the season, but in the heaviest impact (Subplot 9 (T-50, C-2, lower right), the vegetational cover decreased through the first growing season from 77% to 11%, while bare ground increased from 3% to 45%. Litter increased from 19% to 44%.

In subplots receiving only trampling treatments (Subplots 2 and 3), 15 tramplings per week reduced vegetation cover 43% below controls by the end of the 1967 growing season, whereas 50 tramplings per week reduced cover only an additional 4-6%. Thus, the major initial impact had already occurred at 15 treatments. In subplots receiving only clipping treatments (Subplots 4 and 7), one clipping reduced cover 40% below controls by the end of the year, whereas two clippings reduced cover 44%.

The data further show that no clipping and heavy trampling (Subplot 3, T-50, C-0) resulted in very similar percentages of cover, litter and bare ground, as did light clipping and light trampling (Subplot 5, T-15, C-1). Conversely, heavy clipping and light trampling (Subplot 8, T-15, C-2) gave season-end results similar to light clipping and heavy trampling (Subplot 6, T-50. C-1).

At season's end, Subplot 9 (T-50, C-2), receiving the heaviest treatments, averaged only 11% cover, 44% litter

Table 2—Early and late 1967 percentages of vegetation, litter, and bare ground in experimental treatment subplots.

	Early pre-treatment 14 July 1967				Late post-treatment 21 August 1967			
	T-0	T-15	T-50	Mean	T-0	T-15	T-50	Mean
	Percent							
Vegetation (VG)								
C-0	75.7	75.7	83.0	78.1	66.7	23.3	17.3	35.8
C-1	84.0	77.7	78.0	79.9	26.3	17.7	13.0	19.0
C-2	77.0	75.7	77.3	76.7	22.3	14.7	10.7	15.9
Mean	78.9	76.3	79.4	78.2	38.4	18.6	13.7	23.6
Litter (LT)								
C-0	18.7	21.3	14.7	18.2	30.7	66.0	62.7	53.1
C-1	12.7	17.3	18.7	16.2	68.0	62.7	53.3	61.3
C-2	18.0	18.3	19.3	18.6	67.0	63.3	44.0	58.1
Mean	16.4	19.0	17.6	17.7	55.2	64.0	53.3	57.5
Bare ground (BG)								
C-0	5.7	3.0	2.3	3.7	2.7	10.7	20.0	11.1
C-1	3.3	5.0	3.3	3.9	5.7	19.7	33.7	19.7
C-2	5.0	6.0	3.3	4.8	10.7	22.0	45.3	26.0
Mean	4.7	4.7	3.0	4.1	6.3	17.4	33.0	18.9

and 45% bare ground. Vegetation was only 16% of that found in controls.

Recovery After Two Years (1969)

VG replacement made a strong comeback in the two year period between 1967 and 1969 in most subplots. The pooled T-50 (Subplots 3, 6, 9), with mean cover that had dropped from 79% to 14% in 1967 returned to 60% in 1969 (table 3). The pooled T-15 treatments (Subplots 2, 5, 8) whose mean cover dropped from 76% to 19% in 1967 returned to 69% two years later. T-0 treatments (Subplots 1, 4, 7) decreased from 79% to 38% in 1967 increased to 83% in 1969.

Litter among clipping treatments (rows) and trampling treatments (columns) showed almost no differences two years after treatments. The highest litter means occurred in Subplots 4 and 7, which were clipped but not trampled.

Bare ground percentages varied widely among trampling treatments with more moderate differences among clipping treatments.

Recovery After Six Years (1973)

Vegetation had increased approximately 5% among T-15 subplots and 9% among T-50 subplots since the 1969 sample four years earlier, while BG had decreased 10-15% in trampled plots (table 3).

Subplot 9 (T-50, C-2) had regained cover from 55% to 63% since the 1969 sample. The untrampled subplots had lost cover from the sample four years earlier, probably from seasonal fluctuations in soil moisture. Plant cover had increased in all other treatment subplots (average 7% ± 8) since the 1969 sample.

Table 3—1969 and 1973 percentages of vegetation, litter, and bare ground in experimental treatment subplots.

	2nd year post-treatment July, September 1969				**6th year post-treatment July 1973**			
	T-0	**T-15**	**T-50**	**Mean**	**T-0**	**T-15**	**T-50**	**Mean**
	Percent							
Vegetation (VG)								
C-0	87.9	68.0	61.2	72.4	87.3	78.3	75.7	80.4
C-1	80.9	70.4	63.7	71.7	76.7	74.3	67.3	72.8
C-2	80.2	69.8	55.4	68.5	73.3	71.7	63.0	69.3
Mean	83.0	69.4	60.1	70.8	79.1	74.8	68.7	74.2
Litter (LT)								
C-0	8.4	9.6	8.4	8.8	10.7	11.3	12.0	11.3
C-1	12.9	6.9	7.0	8.9	16.0	10.0	15.3	13.8
C-2	12.7	6.4	6.3	8.5	13.7	16.7	21.0	17.1
Mean	11.3	7.6	7.3	8.7	13.4	12.7	16.1	14.1
Bare ground (BG)								
C-0	3.7	22.4	30.3	18.8	2.0	10.3	12.3	8.2
C-1	6.2	22.7	29.3	19.4	7.3	15.7	17.3	13.4
C-2	7.1	23.8	38.2	23.0	13.0	11.7	16.0	13.6
Mean	5.7	23.0	32.6	20.4	7.4	12.6	15.2	11.7

Table 4—1982 and 1997 percentages of vegetation, litter, and bare ground in experimental treatment subplots.

	15th year post-treatment July, August 1982				**30th year post-treatment July, August 1997**			
	T-0	**T-15**	**T-50**	**Mean**	**T-0**	**T-15**	**T-50**	**Mean**
	Percent							
Vegetation (VG)								
C-0	86.6	81.2	82.0	83.3	83.9	85.9	88.8	86.2
C-1	87.6	86.6	78.4	84.2	85.4	87.0	87.0	86.5
C-2	83.2	82.0	77.8	81.0	80.0	87.1	85.1	84.1
Mean	85.8	83.3	79.4	82.8	83.1	86.7	87.0	85.6
Litter (LT)								
C-0	12.6	17.6	15.8	15.3	9.6	12.6	10.0	10.8
C-1	11.6	12.6	18.6	14.3	10.6	11.8	12.5	11.6
C-2	15.4	16.4	19.8	17.2	10.1	11.6	12.6	11.5
Mean	13.2	15.5	18.1	15.6	10.1	12.0	11.7	11.3
Bare Ground (BG)								
C-0	0.8	1.2	2.2	1.4	6.5	1.5	1.3	3.1
C-1	0.8	0.8	3.0	1.5	4.0	1.3	0.5	1.9
C-2	1.4	1.6	2.4	1.8	9.9	1.3	2.3	4.5
Mean	1.0	1.2	2.5	1.6	6.8	1.3	1.3	3.2

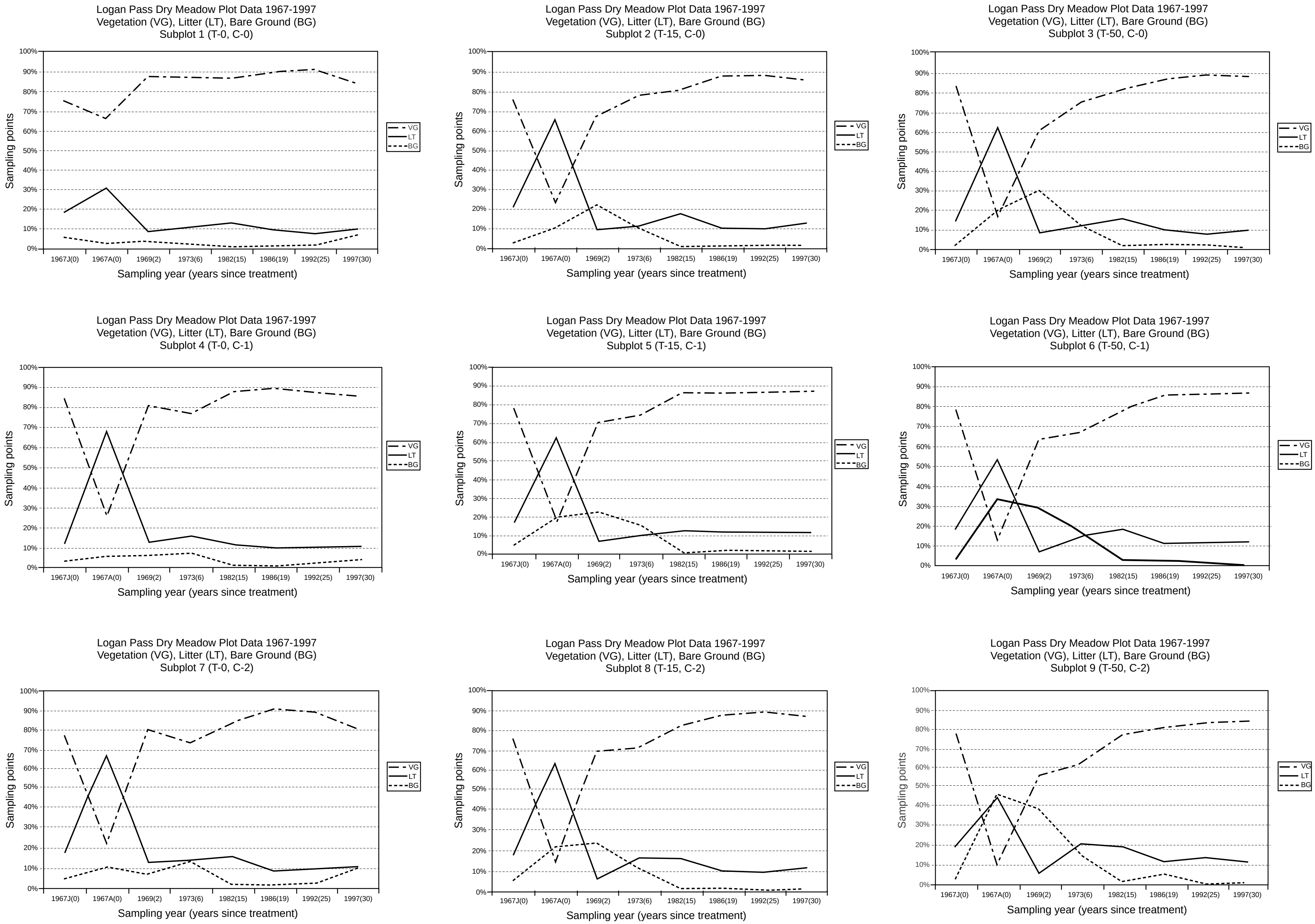


Figure 3—Percentage of vegetation, litter, and bare ground, 1967-1997, in each of nine subplots. Percentages are pooled data from three plots (n = 43).

Recovery After 15 Years (1982)

Vegetation cover in all subplots (n = 36) averaged 82.8% in 1982 after 15 years recovery (range 78-88), a 9% increase since 1973 (table 4). BG had reached an all-time low (mean 1.6%)

Subplot 9 (T-50, C-2) had gained 15% VG and lost 14% BG since 1973. All other treatment plots had gained 3% to 11% cover.

Recovery After 30 Years (1997)

Vegetation cover in all subplots averaged 85.6% [range 80-89%] (table 4). Recovery, *as measured only by total vegetation cover,* appeared to be complete 25 to 30 years post-treatment. The lesson to be learned here is that short-term disturbances can lead to long-term recovery. These findings are consistent with recreation ecology research studies from campsites and trails (Marion 1996).

Litter and bare ground had returned to normal levels, except in some subplots where increases in BG and decreases in VG were observed. These perturbations were brought about primarily by the excavations of Columbian ground squirrels (*Citellus columbianus*) in recent years. Grizzly bear (*Ursus arctos horribilis*) excavations were common near the plots, but fortunately the bears did not dig up any of the 3 x 3 meter plots.

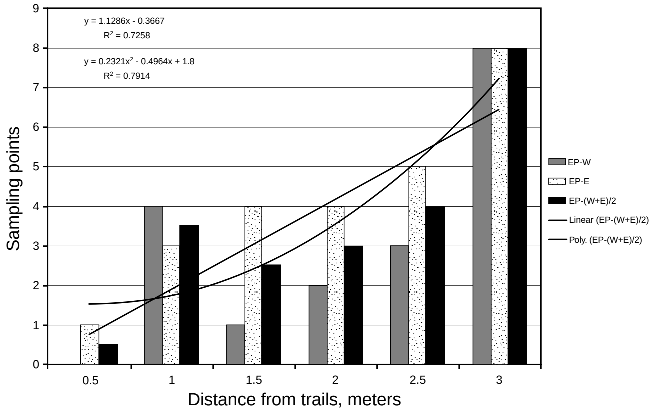
Figure 3 summarizes the field sampling results reported in the tables above, but in this presentation, vegetation, litter and bare ground percentages are plotted within each of the nine treatment subplots through the 30 year period. The graphs are arranged in figure 3 in the same order as the treatment subplots were arranged in the field plots (fig. 2). The rate and degree of recovery can therefore be compared between any of the treatment combinations at various points in time. These graphs illustrate the positive relationship between the intensity of treatment and the number of growing seasons required for a return to natural conditions: In untrampled Subplots 4 and 7, VG, LT and BG return to pre-treatment levels within two years, in 15 years where clipped once, and in 19 years where clipped twice. Light trampling required 19 to 25 years for natural return of groundcover, whereas heavy trampling required 25 to 30 years. The graphs also show pairs of subplots yielding similar results from different combinations of treatments, as in Subplots 3 and 5, and Subplots 6 and 8. These pairs share comparative plotted curve patterns, sometimes differing in degree.

A comparison of the vegetation curves in these graphs also reveals which treatment combinations yield the greatest return of cover in the shortest period of time. Here, the Subplots are arranged from the shortest recovery time to the longest: 4-7-2-5-3-6-8-9. Thus, clipping-only renders the least long-term effects, followed by light trampling and no clipping, intermediate levels of both and finally the heavily trampled and clipped subplots.

Results: Trail-Side Vegetation Sampling

A very clear reduction in species diversity was observed in the vegetation along the Highline Trail's edge. An increase in the number of species was positively correlated with an increase in distance from the trail. Only seven species were sampled in the first 1/2 meter—dominated by Sedges (*Carex nigricans*) and (*Carex phaeocephala)*. At 1.5 to 2.0 meters from the trail, 20 species were sampled—dominated by Glacier Lily (*Erythronium grandiflorum)* and Woodrush (*Luzula wahlenbergii)*. At 2.5 to 3.0 meters from the trail, Arnica (*Arnica alpina)* and Glacier Lily (*Erythronium grandiflorum)* dominated among the 24 species recorded (Hartley 1999). Trail side distribution of Glacier Lily (*Erythronium grandiflorum)* and Fleabane (*Erigeron peregrinus)* are plotted in figure 4. Sedges and grasses dominated the plant community at trail-side (fig. 5 top), while herbaceous dicots (fig. 5 bottom) were predominate at greater distances from the trail.

Highline Trail 1997 – *Erigeron peregrinus* (EP)
(30 transects combined)



Highline Trail 1997 – *Erythronium grandiflorum* (EG)
(30 transects combined)

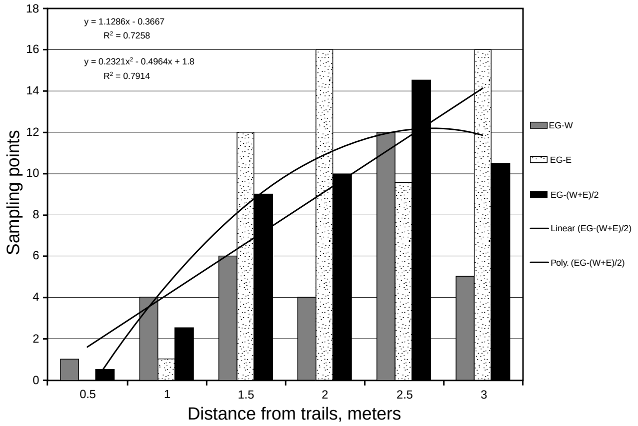


Figure 4—Trail-side distribution of *Erigeron peregrinus* and *Erythronium grandiflorum* on Highline Trail at Logan Pass 7 August 1997: EP-W = *Erigeron peregrinus*, west side of trail; EP-E = *Erigeron peregrinus*, east side of trail; EG-W = *Erythronium grandiflorum* sampled from west side of trail; EG-E = *Erythronium grandiflorum*, east side of trail; Linear = linear regression line and equation; Poly = second order polynomial regression line and equation.

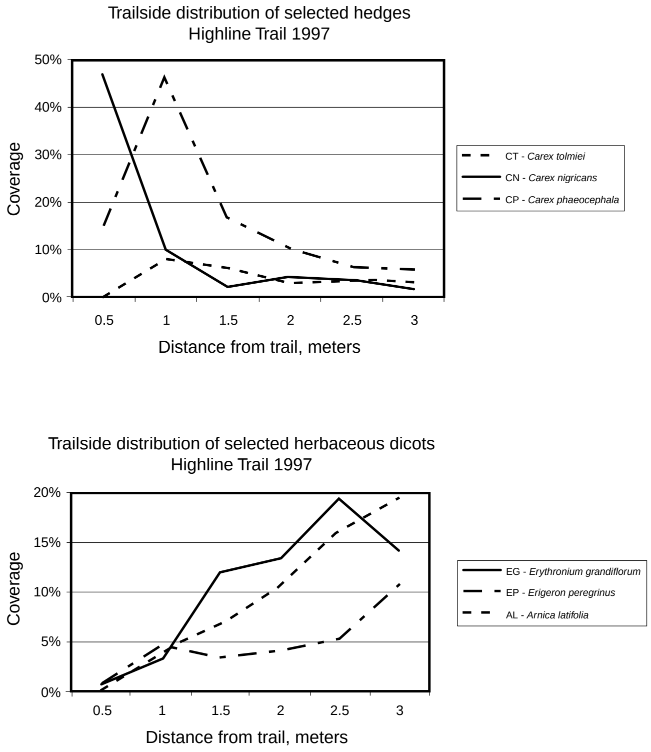


Figure 5—Trail-side distribution of selected graminoids (top) and selected herbaceous dicot species (bottom) on Highline Trail at Logan Pass 7 August 1997: AL = *Arnica latifolia*; CT = *Carex tolmiei*; CN = *Carex nigricans*; EG = *Erythronium grandiflorum*; CP = *Carex phaeocephala*; EP = *Erigeron peregrinus*.

Discussion

Vascular plants growing at Logan Pass and in other alpine and subalpine areas with high visitor use are subject to injury and destruction by visitor activities. Alpine ecosystems are particularly vulnerable to the presence of people in any numbers. There is a high degree of incompatibility between use by people, directly or indirectly, and the maintenance of ecosystem integrity in high mountains (Billings 1973,1979). The dry meadow plant communities appear to withstand single individuals or even a few people crossing them at one time. Very light use may leave imperceptible traces, but even a small group walking in single file across the Logan Pass meadows will leave a path of trampled plants. Data from experimental trampling plots revealed that a single individual walking in a Glacier Lily field once each week created a 9% reduction in vegetation cover by the end of the growing season (Hartley 1979). Such damage is temporary if the action is not repeated, but research strongly indicates that other visitors will see the path and further contribute to trampling impacts. For example, an informal path was discovered in 1969 near the Logan Pass Visitor Center. Photographic monitoring occurred through the years as the path continued to receive foot traffic. It persisted for about 20 years unabated. When last observed in 1997, after a decade of abandonment, the path was recovering by natural revegetation thanks to Park Service protection.

Trampling destroys photosynthetic tissue and triggers an energy flow rate decrease through the plant. Consequently, stored carbohydrate in the underground portions of subalpine plants is stored at a lower than normal level. Overwinter survival and vigorous, early growth the following year is therefore jeopardized. This depleted condition reduces the plant's ability to produce photosynthetic tissue the following year, so plants are smaller and produce fewer flowers in the season following trampling treatments. Continued trampling triggers further breakdown of the system leading to death of the plant (Hartley 1976). It is unknown how many growing seasons are required for return to normal metabolic rates, but current observations strongly suggest that full recovery may require many decades. Liddle and Kay (1987) rightly differentiated between survival after damage versus recovery after damage. From the data reported here, it is evident that most species of the dry meadow plant community survived the 1967 trampling treatments. Recovery after damage from visitor impact, however, took two to three decades.

Sensitivity and subsequent recovery of individual plants is a function of more than trampling intensity, and more than time. Cole (1995) has described the importance of plant physiognomy, the position of perennating buds, and the stem-leaf architecture in determining the resistance, resiliency and tolerance of plants to trampling pressure. Visitor impact on vegetation and soils is also affected by the size and frequency of hiking groups and their care in staying on existing trails. Hikers exhibit a common tendency of stepping off the trail to socialize with other members of their party or to allow the passing of oncoming hikers. In heavily used narrow trails, both parties are known to step off the trail neglecting to use the trail provided. Such activity is generally due to a lack of awareness of trampling impacts. Never-theless, the larger the hiking groups, the greater the destruction to plant life beside the trail.

During 1967, 50 trampling treatments per week for six weeks removed little more plant cover (4-6%) than 15 trampling treatments per week. If managers were only concerned about the initial removal of vegetation, they might reasonably conclude that there was little need to be concerned about the different trampling impact of these two levels of treatments. Such a conclusion might be drawn from a one- or two-year study. It is important to emphasize, however, that the greater the impact of trampling, the greater number of years required for return to normalcy. For example, recovery required 5 to 10 years longer in the subplots trampled 50 times than in those receiving only 15 trampling treatments. In 1986 and 1992, vegetation cover had peaked in subplots trampled 15 times, but not until 1992 and 1997 did cover reach its highest level in the subplots trampled 50 times.

The rate of natural vegetation cover replacement was more rapid during the first two years following trampling than in later years. Early post-treatment recovery was evidenced by the relatively steep curves in years 0 to 6 followed by a leveling of the curves between 6 and 30 years. The impact of the clipping treatments alone was visible for only the first two years. The combined effects of trampling and clipping, however, were evident for at least 19 years. After 30 years, all subplots had returned to pre-treatment ratios of vegetation, litter and bare ground. Therefore, managers must consider the time elapsed for short-term and long-term recovery.

Long-term data are now recognized as crucial to our understanding of environmental change and management (Gosz 1998). Such studies can only occur, however, if planned and coordinated. Essential to this process is the permanent marking of treatment plots so they can be relocated at a future time for observation and re-sampling. This study could not have occurred had we not marked the corners of each plot and subplot with long spikes in 1967. Most corner markers have stayed in place through 30 years of freeze-thaw cycles and the activities of ground squirrels, grizzly bears and human beings. The area was also mapped detailing the directional and distance relationships between plots. The National Park Service recorded the position of the treatment plots in 1997 with global positioning system (GPS) equipment, so the plots can be more easily located in the future.

Throughout this paper recovery has been described in terms of total vegetation cover—all species combined. A more detailed and beneficial description of recovery includes the results of plant community analysis and the response patterns of individual species to trampling treatments. The author is preparing a paper to describe the plant community characteristics and species interactions observed in the treatment plots through the 30-year study.

The 1997 Highline Trail data describe a three-meter zone on either side of this busy trail used by hundreds of visitors each day—some were on short nature walks, while others were backcountry hikers heading to Granite Park Chalet or Canada. The trail is also easily accessed by large numbers of the motoring public who park at the nearby Logan Pass Visitor Center and walk across the Going-to-the-Sun Road to the Highline Trail.

The vegetation adjacent to this trail's border is dominated by Sedges (*Carex nigricans*) and (*Carex phaeocephala*). The side-stepping off the trail had almost eliminated the herbaceous dicots from this plant community. It had not been so severe as to reduce the area to bare ground. The high concentration of *Carex* species and other graminoids next to the trail demonstrate that these species exhibit a high resilience—they have the capacity to return the next season after trampling (Cole, 1995). Glacier Lily, Fleabane, *Arnica*, and other herbaceous dicots have a low tolerance to trampling. Hence, the plant community beside a busy trail differs in physiognomy and species mix when contrasted with the plant community a few meters from the trail. The trail has been widened by off-trail trampling through the years: when this site was first sampled in 1967, the trail was slightly more than 1 meter wide. In 1997 it was about 1.5 meters wide. This may be a section of trail where high hiker traffic warrants a hardening of the site by construction of a boardwalk or paving the trail surface.

Year to year fluctuations of available soil moisture were, no doubt, contributing influences in the 30 year sampling data. Alternating periods of drought or abundant moisture probably triggered seasonal shifts in recovery trends throughout the study. For instance, in 1967 the pre-treatment vegetation sample produced a total vegetation cover of 78.2%. A growing season with less soil moisture than average may have been responsible for the fact that this first measure of cover was approximately 10% lower than normal. In 1997, a year with record high snowpack recordings on nearby Flattop Mountain, SNOTEL data recorded 67.9 inches of snow water equivalent—well above the 43.3 inch average during the previous sampling years (Klasner 1999). Corresponding record high recordings of overall groundcover, species frequencies and flower counts may have indicated recovery from trampling or vigorous growth stimulated by the higher than average moisture. Such elevated levels of leaf, stem and flower production, as observed in 1997, could have masked residual trampling effects or average recovery rates. On the other hand, abundant moisture triggering vigorous plant growth might be expected to accelerate the overall recovery process. The 35th year sampling in the year 2002 may clear up this ambiguity. Correlating growth patterns with available moisture was difficult in the absence of adequate weather data.

Wilderness resource managers of high-elevation natural areas can more effectively decide what constitutes acceptable carrying capacities and acceptable biotic alterations caused by visitor activities if they know the quantitative relationships between various levels of use and their resultant levels of impact on the biota. The most important intended contribution of this research project was to quantify the prolonged recovery period required to repair trampling damage in a slow-growing plant community exhibiting relatively low resilience to visitor activity. It is hoped that the study contributes to that understanding.

Conclusions

The following list summarizes the major findings and implications of this study.

1) In high mountain ecosystems subjected to heavy visitor use, rates of disturbance, can occur rapidly in a day or a season. In contrast, rates of natural recovery may occur slowly over decades or centuries.

2) After 30 years, all subplots subjected to experimental trampling treatments, had returned to pre-treatment ratios of vegetation, litter and bare ground.

3) The study demonstrated that higher trampling intensities produced longer term impacts.

4) Fifty trampling treatments per week for six weeks in 1967 removed little additional ground cover [4-6%] than 15 trampling treatments, but natural replacement of cover in subplots trampled 50 times required 5 to 10 years longer than those trampled 15 times.

5) Vegetation cover peaked in subplots trampled 15 times after 19 to 25 years, but in the subplots trampled 50 times cover peaked after 25 to 30 years.

6) Clipping produced short-term impacts on groundcover lasting two or three years; trampling produced long-term impacts lasting two or three decades.

7) Recovery rates of subalpine dry meadow vegetational cover were more rapid in the first two years following trampling than during the 28 years that followed.

8) These data describe recovery in terms of total vegetation cover including all species present. A more satisfactory measure of recovery is obtained from detailed plant community analysis. A report of individual species responses and species interactions to trampling and clipping treatments will be presented in a future paper.

9) The long-term implications of human impacts on wilderness plant communities cannot be learned using short-term observations. Researchers should consider the real time invested in the actual field study in contrast to the real time required for full recovery. Most two- and three-year trampling impact studies can tell resource managers only the early stages of disturbance and recovery. Treated plots should be permanently marked and monitored through a substantial portion of the recovery stages.

10) There is no question that long-term studies have much higher financial and human resource costs, but the results obtained in long-term studies will equip resource managers with more reliable data upon which to base their management decisions.

11) Long-term studies tend to provide abundant and more useful data for determining recreational carrying capacity. They also more clearly establish the Limits of Acceptable Change in visitor-dense wilderness areas and high mountain ecosystems such as those at Logan Pass.

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