A HALF CENTURY OF CHANGE IN ALPINE TREELINE PATTERNS AT GLACIER NATIONAL PARK, MONTANA, U.S.A.

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A Half Century of Change in Alpine Treeline Patterns at Glacier National Park, Montana, U.S.A.

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Abstract

Using sequential aerial photography, we identified changes in the spatial distribution of subalpine fir (*Abies lasiocarpa*) habitat at the alpine treeline ecotone. Six 40-ha study sites in the McDonald Creek drainage of Glacier National Park contained subalpine fir forests that graded into alpine tundra. Over a 46-yr period, altitudinal changes in the location of alpine treeline ecotone were not observed. However, over this 46-yr period the area of krummholz, patch-forest, and continuous canopy forest increased by 3.4%, and tree density increased within existing patches of krummholz and patch-forest. Change in subalpine fir vegetation patterns within 100 m of trails was also compared to areas without trails. Within 100 m of trails, the number of small, discrete krummholz stands increased compared to areas without trails, but there was no significant change in total krummholz area. We used historical terrestrial photography to expand the period (to 70 yr) considered. This photography supported the conclusions that a more abrupt ecotone transition developed from forest to tundra at alpine treeline, that tree density within forested areas increased, and that krummholz became fragmented along trails. This local assessment of fine-grained change in the alpine treeline ecotone provides a comparative base for looking at ecotone change in other mountain regions throughout the world.

Introduction

Ecological variation along the steep environmental gradients and in the narrow ecotones of mountain environments affects biodiversity, hydrologic outputs, and cultural values while responding to factors such as climatic variability and air pollution. Documenting changes in the alpine treeline ecotone (the zone of transition between subalpine forest and alpine tundra) provides an important indicator of the effects of climate change on mountain ecosystems and is an important component of protected area management (Vale, 1987). Ecotones resulting from environmental gradients are hypothesized to be sensitive indicators of climate change (Risser, 1993; Rochefort et al., 1994), although the use of disturbance-regulated alpine treeline ecotones to monitor climate change is questioned (Noble, 1993).

The alpine treeline ecotone can be divided into zones of alpine tundra, krummholz, patch-forest, and continuous canopy forest (Baker et al., 1995). The uppermost zone is alpine tundra—a mosaic of rock outcrops, bare soil, and herbaceous and shrubby plant species—that grades into forested landscape. The "forested" zones are krummholz—dwarf, flagged, or cushion forms of trees interspersed with herbaceous and shrubby openings, patch-forest—patches of symmetrical or upright trees, and continuous canopy forest—a well-dispersed canopy of symmetrical trees with understory species.

At alpine treeline, gradients in seasonal precipitation and temperature are hypothesized to limit growth (e.g., carbon balance; Cairns and Malanson, 1997), regulate cellular development (Körner, 1999), and affect structurally limiting factors such as size, fecundity, nutrient distribution, and pruning tolerance (Stevens and Fox, 1991), although these relationships are often complex (Lloyd and Graumlich, 1997; Körner, 1999). Incidences of isolated seedling establishment above treeline, on the east side of Glacier National Park, have been documented in areas protected from desiccating winds and favorable to soil development (Butler et al., 1994), and may have been linked with a period of elevated summer temperatures. As demonstrated on Mt. Rainier in the Cascade Mountains (Rochefort and Peterson, 1996) and in Rocky Mountain National Park, Colorado (Hessl and Baker, 1997), correlation of localized tree growth and establishment with snowpack and temperature depends on other environmental gradients and topographic variability. Tree establishment following amelioration of limiting factors is typically widespread within meadows, with topography and existing vegetation regulating much of the variability (Rochefort and Peterson, 1996). These intersite differences, expressed through variations in rates of tree growth and establishment, provide a mechanism for identifying fine-scale environmental differences (Villalba et al., 1994).

The altered spatial structure of alpine treeline vegetation influences landscape function by altering snow accumulation, wind desiccation, and snow-melt patterns (Daly, 1984; Walsh et al., 1994), plant growth rates (Billings and Bliss, 1959), and fuel distribution. Treeline structure also influences wildlife habitat and even cultural significance, as seen in the U.S. National Park Service's emphasis on landscape aesthetics and the popularity of alpine and subalpine picture books (Carr, 1998; McClelland, 1998). Human activity affecting structural change at alpine treeline in Glacier National Park has included trail and road building, oiling of backcountry trails to minimize dust (Fig. 1), horse use, camping, and the spreading of herbicides including Agent Orange (Dichlorophenoxyacetic acid and Trichlorophenoxyacetic acid) to reduce white pine blister rust (*Cronartium ribicola*) in whitebark pine (*Pinus albicaulis*) populations (Kendall and Asebrook, 1998).

In this study, we used repeat photography to identify change

FIGURE 1. Oiling of backcountry trails to eliminate the "dust menace," circa 1932. Glacier National Park management and archive documents indicate that certain trails were oiled from valley-bottom up to alpine passes.

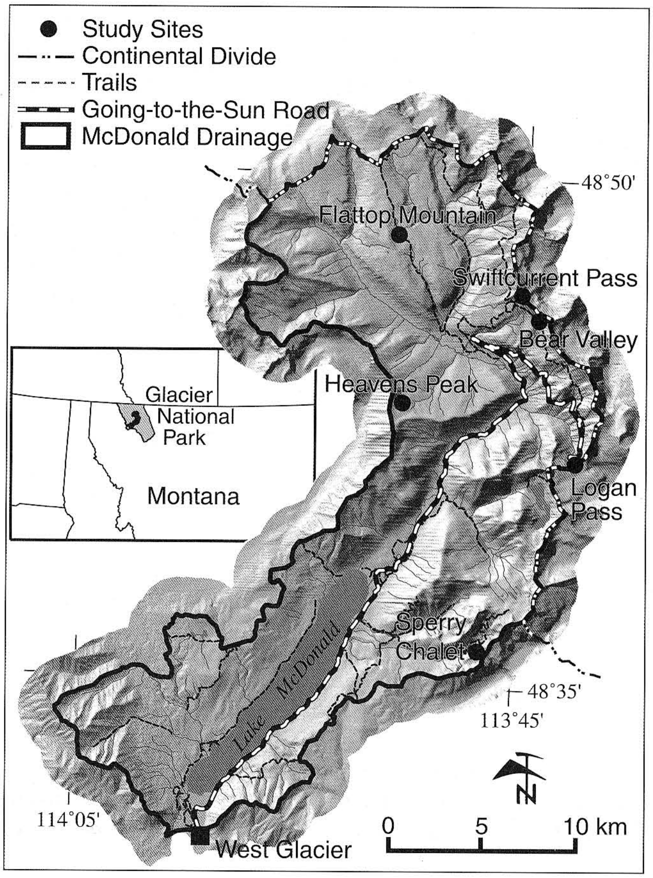

FIGURE 2. Study sites in the McDonald Creek drainage of Glacier National Park, Montana.

in the alpine treeline ecotone in Glacier National Park, Montana. We looked for changes in the spatial location of the ecotone as well as changes in the morphological structure of patches of trees from repeated aerial and terrestrial photographs. We quantified changes in patch area, edge density, and ecotone structure at sites with human activity compared to sites without human activity. In calculating these metrics, we also quantified the rate of change for the alpine treeline ecotone in Glacier National Park, providing a benchmark for comparisons of ecotonal changes in other regions.

Study Area

In the McDonald Creek drainage of Glacier National Park, near the Continental Divide, six 40-ha sites between 1900 and 2200 m elevation (Fig. 2) were selected from the earliest known aerial photographs of the alpine treeline ecotone. Due to the limited spatial availability of the early photographs, only six suitable sites with a minimum of intersite variability were identified. Each of these sites contained a transition from subalpine forest zones to alpine tundra. Because there was a minimum of intrasite variability in slope, aspect, soils (Land and Water Consulting, 1995), and surficial geology (Carrara, 1990), Table 1, we were able to identify trail and nontrail segments within each site for evaluating human impacts.

Climatic influences in the study area have a mix of maritime and continental sources. The majority of annual precipitation occurs as snow. With prevailing western winds and storms tracking inland from the Pacific Ocean, maritime climate influences extend to the Continental Divide, accentuated with increasing altitude (Hansen, 1948). Summer temperatures and spring snowpack from 1927–1991 in the McDonald Creek Drainage (Fig. 3) exhibit variability in both moisture and temperature, with annual precipitation approximately 200 cm and average July temperature of 14°C near the Continental Divide at 1830 m elevation (Finklin, 1986). This variability provides opportunity for species requiring either moist or dry conditions to establish and grow. West of the Continental Divide, this climate supports the easternmost extension of western red cedar (*Thuja plicata*)—western hemlock (*Tsuga heterophylla*) forest, a Pacific Northwest forest type (Hansen, 1948).

TABLE 1

Site characteristics

Site	Bedrock soil source	Surficial geology	Aspect	Slope° (mean)	Average elevation (m)	Dominant tree species
Bear Valley	Quartzite and argillite	Bedrock, colluvial deposits	W	17°	1908	*Abies lasiocarpa*
Flattop Mountain	Quartzite and argillite	Bedrock, alluvium	SSE	15°	2018	*Abies lasiocarpa*
Heavens Peak	Limestone	Bedrock, talus, till	ENE	16°	1918	*Abies lasiocarpa* and *Pinus albicaulis*
Logan Pass	Quartzite and argillite	Bedrock	E	10°	2034	*Abies lasiocarpa*
Sperry Chalet	Quartzite and argillite	Bedrock, colluvial deposits, talus	W	23°	1931	*Abies lasiocarpa* and *Picea engelmannii*
Swiftcurrent Pass	Quartzite and argillite	Bedrock, colluvial deposits	SSW	22°	2160	*Abies lasiocarpa*

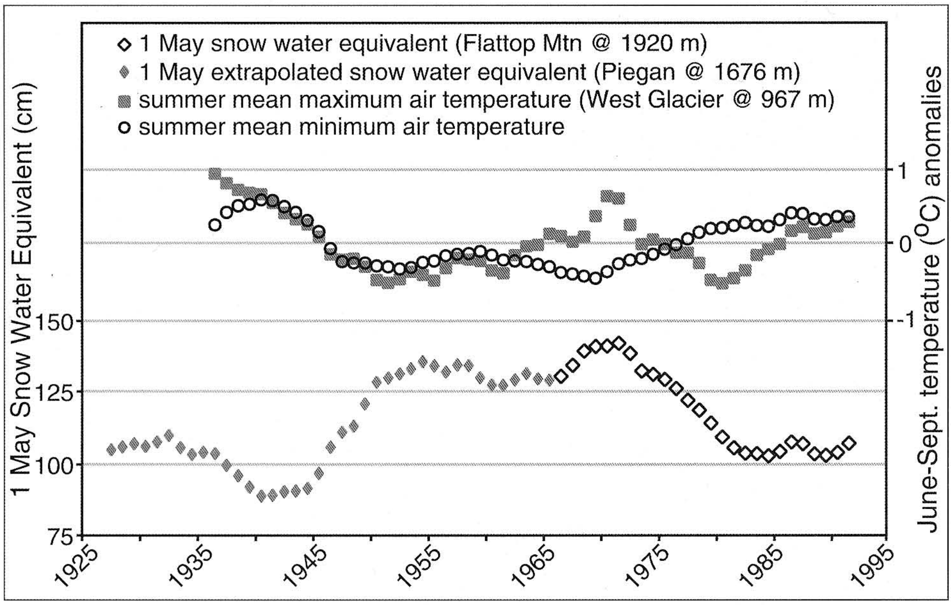

FIGURE 3. Annual spring snowpack and summer (June–September) maximum and minimum temperatures in McDonald Creek drainage, Glacier National Park (10-yr centered moving averages). The linear correlation between Flattop Mountain and Piegan snowpack (74% from 1966–1992) is assumed to have remained constant for the period 1927–1965 when Piegan snowpack was used to extrapolate Flattop Mountain snowpack.

In the study area, subalpine fir (*Abies lasiocarpa*) is the most common tree species, with other species including Engelmann spruce (*Picea engelmannii*), lodgepole pine (*Pinus contorta*), and whitebark pine (*P. albicaulis*) (cf. Pfister et al., 1977). Subalpine and alpine meadows are dominated by low-shrub and heath vegetation (*Salix* spp., *Vaccinium* spp., *Phyllodoce* spp., *Sphagnum* spp., and others), wet meadow vegetation (*Carex* spp., *Senecio triangularis, Erigeron* spp., *Parnassia palustris,* and others), and dry meadow vegetation (*Luzula* spp., *Saxifraga bronchialis, Dryas octopetala, Erythronium grandiflorum,* and others) (cf. Choate and Habeck, 1967; Habeck, 1970; Achuff et al., 1997).

Human activity in alpine treeline areas in Glacier National Park occurred as early as 10,000 yr ago (Reeves, 2000). Trappers, explorers, and hard-rock miners increased in number through the 1800s. In 1895, the region was designated a forest park and National Park status was bestowed in 1910 (Buchholtz, 1976). Fire suppression and extensive horseback use were probably the most influential human activities affecting alpine treeline vegetation patterns prior to the opening of the Going-to-the-Sun Road in 1933. Beginning in the late 1940s, the popularity of outdoor recreation, both near the road corridor and in the more distant backcountry, combined with the growing environmental movement, resulted in increasing numbers of recreational hikers and intensified management efforts. Along road corridors and in select backcountry areas, recent human impacts include facility construction and maintenance and repeated disturbance from road maintenance and reconstruction. Common human influences along trail corridors include trail maintenance (primarily brush removal and rerouting), trampling of vegetation by hikers, and introduction of non-native species, with chemical control conducted at entry points into the backcountry, including trailheads, parking areas, and corrals (Johnson and Fowler, 2001).

Methods

For each of six 40-ha study sites, black-and-white aerial photographs from 1945 (1:15,000-scale prints) were scanned and geo-rectified for comparison to 1991 black-and-white U.S. Geological Survey Digital OrthoQuad (DOQ) images (1:12,000-scale digital data) of the same area. The 1945 scanned images were resampled to 1-m resolution (originally scanned at higher resolution), matching the 1991 DOQ data. Rectification error was less than 5-pixels (5-m) root mean square (rms) for all 1945 images, which does not meet the criterion of ≤0.5-pixel rms error for creation of digital change detection maps (Jensen, 1996). This rectification error, although small, could slightly affect patch area calculations but would not affect density or quantity of patches. Therefore, a subset of landscape metrics identified in "FRAGSTATS: Spatial Pattern Analysis Program for Quantifying Landscape Structure" (McGarigal and Marks, 1995) were calculated in a geographic information system (GIS) and statistically compared for each site.

At each site the study area was delineated into patches, defined as areas of unique vegetation types, with patch edge being the discrete boundary surrounding a patch. Vegetation types were assigned to each patch using an unsupervised classification based on reflectance and spatial pattern, as forest (krummholz, patch-forest, and continuous canopy), moist-shrubby meadow, dry meadow, rock, or water. Identification of vegetation type (especially patch-forest and krummholz) was possible primarily through image shape and texture, which required larger areas for context when establishing classification rules. Individual trees and small patches were not quantitatively evaluated separately, because vegetation patches less than 25 m^2 were included with the larger adjacent patch. This use of larger areas also compensated for the slight improvement in clarity of the 1991 photographs and scale differences between the photographs.

Searches of Glacier National Park and U.S. Geological Survey archives located few useful terrestrial photographs of the study sites. Most terrestrial photographs were of similar or smaller scales than the 1945 aerial photographs and valuable primarily for confirming vegetation patterns identified in aerial photographs. Four photographs, at a scale and resolution containing identifiable trees and other vegetation of the Logan Pass site, were located in construction reports for the Going-to-the-Sun Road in the 1920s and 1930s. These photographs were most likely taken using a "pocket" camera of the time period and were replicated by the authors in 1997 using a 35-mm camera and zoom lens using both black-and-white print and color slide film. Original photopoints were identified using methods outlined by Rogers et al. (1984) and documented using a Global Positioning System. These repeated terrestrial photographs were

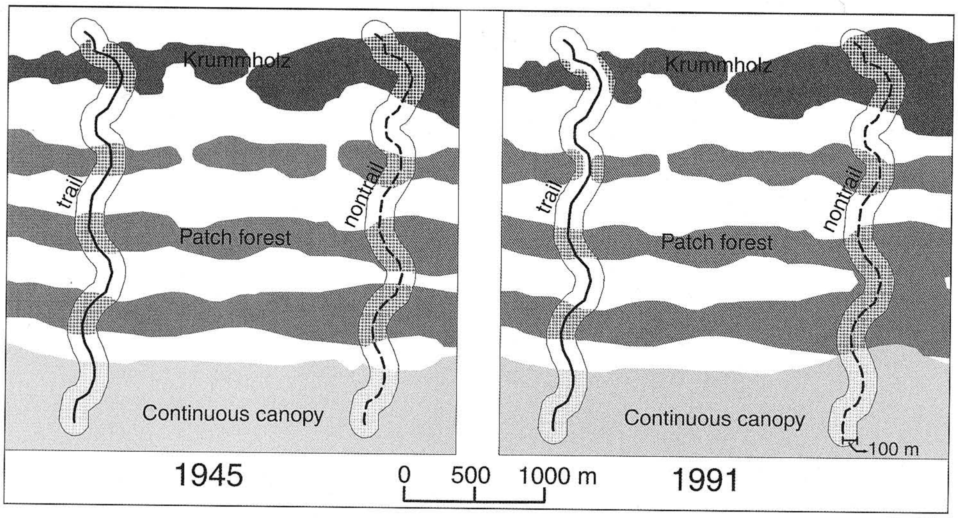

FIGURE 4. Hypothetical study area used to establish overall rate-of-change at alpine treeline ecotone from 1945–1991. Located within this area were "trail" and "nontrail" segments with a 100-m buffer used to identify change in tree distribution as a result of human activity from 1945 to 1991. Measured characteristics include relative change ([1991 trail–1945 trail]–[1991 nontrail–1945 nontrail]) in patch area, number of patches, and edge density.

used to verify vegetation classifications of the 1945 aerial photographs and to draw qualitative conclusions.

RATE OF CHANGE

To analyze the rate of change within these 40-ha sites, krummholz, patch-forest, and continuous canopy forest were aggregated into a single tree category. Change in spatial distribution of trees, through vegetative growth and establishment immediately adjacent to similar vegetation, was quantified as change in patch area (planar area of a tree vegetation) and expressed as percent change (from 1945 to 1991). Change in edge density (patch perimeter/patch area) and the number of patches was also identified, based on terrestrial and aerial photographs.

AREAS WITH TRAILS COMPARED TO AREAS WITHOUT TRAILS

From within the 40-ha areas originally used to establish an overall rate of change, the influence of trails was identified by pairing the area within 100 m of a linear segment of trail (100-m buffer distance) to a nearby "nontrail" region of identical size and shape (Fig. 4). The trail areas were defined using existing trails in 1991, while nontrail areas were defined manually using an identical copy of the trail spatial feature placed up to 2 km distant, parallel, and within the same portion of the alpine treeline gradient. Within these buffer regions, the "tree" vegetation classification was refined to distinguish krummholz, patch-forest, and continuous canopy forest. Trail and nontrail areas, for 1945 and 1991, were identified from within the same scene to calibrate for variability in image characteristics (e.g., contrast and brightness) that might influence classification of patch edges. By making comparisons between trail and nontrail areas within the same scene, quantitative comparisons could be made of edge density and number of patches for krummholz and patch-forest. A 100-m buffer from trails incorporated landscape-level effects from human activity, beyond the 5-m "trampling gradient" typically encountered along trails (Hartley, 1979). Only changes in krummholz and patch-forest vegetation are considered, because these vegetation types were readily identified and delineated in the black-and-white photography. Vegetation change within the buffer surrounding the "trail" segment was compared with change along the "nontrail" segment to identify relative change ([1991 trail–1945 trail]–[1991 nontrail–1945 nontrail]) in patch area, number of patches, and edge density (Fig. 4). Analysis of variance (ANOVA) was used to evaluate if overall differences (measures of krummholz and patch forest habitats combined) were associated with effects of trails, or if observed variability was associated with site differences. Log transformation of ANOVA data was necessary to equalize variance between groups. Analysis of differences by habitat (krummholz and patch-forest considered separately) contained fewer observations than overall differences, and the Mann-Whitney Rank-Sum test (a nonparametric rank transformation) was used.

Results

RATE OF CHANGE

The total patch area of trees (krummholz, patch-forest, and continuous canopy forest combined) increased by an average of 1576 m² from 1945 to 1991 (Table 2). Within each site, increases in patch area were most prevalent surrounding existing patches of trees. These increases in patch area did not result in a visible change in the altitude or position of the alpine treeline ecotone. At Bear Valley, the only site to decrease in tree area, avalanche activity evident in the aerial photography appears to be partly responsible for the reduction (no similar avalanche activity was evident at the other sites).

Within the 40-ha sites, where patches enlarged through tree growth or establishment, edge density of krummholz, patch-forest, and continuous canopy forest decreased as individual patches merged together. As seen in the comparison photographs of Logan Pass from 1927 and 1997 (Fig. 5), edge density for each site decreased to form a more widespread and homogeneous spatial distribution of trees.

The change in patch numbers from 1945 to 1991 is driven by establishment of new patches of trees or fragmentation of existing patches. At the two sites with the greatest change (order of magnitude larger), fragmentation and regrowth after avalanche activity (Bear Valley) and whitebark pine mortality (Heavens Peak) increased patch numbers. Within the six sites, the change in the number of patches from 1945 to 1991 also altered patch density (number of patches/area). Increases in individual tree density within these delineated patches of trees were evident in both the aerial and terrestrial photography.

AREAS WITH TRAILS COMPARED TO AREAS WITHOUT TRAILS

Compared to areas without trails, there was no statistically significant (one-sided P-value = 0.85) change in tree patch area

TABLE 2

Area of trees, change in area of trees, and change in number of tree patches (krummholz, patch-forest, and continuous canopy) at the six 40-ha study sites from 1945 to 1991

Sites (40-ha each)	Area of trees in 1945 (m^2)	% Change in area of trees from 1945 to 1991	Change in area of trees as % of total area	Change in number of tree patches from 1945 to 1991
Bear Valley	188,414	−3.05%	−1.44%	208
Flattop Mountain	214,790	1.36%	0.73%	13
Heavens Peak	77,694	8.14%	1.58%	182
Logan Pass	29,364	8.33%	0.61%	2
Sperry Chalet	63,077	5.18%	1.12%	−18
Swiftcurrent Pass	118,869	0.21%	0.06%	10
Mean	115,368	3.36%	0.44%	66.17

(krummholz or patch-forest, combined or individually) within 100 m of trails (Table 3). At all sites investigated, the direction and magnitude of change were the same for both trail and non-trail areas. The absence of tree area reduction along a trail is evident in both terrestrial and aerial photographs (Fig. 5). In fact, evident in the photographs along both trail and nontrail areas were increases in patch area surrounding existing patches.

Similarly, there was no consistent, significant (one-sided P-value = 0.89) pattern of change in edge density within 100 m of trails compared to areas without trails (Table 3). Intersite differences in edge density were greater than differences between the paired trail and nontrail areas.

There was a statistically significant difference in the number of patches within 100 m of trails compared to areas without trails (Table 3), but only in krummholz (one-sided P-value = 0.03). Krummholz patch size also increased at all three nontrail sites relative to paired trail sites (Fig. 6). The increase in number of patches was observed at all three sites with krummholz, although a similar trend was not observed in analysis of patch-forest vegetation or when krummholz and patch-forest vegetation was combined. Changes in patch numbers due to avalanche activity and whitebark pine mortality, observed in the rate of change analysis, were not evident in the "trail" and "nontrail" comparisons as these disturbances were typically outside the trail—nontrail study areas.

Discussion

Landscape patterns such as spatial distribution of vegetation reflect dynamic ecological processes and are key parts of the visual aesthetic and sense of place that defines a National Park like Glacier. Repeat photography is a powerful tool for spatial investigations of change. However, photography is limited to identifying patterns of change without distinguishing between causal mechanisms that drive variability in tree growth and establishment such as climate change or natural succession. Butler et al. (1994) suggested mechanisms for alpine treeline ecotone change in Glacier National Park, including summer temperature,

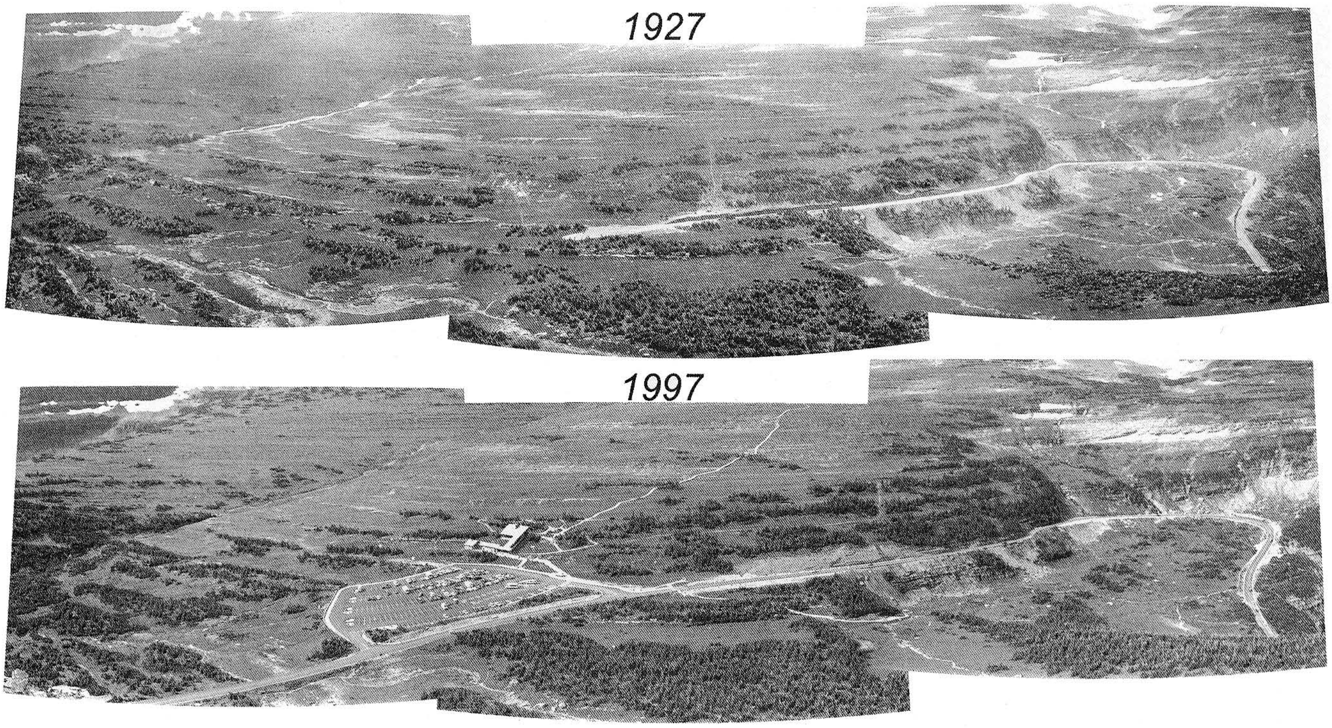

FIGURE 5. Logan Pass in 1927 and 1997. Note the increased density of existing patches of trees and the absence of any indication (in either meadow vegetation or tree distribution) of the 1927 trail in 1997.

TABLE 3

Statistical significance (one-sided P*-values) of change (1945–1991) at trail sites compared to nontrail sites*

	% area	Edge density (m m^{-2})	No. of patches
P-values by overall difference[a] df = 1, 4	0.85	0.89	0.23
P-values by habitat[b]			
Krummholz	0.26	0.41	0.03
Patch-forest	0.41	0.41	0.26

[a] Overall difference values represent a trail effect after accounting for site variability (across both habitat types; ANOVA, extra sum-of-squares *F*-test).

[b] By habitat values represent a trail effect grouped by habitat type (Mann-Whitney Rank-Sum test).

snowpack, and wind. Similar drivers for western North America were identified by Rochefort et al. (1994). Nevertheless, landscape patterns, such as changes in growth and establishment, can be delineated, quantified, and conveyed in a meaningful manner using repeat photography.

RATE OF CHANGE

The observed 3.4% increase in area of trees over a 46-yr (1945–1991) period in our study area occurred in specific locations with identifiable characteristics. Each study site incorporated a gradient of vegetation, from alpine tundra to krummholz or patch-forest. Change occurred in areas with previously existing krummholz or patch-forest and the rate of change was greatest immediately surrounding existing patches.

The spatial patterns resulting from increases in tree area produced a more abrupt transition from treeline to alpine tundra in Glacier National Park, without producing a noticeable shift in treeline position. This could result from altered microclimate and soil characteristics, because patches of trees create favorable conditions for tree growth and establishment in their immediate vicinity (Billings, 1974; Tranquillini, 1979; Stevens and Fox, 1991). This change to a more abrupt transition is not entirely uniform, with localized decreases in density frequently containing dead whitebark pine (Kendall and Keane [2001] estimate that 44% of all standing whitebark pine trees in Glacier National Park are dead).

Lloyd and Graumlich (1997), studying Holocene climate and treeline in Sequoia National Park, identified change in treeline position, as well as in tree density of existing patches, as responses to variation in temperature and moisture. However, changes in the spatial distribution of treeline other than position, can occur because of climate, site, and interspecies relationships. Investigating Swiss stone pine (*Pinus cembra*) in the Swiss central Alps, Hättenschwiler and Körner (1995) noted the absence of tree establishment above existing treeline but its presence within existing stands. Studies of white spruce (*Picea glauca*) in northwestern Canada also identify a trend of increasing stand density with only minor changes in the upper limit of trees during the past 100 to 150 yr (Szeicz and MacDonald, 1995). In addition, Cairns and Malanson (1997) have suggested that change in alpine treeline can be characterized by a shift from krummholz to patch-forest morphological forms.

Comparing rates of ecotonal change in Glacier National Park with other areas in the Northern Rocky Mountains is a valuable tool in identifying the role and interactions of local land-management strategies and climate change. Comparing Glacier National Park with different regions of the same biome type integrates unique combinations of ecotonal influence, ranging from climate and human activity to introduced plant and animal species. For example, grizzly bears (*Ursus arctos horribilis*) serve as a mechanism for maintaining alpine treeline ecotone patterns through positive feedback where regular digging for glacier lilies (*Erythronium grandiflorum*) maintains spatial patterns and increases nitrogen in the soil (Tardiff and Stanford, 1998). This form of disturbance no longer exists at alpine treeline in much of the U.S. portions of the Cascade and Rocky Mountains, where grizzly bears have been removed from the ecosystem.

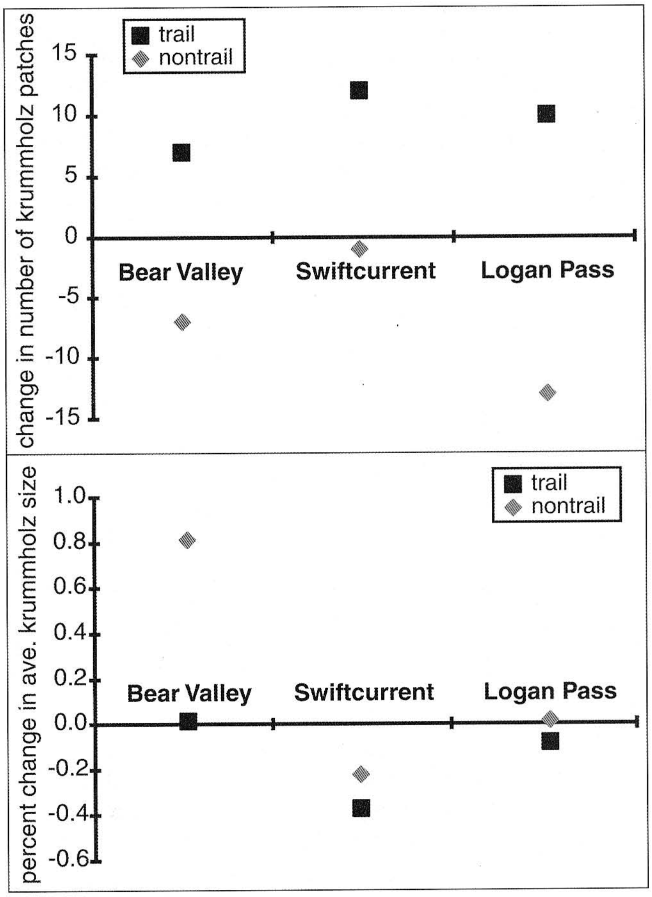

FIGURE 6. Increase in number of krummholz patches (top) and decrease in average krummholz patch size (bottom) at sites with trails paired to areas without trails.

AREAS WITH TRAILS COMPARED TO AREAS WITHOUT TRAILS

Even with evidence of krummholz fragmentation immediately adjacent to trails, there was an increase in the area and density of krummholz and patch-forest in these same sites. Although Noble (1993) questioned the use of disturbance-regulated ecotones to monitor the effects of climate change, not all alpine treeline ecotones are "disturbance" regulated. In our study, the effects of disturbance (from recreational and associated activity) did not have a significant influence on observed change in the ecotone. We found that krummholz and patch-forest grew and expanded at similar rates in areas with and without trails. These similar rates of expansions suggest that the intensive management efforts of the National Park Service to minimize human influence along trails were at least partially successful.

The alpine treeline ecotone is subject to much more human activity in some areas in Glacier National Park than in others. One example is Logan Pass, seen in 1927 and again 70 yr later (Fig. 5) after completion of the Going-to-the-Sun Road, the addition of a large visitor center, and the use of PCP (pentachlorophenol) and petroleum solvents in trail construction materials (Beaver, 1975). Even with such intense human activity, effects on treeline patterns were limited to areas adjacent to development, although longer term changes in treeline pattern could appear in the future (Ives and Hansen-Bristow, 1983). This conclusion applies only to the spatial distribution of krummholz and patch-forest, however, as Hartley (1999) identified altered grass and forb cover and composition nearly 30 yr after a single trampling event at Logan Pass.

SUMMARY

Just as analysis of changes in the distribution of vegetation at various temporal scales provides unique insights into landscape structure and function, so too does analysis at different spatial scales. This study approached the alpine treeline ecotone as a fine-grained landscape, using high-resolution, large-scale photographs for analysis. Had our analysis used coarser scale imagery, the fine-grained impacts of trails may not have been evident although a larger study area would potentially highlight effects of broader scale impacts such as roads or fire protection activities. From this study, we conclude that:

- Increases in area and density of trees resulted in increased homogeneity, affecting snowpack distribution, microclimate, and forest fuel connectivity.
- The ecotone transition from alpine to subalpine (tundra to forest) became more abrupt from 1945 to 1991.
- Fragmentation of krummholz surrounding areas of human activity (trails) was evident at fine spatial scales. Less evidence of an effect from human activity was found when all forest types were integrated.

To ensure effective management of a protected area such as Glacier National Park, documentation and ultimately management for change in alpine treeline across a wide range of spatial and temporal scales is a necessity. Global comparisons across mountain regions, using repeat photography for documenting change in the alpine treeline ecotone, provide a cost-effective opportunity to identify systemic and scale differences resulting from the effects of human use and land management activity. Such comparisons are possible with networks of mountain protected areas for global change research.

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