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Soil-Vegetation Relationships in a Subalpine Grassland in Northeastern Washington¹

Abstract

Clumps of mountain big sagebrush (*Artemisia tridentata* ssp. *vaseyana*) and subalpine fir (*Abies lasiocarpa*) a few meters in diameter dot the subalpine grassland on Calispell Peak in northeastern Washington. The pattern of vegetation is associated with soil properties, primarily rock content, with snow depths, and with exposure to wind and sun. The grassland occurs on soils that are shallow and stony. Clumps of subalpine fir within the grassland occur on pockets of soil that are deeper and less stony. Clumps of mountain big sagebrush and bluebunch wheatgrass (*Agropyron spicatum*) occur on microtopographic mounds of soil that also are deeper and less stony. Because of the differences in rock content, soils of the grassland have only about 60 percent as much available water holding capacity as do those of the mound and tree island. The snowpack, measured on the windward grassland, was thin and contained only 10 to 60 percent as much water per unit area as the deeper snowpack on the leeward slope and under forest canopy. A buried layer of Mount St. Helens "T" volcanic ash indicated that since 1800 AD 5 cm of soil material has accumulated on the mound site and 10 cm under the subalpine fir by vegetation trapping airborne dust. Bands of charcoal within the mound record one fire in the grassland about 1500 AD, and two fires since 1800 AD. Grass balds in areas of otherwise continuous forest cover are often local landmarks. Conditions that lead to these timberlines are of interest to the general public as well as professionals. The reasons why trees have not replaced the grassland may tell about the recent history of the region or have implications for management of these areas.

Introduction

Grassland communities occur on south- and west-facing ridges of some of the highest peaks in northeastern Washington and northern Idaho. The existence of these "grass balds" has long sparked the interest of ecologists (Shaw 1909, Daubenmire 1944). Daubenmire (1968) attributed these subalpine parks in northern Idaho and northeastern Washington to failure of tree seedlings to survive late summer drought. Daubenmire (1981) hypothesized that localized droughty conditions prevail on exposed ridges because wind transfers snow from windward slopes onto protected leeward slopes. Exposure of the south- and west-facing slopes to desiccating winds and direct solar radiation increases evapotranspiration and intensifies the droughty conditions.

During a reconnaissance of vegetation on one such grass bald on Calispell Peak, scattered clumps of subalpine fir (*Abies lasiocarpa*)² were observed in the grassland above the elevation

of continuous forest cover. We hypothesized that differences in soil properties or microtopography within the grass bald might have had localized effects on plant growth and therefore have played a role in the distinctive vegetation patterns. We described the vegetation and microtopography of a representative part of the grassland and described and sampled soils to test our hypothesis. Secondly, we have been able to interpret aspects of the history of the grass bald from features found in the soil profiles and from the properties of the soils.

Study Area

Calispell Peak has an elevation of 2072 m (6837 ft) and is located at 48° 26' 13" N. and 117° 30' 04" W. Approximately 200 hectares of grassland dominate the southeast to west exposures from 1760 to 2060 m (5800 to 6800 ft) elevation (Figure 1).

The principal soil series mapped on Calispell Peak is Brickel stony loam (Donaldson *et al.* 1982). Soils of Brickel series are classified as loamy-skeletal, mixed Typic Cryoborolls. The Brickel series consists of moderately deep, well-drained soils that have formed in residuum,

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²Taxonomy according to Hitchcock and Cronquist (1973), except for *Artemisia* which is described by Beetle (1960).

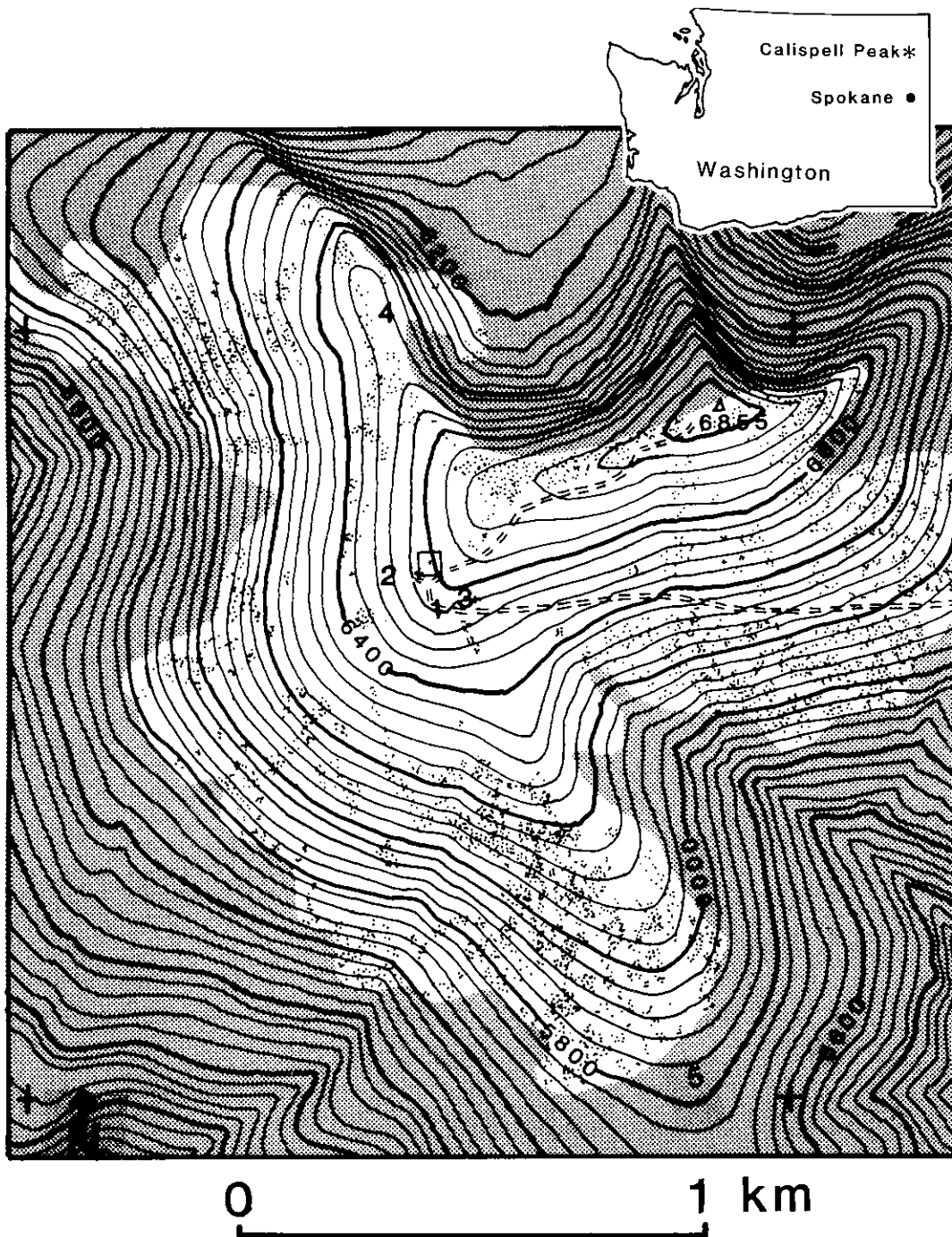


Figure 1. Location and topography of Calispell Peak in northeastern Washington. Shaded area is forested, individual dots show location of tree islands and white is grassland area. Open box shows soils pedon sampling area. Numbers correspond to snow survey sites discussed in text. Contour interval is 40 feet, elevations are in feet. Adapted from U.S.G.S. Calispell Peak Quadrangle, 7.5 minute series.

colluvium, and glacial till from granitic rock mantled with an admixture of volcanic ash and loess.

Since the upper limit of glacial deposits mapped for the latest Pleistocene glaciation is 1524 m (5000 ft) in the vicinity of Calispell Peak (Flint 1937), the upper part of the mountain was likely ice-free. The land surface before addition of volcanic ash and loess in post-glacial time was not glacial till but residuum from granite and gneiss.

Methods

The vegetation has been classed into three community types based on the dominant cover of grass, shrubs or trees. We refer to these as intermound (grass), mound (sagebrush) and tree island, respectively.

After reconnaissance of the grass bald on foot and after observing patterns of soil depth, rock content and vegetation in a roadcut exposure for a distance of approximately one kilometer, we selected a representative site for our sampling. The site has areas of intermound, mound and tree island within a 10 m radius. This site is about two-thirds of the way up the windward, grassed part of the peak (Figure 1).

One soil pedon for each of the three vegetative types was described and sampled on

20 August 1984. We determined particle size distribution and soil water release curves for the fine earth fraction (<2 mm) of each horizon sample by standard methods (Soil Conservation Service 1982). The pressure-plate extraction method for soil water release was modified by wetting the soil samples before placing them on the plate because the soils were hydrophobic and did not wet readily by the standard procedure. Total soil carbon of horizon samples was analyzed by dry combustion using a LECO furnace model CHN 600. We used the soil water release curves and estimates of rock content to calculate total available water storage to 60 cm in each of the three soils.

We sampled and analyzed a layer of volcanic tephra (airborne volcanic material) from the subsurface in the soils of the mound and tree-island (Figure 2) in order to determine the origin and age of the tephra. The volcanic glass in the sample was concentrated by wet sieving and treated with hydrogen peroxide to remove organic matter. Major elements in glass shards of the coarse-silt fraction (20-50 μm) were determined using a Cameca Camebax electron microprobe. We analyzed 20 shards and averaged the results. These analyses were calibrated to an obsidian standard (U of A 5831, Smith *et al.* 1977).

We measured snow depth and water content of the accumulated snow pack on 7 March 1984



Figure 2. Schematic vertical section showing relationship in position and rock content of the three vegetation types. From left: tree island, intermound, mound. Dotted line is the buried tephra layer.

using standard Soil Conservation Service snow survey procedures (Soil Conservation Service 1973). Measurements were made on the exposed west- and southwest-facing slopes, on the ridgelines, in the lee of each ridgeline and below timberline under the forest canopy (Figure 1).

Results and Discussion

Vegetation

The intermound or grassland area is dominated by a mixture of Idaho fescue (*Festuca idahoensis*) and green fescue (*F. viridula*), with Ivesia (*Ivesia tweedyi*), yarrow (*Achillea millefolium*), western hawkweed (*Hieracium albertinum*), silky lupine (*Lupinus sericeus*), Rocky Mountain aster (*Aster stenomerus*), and subalpine daisy (*Erigeron peregrinus*). Parry's rush (*Juncus parryi*) and tufted hairgrass (*Deschampsia caespitosa*) occur in more moist locations, primarily along roadsides and near late-melting snowdrifts.

Mounds within the grassland support mountain big sagebrush (*Artemisia tridentata* ssp. *vaseyana*). Rhizomatous bluebunch wheatgrass (*Agropyron spicatum*) forms the dominant understory of the sagebrush mounds.

Tree islands within the grassland are less than about 6 m in diameter and are composed of subalpine fir up to 4.5 m in height. The trees do not appear to be reproducing vegetatively by adventitious rooting of lower branches, but have multiple tops due to repeated damage. Some of the tree islands are doughnut or horseshoe shaped, indicated that the clump may have started as an individual tree that died after other trees became established around it. The understory vegetation of the tree islands includes elderberry (*Sambucus racemosa* var. *melanocarpa*), yarrow, mountain heliotrope (*Valeriana sitchensis*), woodrush (*Luzula hitchcockii*), and sedge (*Carex paysonis*).

Trees on the broad ridge that extends north from Calispell Peak (Figure 1) fit the pattern of "ridgetop ribbon forests" described by Arno and Hammerly (1984) on mountain ridges southwest of Missoula, Montana. A portion of the leeward slope supports no trees because a very deep snow bank lingers late into the growing season, and there exists instead a meadow of sedge (*Carex* spp.) and tufted hairgrass.

Microtopography and Soil Properties

The (sagebrush) mounds comprise only about five percent of the grassland area and so the microtopography cannot be described as classical mound-and-swale, instead it might be described as consisting of infrequent mounds on a sloping hillside. The mounds are several meters in diameter and up to one-half meter higher than the surrounding intermound.

Tree islands also occupy about five percent of the grassland. The land surface is nearly level from the intermound areas to the tree islands, or is slightly concave under the trees (Figure 2).

All of the fine earth (<2 mm) fractions of horizon samples are loamy fine sand, loamy very fine sand, or fine sandy loam (Table 1). Changes in soil texture down each profile appear to result from stratification of parent materials. Rock content of the upper part of the profile is quite different from one soil to another: 5-15 percent in the mound, 50-60 percent in the intermound, and 10-40 percent in the tree island (Table 1; Figure 3). Rock content increases with depth to about 70 percent in the lower part of all three profiles.

The calculated water storage capacity to a depth of 60 cm is 9 cm in the tree island site, 8 cm in the mound site, and only 5 cm in the intermound site (Table 2). The differences in water storage among the sites are largely due to the differences in rock content.

The total carbon content of all three soils decreases with depth (Table 1). The mound soil has the highest carbon content (9.7 to 5.9 percent), followed by the tree-island soil (8.5 to 4.2 percent), and the intermound soil (7.6 to 2.4 percent). Carbon is highest in the surface horizon of the mound soil and decreases gradually with depth, a typical pattern for a grassland soil. The carbon distribution in the soil of the tree island reflects the incorporation of tree litter principally at the surface, and because of this it decreases sharply with depth. The lower overall carbon content in the soil of the intermound reflects the sparser vegetation and the greater proportion of forbs than occur on the other two sites. Few roots penetrate below 50 cm in the intermound soil and this is reflected in a low carbon content below 60 cm (Table 1).

The pattern of vegetation types appears to be strongly associated with the microtopography and with rock content in the soil profiles (Figures

TABLE 1. Soil Properties

| Soil Depth (cm) | Total Carbon % | Rock Content (Coarse Fragments) (volume % ≥ 2 mm) | Sand 2.0-0.05 mm | Silt 0.05-0.002 mm (weight %) | Clay <0.002 mm |
|--------------------|----------------------|--|---------------------|-------------------------------------|-------------------|
| MOUND | | | | | |
| 0-5 | 9.7 | 5 | 75.3 | 22.8 | 1.9 |
| 5-31 | 7.1 | 15 | 78.8 | 18.0 | 3.2 |
| 31-36 | 5.9 | 40 | 75.4 | 21.2 | 3.4 |
| 36-40 | — | 70 | — | — | — |
| INTERMOUND | | | | | |
| 0-8 | 7.6 | 50 | 77.6 | 18.4 | 4.0 |
| 8-40 | 5.9 | 60 | 63.9 | 32.4 | 3.7 |
| 40-60 | — | 70 | — | — | — |
| 60-70 | 2.4 | 70 | — | — | — |
| TREE ISLAND | | | | | |
| 0-6 | 8.5 | 10 | 74.2 | 22.3 | 3.5 |
| 6-20 | 7.0 | 40 | 74.4 | 22.8 | 2.8 |
| 20-54 | 4.3 | 50 | 69.2 | 29.6 | 1.2 |
| 54-60 | 4.2 | 60 | 74.9 | 22.2 | 3.0 |

TABLE 2. Estimated Water Storage Capacity

| Soil Depth (cm) | Available Water ¹ (Fine earth ³) (cm cm ⁻¹) | Rock Content (Coarse fragments ²) (volume %) | Available Water Storage per Horizon (Whole soil ²) (cm) | Total Available Water Storage in Profile ² (Whole Soil ²) (cm) |
|--------------------|---|--|--|---|
| MOUND | | | | |
| 0-5 | 0.22 | 5 | 1.5 | |
| 5-31 | 0.14 | 15 | 4.3 | |
| 31-36 | 0.17 | 40 | 0.7 | |
| 36-60 | 0.17 | 70 | 1.7 | 8 |
| INTERMOUND | | | | |
| 0-8 | 0.15 | 50 | 0.8 | |
| 8-25 | 0.17 | 60 | 1.6 | |
| 25-40 | 0.17 | 60 | 1.4 | |
| 40-60 | 0.17 | 70 | 1.4 | 5 |
| TREE ISLAND | | | | |
| 0-6 | 0.34 | 10 | 2.5 | |
| 6-20 | 0.17 | 40 | 2.0 | |
| 20-54 | 0.16 | 50 | 3.8 | |
| 54-60 | 0.16 | 60 | 0.5 | 9 |

¹Available water is the water held between potentials of -0.03 MPa and -1.5 MPa, estimates of field capacity and permanent wilting point.

²Total available water storage in the profile is calculated from the available water and the following other factors: A bulk density value of 1.4 Mg m^{-3} is used for all horizons. Estimated storage capacity = cm of soil x available water per cm depth x percent volume of fine earth x bulk density. Water storage is estimated to a uniform depth of 60 cm for all soils. Some plants may draw water from greater depths.

³Fine earth consists of mineral particles < 2 mm in diameter; coarse fragments are those mineral or rock particles ≥ 2 mm in diameter; whole soil consists of fine earth plus coarse fragments.

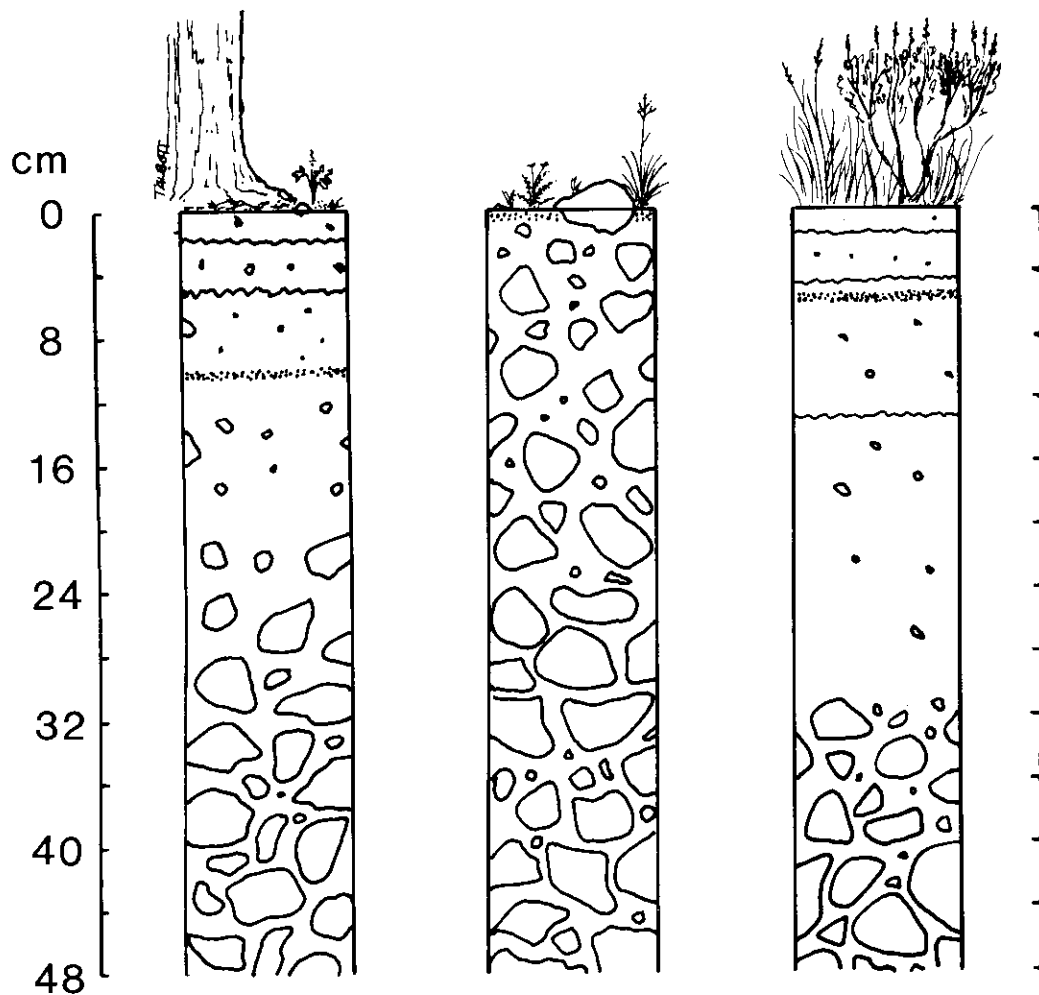


Figure 3. Soil profiles, from left: tree island, intermound, mound. Wavy lines are charcoal layers; dotted lines are volcanic tephra. Soils are not shown in their natural microtopographic relationship to one another.

2, 3). Both of these factors may influence water availability for plant growth: the differences in rock content mean that soils of the sagebrush mound and tree island have almost twice as much available water storage capacity as do soils of the intermound (Table 2). Additionally, drainage of soil water into the stone-free pockets of the tree island may increase the amount of water received. Together, these two factors may lengthen the time during the growing season that water is available for plants in the tree island site.

Tephra and Charcoal in the Soils

Layers of charcoal were found at depths of 2, 4, and 13 cm in the mound soil and at depths of 2 and 5 cm in the tree island soil (Figure 3). We found no charcoal in the intermound soil.

We found two discrete bands of grayish-white volcanic tephra in the soil profiles (Figure 3). The first was within the litter at the soil surface of the intermound site and was from the 18 May 1980 eruption of Mount St. Helens. Silt-sized glass shards dominated the second band of tephra, which was about 1 cm thick and was

preserved at 10 cm depth in the soil profile of the tree island and at 5 cm depth in the soil of the mound. This layer was not preserved in the intermound soil.

The buried tephra in the soils most likely correlates with either the T or W layers from eruptions of Mount St. Helens about 1800 AD and 1480 AD, respectively (Smith *et al.* 1977, Yamaguchi 1983). Both layers have been reported within a few tens of kilometers of Calispell Peak (Smith *et al.* 1977, Okazaki *et al.* 1972).

From electron microprobe analyses of glass shards we calculated the ratio of Ca to Fe to K. This method has been used successfully to identify the origin of tephra layers (Westgate *et al.* 1970, Smith *et al.* 1975). Based on the similarity of this key element ratio in the buried tephra to those reported previously for layer T (Figure 4) we correlate this sample with Mount St. Helens layer T.

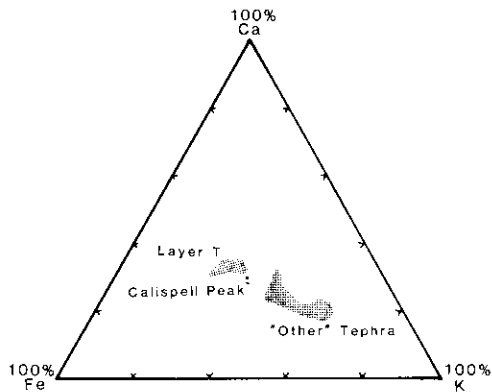


Figure 4. Electron microprobe data for Ca, K, and Fe in glass shards from buried tephra layer on Calispell Peak, Mount St. Helens pyroclastic layer "T," and "other" tephra. Adapted by permission from Smith *et al.* (1975). "Other" tephra include Glacier Peak (upper and lower), Mount Mazama, Mount St. Helens W and Y, Bridge River (three types) and a tephra of unknown origin that is common north of Wenatchee, both east and west of the Okanogan River.

The stratigraphic relationship of layer T to the charcoal layers and a difference in the type of charcoal found in the tree island versus the sagebrush mound provides information about the history of the grassland. The two charcoal bands above the tephra layer represent two fires in the last 186 years. This frequency is consistent with

the 90 to 130 year fire recurrence interval in the subalpine fir forests that surround grass balds in the northern Rocky Mountains (Arno 1980). The third band of charcoal, 8 cm beneath the tephra layer in the mound site, records at least one fire before 1800 AD.

The charcoal in the three layers in the sagebrush mound consists of fine filaments, whereas that in the two layers in the tree island consists of pieces of charred wood up to 2 cm long. The fine filaments of charcoal represent burned grasses and forbs indicating that the subalpine grassland has persisted for at least several hundred years on Calispell Peak. The fragments of burned wood in the tree site are evidence that the tree islands also have been a component of the grassland in the pre-historic past. Fragments of burned wood under the tree island and fragments of burned grasses under the mound also indicate to us that fires did not change the dominant vegetation on either the tree or mound sites. Fire could have played a role in maintaining the pattern of vegetation by killing tree seedlings in the grassland or on the outer edges of the tree islands.

Trees are limited to apparent depressions in the original stony bedrock surface. From the low rock content in the A and B horizons of the soils of the tree island and mound and from the dominance of very fine sand in the fine earth we infer that these soils have formed by vegetation trapping airborne dust.

Relatively stone-free mounds also have been observed in subalpine grassland by Daubenmire (1981) on Gisborne Ridge, Bald Mountain (both in Idaho) and Roundtop (in Washington). These mounds, and as well those observed by one of us (Roché) on North and South Baldy Mountains in Pend Oreille County, Washington, are covered by a dense stand of rhizomatous bluebunch wheatgrass and lack sagebrush. Daubenmire (1981) hypothesized that the mounds are solifluction lobes that originated in late-glacial time. The mounds on Calispell Peak appear to have originated by clumps of dense grass or grass-sagebrush cover trapping dust. The presence of tephra layer T indicates that these microtopographic features are much younger than late glacial; the lack of stones and the horizontal bedding of the tephra and charcoal indicate an eolian origin and suggest a lack of solifluction processes in forming the microtopography.

Since the year 1800, windblown soil material has accumulated on the tree site at a net average rate (deposition minus erosion) of 0.5 mm per year and on the mound site at 0.3 mm per year. The absence of either a discrete tephra layer or charcoal bands in the soil of the intermound site indicates net erosion or severe soil mixing on this vegetation type since at least the year 1800.

Pattern of Snow Depth

The minimum thickness of snow, 16.5 cm, which contained 3.8 cm of water, occurred on the break of the north-south ridgeline (site 1, Figure 1). On the windward slope in the grassland, the snow averaged 71 cm in thickness and contained 23.4 cm of water (site 2). A few meters on the lee side of the north-south ridgeline, snow was 114 cm thick and contained 38.7 cm of water (site 3). On the top of the ridge and on its lee side, the snow was deeper than 229 cm (site 4), the maximum length of the snow-measuring equipment. Under continuous forest cover at approximately 1750 m on the windward slope (site 5), the snow averaged 125 cm deep and contained 39 cm of water.

This pattern corresponds to exposure to prevailing southwesterly winds. Wind transfers snow from the grassland on the windward slope and deposits it on the lee side of the ridge where it accumulates to form a thick cornice. As a result, the grassland receives only 10 to 60 percent as much water per unit area from snow as do the forested sites, as measured near the end of the period of snow accumulation. Rates of sublimation may also be higher in the grassland than in forest due to exposure of the snowpack to wind and solar radiation. Measured snow depths are adequate to saturate the soil profiles beneath. However, due to sublimation and early melting of the snow in the exposed grassland, the shallow soils on the southwest slope are likely to retain only a part of this moisture until temperatures become favorable for plant growth. Our snow survey supports Daubenmire's hypothesis (1981) that droughtiness in subalpine grasslands of the area are caused at least in part by wind transfer of snow.

Conclusions

The subalpine grassland on the windward slope of Calispell Peak occurs on shallow stony soils.

Wind transfer of snow and low water storage capacity reduce the available soil moisture. High sublimation rates of the snowpack and high evapotranspiration rates due to southwest exposure also may contribute to droughtiness. Trees occur in microsites where the soils are less stony (greater water storage capacity) and in areas where snow accumulates.

The mounds, which have a water storage capacity similar to that of the tree islands, support sagebrush. A key difference between the two microsites could be that the concave-shaped tree sites (Figure 2) receive additional water as runoff and throughflow, whereas the convex-shaped sagebrush mounds give up water to runoff and throughflow.

The deeper, less stony soils of the tree islands and mounds have formed by trapping of airborne dust. Using the Mount St. Helens T layer as a dateline, 5 cm of soil material has accumulated on the mound site since the year 1800, and 10 cm has accumulated on the tree island site.

Bands of charcoal in the soil of the mound site record one fire before and two after 1800 AD. These fires may have killed tree seedlings in the grassland, thus preventing expansion of the tree islands. Fire has not prevented establishment of trees, however, where moisture conditions are more favorable: pockets of deeper soil, the ridgetop, and northeast slopes. Using the average net deposition rate of 0.5 mm per year that we calculated for the mound site and assuming a similar rate of soil accumulation before 1800 AD, the band of filamentous charcoal below layer T records a fire in grassland about 1500 AD and provides a minimum age for the subalpine grass bald on Calispell Peak.

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Literature Cited

- Arno, S. F. 1980. Forest fire history in the northern Rockies. *J. For.* 78:460-465.
- Arno, S. F., and R. P. Hammerly. 1984. *Timberline: Mountain and Arctic Forest Frontiers*. The Mountaineers, Seattle.
- Beetle, A. A. 1960. A Study of Sagebrush. *Agr. Exp. Sta. Bull.* 368. University of Wyoming, Laramie.
- Daubenmire, R. F. 1944. Mountain parks in northern Idaho. *Ida. Forest.* 26:16.
- . 1968. Soil moisture in relation to vegetation distribution in the mountains of northern Idaho. *Ecology* 49:431-438.
- . 1981. Subalpine parks associated with snow transfer in the mountains of northern Idaho and eastern Washington. *Northw. Sci.* 55:124-135.
- Donaldson, N. C., J. T. DeFrancesco, and D. W. Barron. 1982. *Soil Survey of Stevens County*. USDA-Soil Conservation Service, Washington, D.C.
- Flint, R. F. 1937. Pleistocene drift border in eastern Washington. *Geol. Soc. Amer. Bull.* 48:203-232.
- Hitchcock, C. L., and A. Cronquist. 1973. *Flora of the Pacific Northwest*. University of Washington Press, Seattle.
- Okazaki, R., H. W. Smith, R. A. Gilkeson, and J. Franklin. 1972. Correlation of West Blacktail Ash with pyroclastic layer T from the 1800 A.D. eruption of Mount St. Helens. *Northw. Sci.* 46:77-89.
- Shaw, C. H. 1909. The causes of timberline on mountains: the role of snow. *Plant World* 12:169-181.
- Smith, H. W., R. Okazaki, and C. R. Knowles. 1975. Electron microprobe analysis as a test of the correlation of West Blacktail ash with Mount St. Helens pyroclastic layer T. *Northw. Sci.* 49:209-215.
- . 1977. Electron microprobe analysis of glass shards from tephra assigned to Set W, Mount St. Helens, Washington. *Quat. Res.* 7:207-217.
- Soil Conservation Service, USDA. 1973. *Snow survey sampling guide*. Agr. Handbook No. 169, Washington, D.C.
- . 1982. *Procedures for collecting soil samples and methods of analysis for soil survey*. Soil Surv. Invest. Rep. No. 1, Washington, D.C.
- Westgate, J. A., D. G. W. Smith, and M. Tomlinson. 1970. Late Quaternary tephra layers in southwestern Canada. *Proc. 2nd Annual Paleo-environmental Workshop of the University of Calgary Archeological Association*. The Student's Press. Calgary, Alberta, Canada. Pp. 13-34.
- Yamaguchi, D. K. 1983. New tree-ring dates for recent eruptions of Mount St. Helens. *Quat. Res.* 20:246-250.

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