A comparison of plant communities and substrates of avalanche and non-avalanche areas in South-Central Montana

by Sharon Thornberry Eversman

A thesis submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in Botany
Montana State University

Abstract:
A study was conducted in the Bridger Bowl area in the Bridger Range in south-central Montana, U,S,A., to determine vegetation and soil features of an avalanche area and compare avalanche tracks with areas where no avalanches occurred, 2x5 dm plots and quarter methods were employed in obtaining quantitative data of plant communities. Surface soil analyses were made. Increment cores were obtained to determine ages of trees, and some trees were cut to determine patterns of tree ring growth, Abies lasiocama is the dominant tree taxon in all timbered areas above 7000 feet. Fseudotsuga menziesii occurs where there is no snow movement and is dominant on forested slopes below 7000 feet. Perennial forbs and grasses occur on all open slopes in communities that have no correlation with snow movement. Exposure, substrate, available moisture, and altitude affect local variations of the herbaceous communities, The topographic features, long-existing snow movement, and the present vegetation patterns have developed concomitantly.

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Approved:

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MONTANA STATE UNIVERSITY
Bozeman, Montana

June, 1968

ACKNOWLEDGMENT

The author wishes to extend sincere appreciation to the following, among others, for their contributions to this study: Dr. John H. Rumely, Montana State University, for supervision in field methods and help in preparing the manuscript; Dr. John de la Montagne, Montana State University, who made available much of the information on snow movement and examined the paper for geological accuracy; Dr. W. E. Booth, Montana State University, for aid in plant identification; Paul Sawyer, Montana State University, for aid in plant identification; and to her husband, Thomas, for his help and patience.

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ABSTRACT

A study was conducted in the Bridger Bowl area in the Bridger Range in south-central Montana, U.S.A., to determine vegetation and soil features of an avalanche area and compare avalanche tracks with areas where no avalanches occurred. 2x5 dm plots and quarter methods were employed in obtaining quantitative data of plant communities. Surface soil analyses were made. Increment cores were obtained to determine ages of trees, and some trees were cut to determine patterns of tree ring growth.

Abies lasiocarpa is the dominant tree taxon in all timbered areas above 7000 feet. *Pseudotsuga menziesii* occurs where there is no snow movement and is dominant on forested slopes below 7000 feet. Perennial forbs and grasses occur on all open slopes in communities that have no correlation with snow movement. Exposure, substrate, available moisture, and altitude affect local variations of the herbaceous communities. The topographic features, long-existing snow movement, and the present vegetation patterns have developed concomitantly.

INTRODUCTION

The Bridger Bowl Ski Area and adjacent region in the Bridger Range in south-central Montana, U.S.A., is the site of extensive snow research by the Earth Science Department at Montana State University at Bozeman. Some studies concentrate on snow metamorphosis and strength of the snow pack (Bradley, 1966, 1967). These studies determine conditions leading to collapse of unstable snow layers that contribute to slab avalanches. Other work deals with avalanche forecast, control, and prevention, including installation of devices to inhibit cornice formation at the top of the ridge under which the ski area is located (Montagne, et al., 1967).

Observations indicate that avalanches and other snow movements occur consistently in the same paths on the same slopes. It has been speculated that ecological features might contribute to the susceptibility and maintenance of specific areas as snow movement paths. The present study was undertaken to attempt to ascertain whether plants and soil of avalanche tracks vary significantly from adjacent or similar slopes where snow movement does not occur.

Abundant information is available on snow physics (Davos Symposium, 1965; International Conference on Low Temperature Science, 1966; Forest Service, 1961). This literature concentrates on snow types and metamorphosis, weather and other conditions affecting avalanche release, slope characteristics, and avalanche control and rescue. Slope vegetation, if mentioned, is given in very general terms.

European ecological studies in the Alps focus on deforested slopes that subsequently became dangerous avalanche paths. The avalanches start either above timberline and slide through the deforested area, or they are able to start in a formerly timbered area. Wind control for reforestation projects is discussed by LaChapelle (1966) and Hopf and Bernard (1963). In the Austrian Alps, wind deflection structures are being placed where they will affect snow distribution as natural forests do. These devices prevent extremely deep snow accumulations in localized areas, and inhibit wind scouring of trees and exposed sites. Controlled grazing and timber cutting are also being practised.

This kind of information is not directly applicable to the Bridger Bowl area, since timberline extends to the top of the ridge wherever there is a suitable substrate. Very little, if any, tree cutting has been done in the avalanche zones. There is no evidence that the present avalanche paths have ever been forested.

DESCRIPTION OF THE AREA

The Bridger Range extends for about 30 miles along a north-northwest to south-southeast axis in Gallatin County in south-central Montana. The Bridger Bowl Ski Area is situated on the east side of an 8500-foot ridge in the Bridger Range (Appendix A).

An aerial photograph (Figure 1) illustrates the topography and vegetation patterns of the Bridger Bowl region. Forested slopes are darkest in color and are usually convex slopes, ridges or mounds of soil. Meadow vegetation, primarily herbaceous perennials and grasses, appears light gray and occurs on convex and concave slopes. Loose rock and outcrops appear white. The specific sites studied are numbered in Figure 2; their more detailed descriptions appear in Table I.

Bridger Bowl slopes face nearly due east; northeast and southeast exposures are formed only on the sides of the ridges that alternate with gullies and wide circular depressions (bowls). The average slope is about 27°, with generally steeper slopes above 7000 feet, and gentler slopes below 7000 feet.

The streams draining the area are intermittent above 6500 feet, being filled with water only while the snow is melting. They are usually dry by mid-July. Occasional springs contribute a small amount of water.

Man's activities have altered the vegetation patterns in the avalanche zone very little. Some tree cutting has been done during continuous development of the area for skiing, but most of this is well below the avalanche zone. Extensive logging has been done on the slopes below the ski area.

Grazing pressure on the meadows is slight. Flocks of domestic sheep use some of the land below 7000 feet about once in four years. Some mule deer and blue grouse inhabit the area, and elk and mountain lions are occasionally seen.

Weather records have been kept since 1951 at the Forsythe Ranch, altitude 6000 feet. The average annual temperature is about 38.6° F. July is the warmest month and January is the coldest (Table II).

Average annual precipitation is 33.88 inches. July is the driest month and June is the wettest. Most of the precipitation from September to May is snow. Maximum snow depth is usually 95 to 100 inches in the Bridger Bowl area, with local depths ranging from 50 to 100 inches, depending on topography and altitude. Bridger Bowl is on the lee side of the Bridger Range. On the windward, or west, side of the ridge, maximum snow depth is about 60 inches.

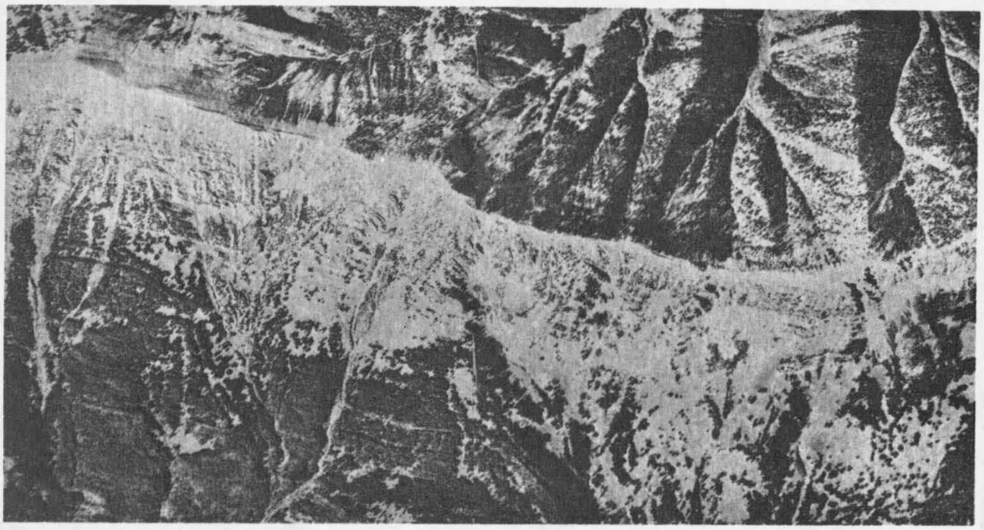

Figure 1. Aerial photograph of Bridger Bowl and adjacent areas. The top of the photograph is west.

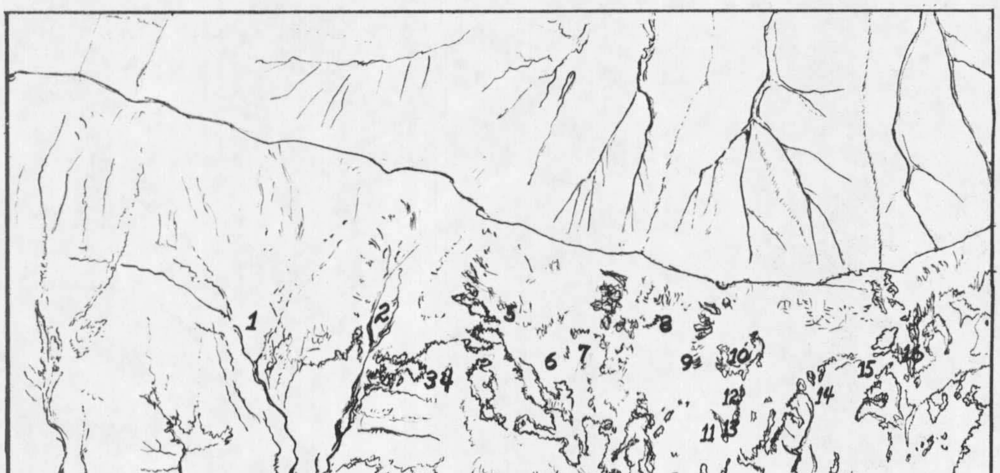

Figure 2. Diagram of aerial photograph. The numbers indicate sites studied. Detailed descriptions appear in Table I.

TABLE I. DESCRIPTION OF SITES NUMBERED ON DIAGRAM OF AERIAL PHOTOGRAPH.

Site	Elevation in feet	Slope in degrees	Snow Movement	Vegetation
1. Bridger Peak, northeast side	7100-9156	18-40	Avalanches[1]	Damaged trees
2. Unnamed Gulch	6600-7100	18	Avalanches	Damaged trees
	6600-7100	18-20	Avalanches	Forbs-grasses
3. Trees near SCSC[2]	6960	14	None	Undamaged trees
4. Park near SCSC	6950	14	None	Forbs-grasses
5. South Bowl	6860-7060	30-36	Avalanches	Damaged trees
6. South Bowl Meadows	6500-7100	20-25	Occasional avalanches	Forbs-grasses
7. North part of South Bowl	6950-7100	32	Creep	Forbs-grasses
8. Avalanche Gulch	7400-8100	35	Avalanches	Forbs-grasses
9. Upper Face	7400-8100	27-30	Negligible creep	Forbs-grasses Undamaged trees
10. North Bowl	7360-7605	17-22	Frequent	Damaged trees
	7200-7700	25-35	avalanches	Forbs-grasses
11. North Meadows	6530-7000	16	None	Forbs-grasses
12. Trees, North Meadows	7070-7290	18	None	Undamaged trees
13. Meadow	7000-7200	16	Occasional avalanches	Forbs-grasses
14. Bridger Gully	7100-7400	30-35	Avalanches	Forbs-grasses Damaged trees
15. New Chair Lift Terminal	7100-7600	32-33	Creep; glide Avalanches	Forbs-grasses
16. North Basin	7500-8000	30	Avalanches	Damaged trees

[1] Avalanches are the slab type, usually on glide layers; they are initiated artificially or by cornice collapse.

[2] Snow Course Survey Center is a station for gaging the amount of snow and water content, maintained by the Soil Conservation Service.

TABLE II. AVERAGE MONTHLY TEMPERATURES AND PRECIPITATION, AND MAXIMUM AND MINIMUM TEMPERATURES AT FORSYTHE RANCH BELOW BRIDGER BOWL IN THE BRIDGER RANGE, MONTANA, 1951-1967.

Month	Average Precipitation in inches	Average Temperature	Maximum Temperature	Minimum Temperature
January	2.54	20.5°F.	31.3°F.	9.8°F.
February	2.28	23.9	34.9	12.9
March	3.09	26.0	38.5	13.5
April	2.95	34.9	46.8	23.1
May	4.19	44.5	57.6	31.4
June	4.63	51.9	66.2	37.7
July	1.39	58.8	76.3	41.3
August	2.08	57.4	75.1	39.7
September	2.88	51.0	68.4	33.6
October	2.81	42.0	55.6	28.4
November	2.50	29.3	40.6	17.9
December	2.54	28.4	33.9	12.9

SNOW MOVEMENT IN BRIDGER BOWL

Snow movement can be classified into three types: avalanches, creep, and glide.

Avalanches, rapid snow movements, are subdivided into loose snow and slab avalanches. Loose snow avalanches start from a point or very small area; as they descend, they fan out and pick up additional snow and form billowy clouds of snow. They occur in fresh powder snow with little internal cohesion, and leave a poorly-defined path. This type is rare in Bridger Bowl.

Slab avalanches originate from a fracture-line perpendicular to the fall-line of the slope. They are characterized by large amounts of snow with considerable internal cohesion moving as a single mass, and they leave an easily distinguishable slide path. Typically, blocky debris collects at the downhill end as the avalanche halts. Slab avalanches can occur with snow of nearly any moisture content.

Bridger Bowl has frequent slab avalanches throughout the winter and spring. Some are triggered naturally when cornices collapse and fall from the ridge top or rim of North Bowl. Others form from unstable snow conditions as a result of very rapid accumulation of snow by wind or during a storm. Presently, the majority of avalanches are artificially triggered, either by shooting or blasting. This activity allows for removal of unstable snow that may threaten the safety of a ski slope. The fracture lines for the artificially initiated avalanches are near the upper parts of North Bowl and South Bowl, or other slopes where rock ledges begin. These are usually slab avalanches where the unstable snow layer slides on more stable layers underneath (surface type).

According to records of snow movement kept by the Earth Science Department at Montana State University, most of the avalanches, both natural and artificially triggered, are a slab surface type. Many avalanches have run on thin glide layers one to five inches above the ground, and only one avalanche in ten years was observed to run absolutely on the ground. Small sluffs occur frequently; these tend to stabilize snow layers and prevent snow build-up.

Since snow has a somewhat plastic nature, it can flow slowly down a slope under the influence of gravity; this is snow creep or glide. The snow can either flow within itself (creep), or slide along the ground surface (glide), or both. A fracture line usually forms at the top of the snow mass which is slowly creeping or gliding downhill. Glide and creep occur particularly on a smooth slope where trees, large rocks, or other obstructions to inhibit movement are lacking. The convex open slope near number 15 on Figure 2 exhibits glide at least once a year.

METHODS OF ANALYSES

For investigating the herbaceous vegetation of both open and tree-covered slopes, 2x5 dm plots were used (Daubenmire, 1958). A cord 50 meters long, with ten beads spaced at five-meter intervals, was placed on the ground, extending up and downhill, and was anchored at both ends. The number of individuals and canopy coverage by class of each taxon were recorded for each plot at each bead. Cover class is determined by estimating the percentage of the ground in the plot that would be covered by a polygon extended down from the natural foliage. Classes are 0-5, 5-25, 25-50, 50-75, 75-95, and 95-100 per cent cover. On narrow strips of ground, such as small fingers or narrow ridges, only ten plots were taken; this gives an actual plotted area of one square meter. For wider slopes, the cord was moved one way or the other from the first line for the second series of ten plots, giving an observed area of two square meters; the series were then averaged for slope data.

Tree data were obtained by using the quarter method (Phillips, 1959). The same 50-meter cord was extended through the center of the tree stands. At each point, quadrants were envisioned, and the taxon and diameter at breast height (dbh) of the closest living tree within five meters in each quadrant were recorded. If the closest tree was dead, had already been counted, or was more than five meters away from the point on the cord, it was not recorded. 2x5 dm plots were surveyed at each bead for field layer analysis.

Surface soil samples from nine sites were analyzed for pH, conductivity, organic matter percentage, available phosphorus and potassium, and soil texture by the Soil Testing Laboratory at Montana State

University.

In order to establish possible differences in winter soil temperatures under various kinds of vegetation, a recording thermograph was installed in South Bowl from 19 October to 24 November, 1967. The site was at an altitude of 6600 feet, with an 18° slope and an east-southeast exposure. The recording mechanism had three thermometers attached to it, each on a 12-foot wire. The thermometers were each buried six inches deep, one under a bare rocky spot about one foot in diameter, the second under dried herbaceous vegetation, the third in the middle of a small <u>Abies lasiocarpa</u> stand.

Figure 3. Cornice at top of ridge, site 2, 1 April, 1967. The trees extend 2 meters above snow 2-3 meters deep.

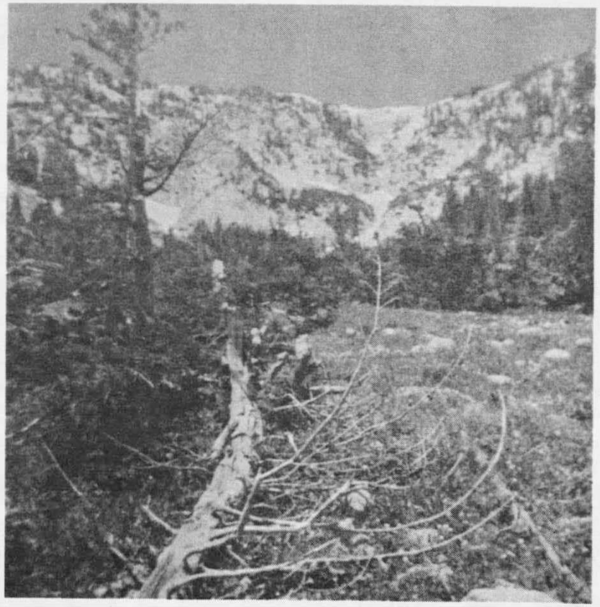

Figure 4. Similar view, 10 July, 1967. Figures 3 and 4 face west, on ridge between deep gullies.

RESULTS AND DISCUSSION

Open Slopes

The vegetation of the open slopes seems to show no correlation with snow movement. Nearly the same taxa appear throughout the Bridger Bowl area, although the numbers and stature of the plants decrease as altitude increases.

The dominant taxon on the open slopes is Artemisia ludoviciana, with an average relative frequency of 57 and cover percentage of 8.42. It is conspicuous in the landscape throughout the growing season. Geranium viscossissimum, Achillea millefolium, Arabis spp., Bromus spp., and Viola praemorsa each have a frequency of over 20. Grasses, Agrostis scabra, Dactylis glomerata, Elymus virginicus, Poa spp., Phleum pratense, and Melica spectabilis, have a combined frequency of 72 and provide about 5% cover. A complete list of taxa is given in Table V, Appendix B.

Two locations, the upper part of Avalanche Gulch, site number 8, and the upper part of site number 2, vary somewhat from the other open slopes. Many species found on other slopes are absent, and local concentrations of Arenaria congesta occur with high frequency and cover percentage (Table VI, Appendix B).

Erythronium grandiflorum, Claytonia lanceolata, Ranunculus eschscholtzii, Viola praemorsa, and Mertensia oblongifolia (in wetter locations) dominate the spring aspect in June and early July. Veratrum viride, Delphinium occidentale, and composites (Aster spp., Rudbeckia occidentalis, Senecio canus, and others) are most conspicuous in gross appearance of open slopes below 7400 feet in late August.

The forbs and grasses, with the exceptions of a few low-stature plants like Polygonum douglasii and Microsteris gracilis, are perennial or biennial plants. In two regions of creep and glide, sites 7 and 15, Figure 2, the vegetation is dominated by the same forbs and grasses that are dominant on slopes where surface slab avalanches occur, and where there is no snow movement at all. These two situations indicate the lack of specificity between herbaceous vegetation and snow movement.

Tree Stands

Tree stands above 7000 feet are dominated by Abies lasiocarpa (subalpine fir), with a few Pinus flexilis (limber pine) interspersed. Trees in avalanche paths are exclusively Abies and Pinus. The major field layer taxa in the damaged Abies stands are Thalictrum venulosum, Achillea millefolium, Galium boreale, with several grasses: Bromus spp., Elymus virginicus, Poa spp., Phleum pratense, Melica spectabilis. The list of taxa in damaged Abies stands is given in Table VII, Appendix B.

The damaged tree stands in North Bowl and South Bowl are located below and among accumulations of angular limestone boulders of the Madison Group which forms the ridge top. The boulders range from one foot to four feet in diameter, and decrease in size and depth of accumulation as one ascends from the Abies stands. They have presumably been deposited by avalanches and gravity. The bowls decrease in slope from 40° to 20° or less toward the bottoms, and this is where the trees and rocks have accumulated (Figure 5).

The accumulation of boulders may be responsible for the formation of the tree stands. Generally, the trees in the Bridger Bowl area are on convex slopes or ridges, or are well below the avalanche zone. Tree seedlings may have become established below boulders and were able to survive the winter avalanches. The growth of trees may have contributed to more rock accumulation, which afforded more protection for more seedlings.

In Bridger Gully (site 14) a damaged _Abies_ stand does not have the boulders above it, but it is located on a mound of soil within the avalanche path. Perhaps less avalanche stress occurs on the elevated mound than in the lower surrounding gullies, allowing establishment of tree seedlings.

The other damaged _Abies_ stands are on ridges adjacent to lower troughs which serve as funnels for most of the avalanching snow (sites 1 and 2, Figure 2). Boulders on site 16 have apparently provided some protection for seedling and tree establishment.

Deep snow accumulation, running water during spring snow melt, and rock, soil and snow movement occur on the concave slopes above 7000 feet. These phenomena may have discouraged the formation of tree stands in these sites that are now covered with herbaceous plant communities.

The snow-damaged _Abies_ stands are characterized by downhill trunk curvature, dense horizontal branch growth within 1.5 meters of the ground, and sparse branching above this height. The trees have few or no branches, especially on the uphill side, from a height of 1.5 to 3 meters. Above 3 meters, there are usually short battered branches on all sides. Since there is almost no shading from upper branches, lower branches are able to continue growth. The weight of winter snows contributes to their lying close to the ground. Maximum height of both

Abies and Pinus in avalanche-damaged stands is less than 5 meters, and the average diameter is about one decimeter (Table VIII, Appendix B).

The bare middle sections of the trees is caused partly by avalanche snow breaking off lateral branches, and also by the abrasion of wind-borne ice crystals. A one-foot rock wedged between two trees at a height of 1.4 meters gives evidence for the damage by and transporting action of moving snow. The tops of many trees have been broken off at two or three meters and have been carried away; they are not lying at or near the branched bases.

The downhill curvature of the damaged Abies is within 1.5 meters of the ground. Snow creep is responsible for most of the curvature, although in some cases, soil creep is a contributing cause.

The undamaged Abies in the stand more or less continuous around the north and west sides of part of Avalanche Gulch have no low branches, and normal branch growth to the top. Their average diameter is about 1.4 decimeters and they reach heights of 14 meters. Ages of trees in damaged and undamaged Abies stands are comparable, ranging from seedlings to trees of at least 50 to 60 years old. An old dead Pseudotsuga in the undamaged stand has a diameter of one meter.

The field layer under the undamaged Abies stand is dominated by Astragalus miser, Viola praemorsa, Arnica latifolia, Besseya wyomingensis, and Mertensia oblongifolia, with some grasses and lichens (Table IX, Appendix B). Shading by the trees is quite complete. Taxa tolerant of less direct sunlight and more moisture are more common here than in the damaged Abies stands where there is little shade.

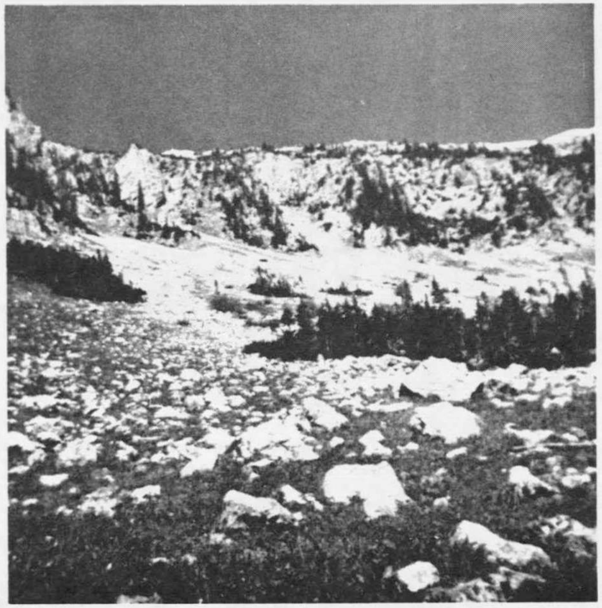

Figure 5. Damaged <u>Abies</u> stand and limestone boulder accumulation. North Bowl, 7 July, 1967.

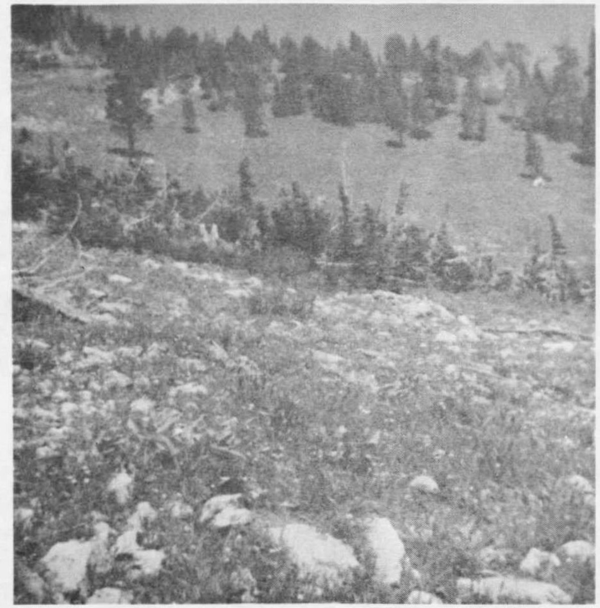

Figure 6. <u>Abies</u> stand in avalanche path with undamaged <u>Abies</u> and Pseudotsuga on adjacent ridge. North Bowl, facing north.

Pseudotsuga menziesii, Douglas fir, occurs above 7000 feet in sites not affected by avalanches, and is found alone or in small clumps. Below 7000 feet, it is the dominant tree taxon, forming nearly pure stands containing seedlings to trees more than 100 years old. Old Pinus flexilis are present in small numbers. None of the Pseudotsuga stands have any avalanche damage.

The field layer of Pseudotsuga stands varies somewhat with altitude. Above 6500 feet, the dominant field layer taxa are Bromus inermis, Thalictrum venulosum, and Galium boreale. Compared to the Abies stands, the amount of bare ground is less and fewer taxa are in the field layer (Table X, Appendix B).

Tree Rings

Potter (personal communication, 1968), while investigating rock glaciers in the Absaroka Mountains in Wyoming, felled a large tree, from a stand near an avalanche path, that had irregular rings on one side indicating a period of avalanche stress several years ago. It was felt that the same procedure in Bridger Bowl might indicate avalanche history here; that is, a normal-appearing tree in an undamaged stand could have abnormal growth for a part of its history which would indicate that avalanches had occurred in the past where they do not now run.

An interesting vegetational pattern exists at the base of the north-east side of Bridger Peak. Sparse stands of avalanche-damaged Abies lasiocarpa occupy about an eighth-mile path between creek beds hidden by tree debris and shrubs. On the north and south sides of the severely damaged Abies are small ridges between creek beds that contain stands of

Abies and _Pseudotsuga_ that show only slight signs of damage -- some bare uphill sides, trunk curvature, and basal branch growth. North and south of the less-damaged stands are undamaged stands of old _Pseudotsuga_ with some _Pinus flexilis_.

A specimen of normal-appearing _Abies_ from the less-damaged stand was felled and examined for irregular growth rings. They were all normal and ranged in width from 1 to 3 mm in width. The tree was 63 years old.

Another _Abies_ tree, from the ridge at the base of site 2, the unnamed avalanche path, was felled and its bole examined. It was about 56 years old. It was thought that this normal-appearing tree might indicate years of severe avalanching where more snow travelled on top of the ridge than at the present time. Again, the growth rings were normal on all sides and averaged 1 to 3 mm in width.

Annual rings of _Abies_ specimens from avalanche paths range in width from 0.3 to 1.5 mm.

Increment cores obtained from undamaged _Pseudotsuga_ trees adjacent to avalanche paths showed no annual ring irregularities that might be attributed to avalanche stress. These cores are interpreted to indicate that avalanche patterns have been similar to the present for at least 60 years.

Soils

The results of the soil analyses by the Soil Testing Laboratory are summarized in Table III. The soil pH and conductivity values were all within a range suitable for plant growth. Organic matter percentages for the open slopes are in the very low to low range. The organic matter content of the soil under the undamaged Abies stand is much higher than on open slopes. Field observation indicated no consistent pattern of differences between snow movement paths and areas of no snow movement; this opinion is substantiated by the results of the soil analysis.

Table IV reports the daily maximum and minimum temperatures of the soil in South Bowl, at a depth of six inches, from 20 October to 24 November, 1967. Missing dates are days when the paper was changed or when the thermograph mechanism stopped. About eight inches of snow fell 23-24 October, and snow accumulated after those dates to a depth of two feet on the two sites on open ground. The snow depth reached a maximum of three inches under the trees.

Snow cover appears to stabilize the soil temperatures close to the freezing point. Before 25 October, the average daily fluctuation for the bare spot was 3.6°, compared with 1.5° for the vegetated site and 0.9° under the trees. Snow cover decreased the daily variations to 0.7° or 0.6° on all sites. Average temperatures are slightly higher under vegetation, herbaceous or trees, than under the bare spot while snow-covered.

Absorption of radiant heat by the tops of the plants and shading of the ground prevented the vegetated ground from heating as much as bare ground on days when there was no snow cover. Minimum temperatures tended to be slightly higher in soil with some kind of plant cover.

From these results, it seems that the presence of vegetation, whether sparse herbaceous or tree cover, influences heat retention by soil during winter snow cover slightly better than completely bare ground. Whether this difference is significant in forming and maintaining avalanche tracks is doubtful, although this may be a point for further investigation. Avalanche paths are similar to this small test plot, with areas of bare ground and rocks from one inch to several feet in size adjacent to plant-covered ground of about the same range of dimensions. The minute temperature variations could affect metamorphosis in basal snow layers and thus influence snow movements.

Snow under trees is usually stable. Snow accumulation depth is less under trees than in open areas, and the trees inhibit creep and glide.

TABLE III. RESULTS OF SOIL ANALYSES BY THE SOIL TESTING LABORATORY, MONTANA STATE UNIVERSITY.

Site	Vegetation	Soil pH	Organic Matter %	Available Phosphorus	Available Potassium	Soil Texture
UNDAMAGED TREES						
9. Upper Face	*Pseudotsuga*	7.5	unable to determine	v. low	medium	clay loam medium
8. Avalanche Gulch	*Abies*	6.7	32.8	v. low	medium	organic
PATHS OF SNOW MOVEMENT						
8. Avalanche Gulch	Forb-grass	7.7	3.4	low	high	clay loam medium
15. New Terminal	Forb-grass	6.4	3.8	high	high	sand loam medium
2. Unnamed Gulch	Forb-grass					
	Damaged *Abies*	6.7	3.6	v. low	high	silt loam medium
8. Avalanche Gulch	Forb-grass	7.5	2.4	low	medium	silt loam medium
NO SNOW MOVEMENT						
9. Upper Face	Forb-grass	7.1	3.1	medium	high	clay loam medium
9. Upper Face	Forb-grass	7.5	0.3	v. low	medium	sand loam medium
11. North Meadows	Forb-grass	7.6	5.0	high	high	clay loam medium

TABLE IV. DAILY MAXIMUM AND MINIMUM SOIL TEMPERATURES IN °C. OF THREE SITES: BARE GROUND, HERBACEOUS-VEGETATED, AND TREE-COVERED.

Date	Bare Ground Max	Bare Ground Min	Herbaceous Vegetated Max	Herbaceous Vegetated Min	Tree Covered Max	Tree Covered Min
Oct. 20	10.0	4.5°C.	7.5	4.5°C.	7.0	5.2°C.
21	10.0	6.5	7.5	6.0	7.5	7.0
22	7.0	5.5	6.0	5.5	7.0	6.5
23	5.0	3.0	5.5	3.5	6.0	4.5
24	4.5	3.0	5.0	3.8	5.0	4.8
25	3.5	2.5	3.8	3.0	4.8	4.0
27	1.0	0.0	1.0	0.7	1.5	1.0
Nov. 3	0.0	-0.5	0.9	0.2	1.0	0.5
4	1.0	0.0	1.0	0.5	0.5	0.2
5	1.0	1.1	1.2	0.8	1.5	0.1
6	1.0	0.0	1.0	0.0	0.5	-1.0
7	1.0	0.0	0.7	0.2	0.0	-1.0
8	1.0	1.1	0.9	0.2	0.5	0.0
10	2.0	1.5	2.5	2.0	2.2	2.0
11	2.0	2.0	2.5	2.2	2.5	2.0
12	2.0	2.0	2.8	2.2	3.0	2.5
13	2.0	2.0	2.5	2.2	4.0	3.0
14	2.0	1.5	2.5	2.1	4.0	4.0
15	3.0	1.5	3.0	2.1	4.5	3.1
17	2.5	1.0	3.0	2.0	3.0	2.8
18	2.5	1.5	2.8	1.9	3.0	2.5
19	1.5	1.0	2.1	1.5	3.0	2.0
20	1.5	1.0	2.0	1.5	2.2	1.5
21	1.5	1.0	2.0	1.8	2.0	1.5
23	-0.5	-0.5	0.2	0.0	0.2	0.0
24	1.0	0.0	1.0	0.5	0.5	0.0
Averages:						
Oct. 20-25	7.8	4.2	5.9	4.4	6.2	5.3
Oct. 27-Nov. 24	1.5	0.8	1.8	1.2	1.9	1.3

Figure 7. Herbaceous vegetation and undamaged <u>Abies</u> and <u>Pseudotsuga</u>. South Bowl, site 7.

Figure 8. Soil profile. 2.5 meters deep. Road cut in Upper Face, site 9.

CONCLUSIONS

Vegetational development and soil and snow movement in the Bridger Bowl area have been coincident since the end of the most recent glacial period. Soil creep and flow are responsible for building some mounds or ridges where tree stands are located. Most topographic ridges support undamaged tree stands. The heavily forested zones of the lower altitudes (5500-7000 feet) are areas of less snow accumulation and are generally below altitudes where avalanches regularly occur.

The west side of the ridge has less snow, partly because it is the windward side and the snow blows over the ridge top to be deposited on the east side. Heavy tree cover on the west side also decreases snow deposition at ground level.

According to the Forest Service Avalanche Handbook (1961), avalanche hazards are greatest in mountain areas with the following characteristics:

1. Presence of steep gullies and steep open slopes.
2. Slope angle between 25° and 60°.
3. Slopes whose profiles are convex in vertical plane (especially favorable for slab avalanches).
4. Smooth grassy slopes where there are no outcrops or large boulders to interfere with a sliding surface.
5. Lee slopes where snow deposition is greater than on windward slopes and where cornice formation is prevalent.

The Bridger Bowl slopes that have regular snow movement fit this entire pattern almost perfectly, and presumably have been topographically similar since the end of glacial time. The plant communities and patterns of vegetation that have developed here seem to be a result of the total environment of the area, and not a cause of snow movement patterns.

The gullies and troughs in the avalanche paths in the Bridger Bowl area appear to have been formed by water erosion, particularly during spring snow melt. The concave bowls that avalanche frequently are of glacial origin. The troughs and bowls show no evidence of being tree-covered recently. Increment cores from trees at least 60 years old adjacent to avalanche paths have normal tree-ring development.

Trees have become well established on certain convex slopes with no present avalanche activity and with little water erosion. Trees have reached sizable growth immediately adjacent to and below present avalanche paths. Occasional avalanches larger than usual can uproot or damage these marginal trees. However, the general patterns of tree stands, herbaceous vegetation, and snow movement paths seem to have developed concurrently as a permanent, natural condition in the Bridger Bowl area.

APPENDIX A

GEOLOGIC DESCRIPTION OF THE BRIDGER RANGE

The Bridger Range is in Townships 1, 2, and 3 North, Townships 1 and 2 South, Ranges 5, 6, and 7 East, in Gallatin County, Montana. The highest peaks are Sacajawea, 9665 feet, and Bridger Peak, 9162 feet.

Bridger Bowl Ski Area is located in Township 1 North, Range 6 East, Sections 24 and 25; and Township 1 North, Range 7 East, Sections 19 and 30. The ski slopes range from 6000 to 8100 feet in altitude.

Streams draining Bridger Peak are the headwaters of Slushman Creek. Intermittent streams in Bridger Bowl form headwaters of Maynard Creek. Both creeks are tributaries of Bridger Creek that flows south through Bridger Canyon, then east in the Gallatin Valley to empty into the East Gallatin River.

The Bridger Range, part of the Rocky Mountains in Montana, was formed during two phases of folding and faulting, before which the region was submerged. Laramide orogeny, with east-west compression in mid-Paleocene time, produced north-trending structures. A subsequent period of quiescence occurred, followed by late Paleocene or early Eocene deformation which developed north-northwest trending structures by further folding and faulting caused by a south-southeast to north-northwest compressional force. Isostatic arching during Oligocene time produced normal faults on the west side of the Bridger Range, and down-dropped the adjacent Gallatin Valley. Movements and deposition have continued sporadically to the present (McMannis, 1955).

Pleistocene glaciation shaped much of the Bridger Range topography visible today. Localized ice masses gouged out wide circular depressions, such as North Bowl and South Bowl in the Bridger Bowl Ski Area.

Mud flows and debris avalanches have contributed tongue-like rubble masses that extend down the eastern mountain slopes as far as Bridger Creek. They are partly dissected by modern drainage streams.

APPENDIX B

TABLE V. TAXA OF THE ARTEMISIA LUDOVICIANA-DOMINATED OPEN SLOPES.

Taxon	% Average Frequency[1]	% Canopy Cover[2]	Density[3]	% Relative Density[4]
Artemisia ludoviciana	57	8.42	54	10.34
Grasses[5]	72	3.36	57	10.92
Achillea millefolium	40	4.08	47	9.00
Geranium viscossissimum	24	3.72	7	1.34
Bromus inermis	23	0.48	11	2.11
Viola praemorsa	21	1.51	7	1.34
Antennaria spp.	18	1.67	29	5.56
Ranunculus eschscholtzii	18	1.93	9	1.72
Melica spectabilis	17	0.38	31	5.94
Besseya wyomingensis	16	2.04	6	1.15
Valeriana dioica	14	1.45	7	1.34
Mertensia oblongifolia	11	1.70	4	0.77
Galium boreale	11	0.82	1	0.19
Arenaria congesta	11	0.53	12	2.30
Potentilla glandulosa	10	1.17	4	0.77
Microsteris gracilis	10	0.55	11	2.11
Delphinium bicolor	10	0.77	3	0.57
Helianthella uniflorus	9	2.43	10	1.92
Bare ground	97	31.23		
Litter	83	8.36		

[1]Average frequency is the percentage of 2x5 dm plots in which the taxon was found.

[2]Canopy cover is the percentage of ground covered by a taxon, found by extending a polygon downward from the plant foliage.

[3]Density is the number of individuals per square meter.

[4]Relative density is the number of taxon individuals divided by the total number of all plants, expressed as a per cent.

[5]Grasses included are: Poa pratensis, Poa spp., Bromus inermis, B. marginatus, Agrostis scabra, Phleum pratense, Elymus virginicus, Dactylis glomerata.

TABLE V. Continued.

The following taxa occurred on the open slopes with an average frequency of less than 10, and with low values for canopy cover, density, and relative density:

Aquilegia flavescens
Artemisia spp.
Aster engelmannii
Aster spp.
Astragalus miser
Carex spp.
Claytonia lanceolata
Lichens and mosses
Lupinus sericeus
Thalictrum venulosum
Agoseris auranticum
A. glauca
Allium brevistylum
Amelanchier alnifolia
Anemone multifida
Arnica cordifolia
A. latifolia
Balsamorrhiza sagittata
Campanula rotundifolia
Castilleja miniata
Cirsium arvense
Clematis hirsutissima
Delphinium occidentale
Epilobium angustifolium
Eriogonum umbellatum
Erythronium grandiflorum
Hackelia floribunda
Hedysarum sulphurescens
Heracleum lanatum
Hydrophyllum capitatum
Linum perenne
Lithophragma parviflora
Lithospermum ruderale
Lomatium ambiguum
L. cous
L. macrocarpum
Monarda fistulosa
Perideridia gairdneri
Pedicularis paysoniana
Phacelia hastata
Plantago major
Polygonum douglasii
Ribes setosum
Rubus parviflorus
Rudbeckia occidentalis
Sedum stenopetalum
Selaginella densa
Senecio canus
Shepherdia canadensis
Spiraea betulifolia
Taraxacum officinale
Thlaspi arvense
Townsendia parryi
Tragopogon dubius
Polemonium pulcherrimum
Trifolium hybridum
Urtica dioica
Veratrum viride
Zygadenus elegans

TABLE VI. TAXA, BARE GROUND, AND LITTER OF THE <u>ARENARIA</u> <u>CONGESTA</u>-DOMINATED OPEN SLOPES.

Taxon	% Average Frequency	% Canopy Cover	Density	% Relative Density
Arenaria congesta	78	9.91	188	30.52
Achillea millefolium	64	6.44	74	12.01
Arabis spp.	63	5.47	17	2.76
Besseya wyomingensis	37	3.17	7	1.14
Artemisia ludoviciana	30	1.75	23	3.08
Townsendia parryi	28	3.00	16	2.44
Melica spectabilis	23	0.88	9	1.46
Viola praemorsa	20	1.91	5	0.81
Arnica latifolia	20	1.06	5	0.81
Sedum stenopetalum	20	0.50	14	2.27
Delphinium bicolor	18	0.40	2	0.32
Lithospermum ruderale	18	0.75	8	1.30
Lomatium cous	17	1.69	48	7.79
Thlaspi arvense	15	0.69	3	0.49
Geranium viscossissimum	13	1.28	3	0.49
Artemisia spp.	13	0.63	8	1.30
Grasses[1]	13	3.19	89	14.45
Eriogonum umbellatum	10	2.60	11	1.79
Lupinus sericeus	10	1.28	6	0.97
Erigeron sp.	10	0.88	4	0.65
Erythronium grandiflorum	10	0.69	3	0.49
Bromus inermis	10	0.25	6	0.97
Bare ground and rock	100	26.75		
Litter	83	6.18		

[1]Grasses include: <u>Poa</u> spp., <u>Bromus</u> spp., <u>Phleum pratense</u>, <u>Agrostis scabra</u>.

The following taxa occurred with an average frequency of 5 or less, and have low values for canopy cover, density, and relative density:

Anemone multifida
Hackelia floribunda
Campanula rotundifolia
Lomatium ambiguum
Taraxacum officinale
Thalictrum venulosum
Tragopogon dubius
Mertensia oblongifolia
Zygadenus elegans

TABLE VII. TAXA, BARE GROUND, AND LITTER IN FIELD LAYER OF AVALANCHE-DAMAGED *ABIES LASIOCARPA* STANDS.

Taxon	% Average Frequency	% Canopy Cover	Density	% Relative Density
Thalictrum venulosum	60	5.46	16	4.97
Achillea millefolium	37	1.92	17	5.28
Grasses[1]	25	2.42	52	16.18
Galium boreale	25	3.08	18	5.59
Carex sp.	18	3.63	57	17.71
Moss	17	2.58		
Aquilegia flavescens	17	2.00	8	2.48
Arabis spp.	17	1.04	2	0.62
Astragalus miser	17	1.46	6	1.87
Erythronium grandiflorum	15	0.42	3	0.93
Geranium viscossissimum	15	1.21	3	0.93
Amelanchier alnifolia	13	2.38	4	1.24
Epilobium angustifolium	10	0.46	2	0.62
Linum perenne	10	0.67	8	2.48
Bare ground and rock	73	24.71		
Litter	87	34.25		

[1]Grasses include: *Phleum pratense*, *Elymus virginicus*, *Bromus* spp., *Dactylis glomerata*, *Poa* spp.

The following taxa occur with an average frequency of less than 10, and have low values for canopy cover, density, and relative density:

Anemone multifida
Arenaria congesta
Arnica latifolia
Artemisia spp.
Aster spp.
Aster engelmannii
Balsamorrhiza sagittata
Besseya wyomingensis
Castilleja miniata
Cirsium arvense
Clematis columbiana
Delphinium bicolor
D. occidentale
Equisetum arvense
Cystopteris fragilis
Hackelia floribunda
Hydrophyllum capitatum
Lichens
Lithophragma parviflora
Mertensia oblongifolia
Pedicularis paysoniana
Potentilla glandulosum
Ranunculus eschscholtzii
Ribes setosum
Rubus parviflorus
Rudbeckia occidentalis
Sedum stenopetalum
Selaginella densa
Senecio canus
Shepherdia canadensis
Taraxacum officinale
Thlaspi arvense
Townsendia parryi
Trifolium hybridum
Valeriana dioica
Viola praemorsa

TABLE VIII. COMPARISONS OF SIZES AND DENSITIES OF TREES IN TREE STANDS.

A = *Abies lasiocarpa*
Pi = *Pinus flexilis*
Ps = *Pseudotsuga menziesii*

Tree Stand	Ave. Diameter in decimeters			Maximum Height in meters			% more than 1 dm in diameter			Number per quarter series		
	A	Pi	Ps	A	Pi	Ps	A	Pi	Ps	A	Pi	Ps
Damaged *Abies*	1.09	1.06	--	5	5	--	16.23	11.11	--	32	1	--
Undamaged *Abies*	1.43	1.50	--	14	14	--	67.11	44.45	--	27	3	+
Undamaged *Pseudotsuga*	--	2.13	1.57	--	16	16	--	75.00	57.14	--	6	35

TABLE IX. TAXA, BARE GROUND, AND LITTER OF FIELD LAYER OF UNDAMAGED *ABIES LASIOCARPA* STANDS.

Taxon	% Average Frequency	% Canopy Cover	Density	% Relative Density
Galium boreale	45	3.67	39	14.55
Viola praemorsa	36	1.85	8	2.98
Astragalus miser	33	4.78	41	15.30
Lichens	27	1.55		
Grasses[1]	27	0.57	6	2.24
Arnica latifolia	21	5.73	21	16.27
Achillea millefolium	21	2.68	25	9.32
Mertensia oblongifolia	21	3.10	13	4.85
Besseya wyomingensis	20	1.72	6	2.24
Arabis spp.	18	2.49	12	4.47
Senecio canus	15	1.25	8	2.98
Thalictrum venulosum	15	1.65	6	2.24
Townsendia parryi	15	0.72	4	1.49
Microsteris gracilis	12	0.20	1	0.37
Hydrophyllum capitatum	12	0.31	2	0.74
Arenaria congesta	12	1.06	9	3.36
Lomatium cous	12	0.33	1	0.37
Bare ground and rock	82	24.32		
Litter	88	31.89		

[1] Grasses include: *Poa* spp., *Bromus* spp., *Phleum pratense*, *Melica spectabilis*.

The following taxa occurred with a frequency of less than 10, and had low values for cover, density, and relative density:

Anemone multifida
Aquilegia flavescens
Artemisia spp.
Aster engelmannii
Castilleja miniata
Cirsium arvense
Claytonia lanceolata
Cystopteris fragilis
Heuchera cylindrica
Lithophragma parviflora
Lithospermum ruderale
Lupinus sericeus
Moss
Ranunculus eschscholtzii
Sedum stenopetalum
Thlaspi arvense
Valeriana dioica
Polemonium pulcherrimum
Ribes setosum
Taraxacum officinale
Zygadenus elegans

TABLE X. TAXA, BARE GROUND, AND LITTER OF FIELD LAYER OF PSEUDOTSUGA MENZIESII STANDS ABOVE 6550 FEET.

Taxon	% Average Frequency	% Canopy Cover	Density	% Relative Density
Bromus inermis	75	12.13	75	59.26
Galium boreale	4	5.75	32	9.63
Thalictrum venulosum	4	5.88	16	5.37
Spiraea betulifolia	3	2.50	7	4.32
Carex sp.	1	1.50	25	6.17
Geranium viscossissimum	2	2.38	3	0.93
Valeriana dioica	2	1.63	3	0.93
Hedysarum sulphurescens	1	1.50	5	1.11
Bare ground and rock	30	5.50		
Litter	100	44.00		

The following taxa have an average frequency of less than 1, and low values for canopy cover, density, and relative density:

Achillea millefolium
Aquilegia flavescens
Delphinium occidentale
Epilobium angustifolium
Erythronium grandiflorum
Lichens
Mitella sp.
Pedicularis paysoniana
Phleum pratense
Potentilla glandulosum
Rudbeckia occidentalis
Viola praemorsa
Zygadenus elegans

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