SNOW AVALANCHES AND VEGETATION PATTERN IN CASCADE CANYON, GRAND TETON NATIONAL PARK

Robin S. Patten
and
Dennis Knight
Department of Botany
University of Wyoming
Laramie

Snow avalanches are an important factor in the landscape of Cascade Canyon, influencing both the vegetation types and their distribution. The relationship between avalanches and vegetation is most apparent in the conifer woodlands. Large-conifer woodlands are found primarily outside of avalanche areas while essentially all of the Small-conifer woodlands are within avalanche areas. This suggests that Small-conifer woodlands are created and maintained by avalanches. Slope aspect is also important in the vegetation pattern of Cascade Canyon. Environmental conditions resulting from the aspect of the slope affect vegetation distributions and potentially reduce the importance of avalanches in structuring vegetation patterns, especially on the south-facing slope.

Shrub Cover and Conifer Density

Shrub cover and conifer density in the avalanche communities of Cascade Canyon can be influenced by avalanche frequency. The resilient nature of the shrub growth form allows them to withstand repeated avalanche occurrence, potentially increasing their density as avalanche frequency increases (Butler 1979, Cushman 1981, Butler 1985, Johnson, Hogg, and Carlson 1985, Johnson 1987). The fact that shrub cover is not related to elevation or avalanche frequency on the south-facing slope of Cascade Canyon may be due to the drier, more rocky conditions that exist on this slope.

Species composition in Cascade Canyon appears to be site specific, not a function of avalanche frequency. Shrub species on Cascade Canyon tracks are similar to the species on avalanche tracks in other parts of the Rocky Mountains. Shrubs such as Sorbus scopulina, Menziesia ferruginea, Salix sp., and Vaccinium membranaceum were common on avalanche tracks in Cascade Canyon and have also been found on tracks in Montana (Stauffer 1976, Butler 1979) and Washington (Cushman 1981).

Conifer density in Cascade Canyon is not adversely affected by frequent avalanches. This observation differs from the results of other studies on similar sized trees in avalanche tracks (Butler 1979, Johnson 1987). It is possible that the frequency of avalanches is relatively high throughout the tracks in Cascade Canyon, so that no increase in conifer density occurs, even in runout zones.

Conifer Growth and Survival

Despite the fact that avalanches do not adversely affect conifer density, they do have an impact on other aspects of conifer growth and survival. Conifer survival in avalanche tracks is partly a function of tree diameter. Because of the relationship between size and breakage, trees can continue to grow with little probability of being destroyed until they reach a certain size, approximately 10 cm dbh. Beyond this point, an avalanche will probably destroy the tree. In areas of low avalanche frequency, trees have a better chance of growing beyond the critical diameter due to the length of time between successive avalanches, yet these trees will have a high probability of breaking when the next avalanche does occur. In areas of high avalanche frequency there is little chance trees will be able to survive at diameters greater than 10 cm dbh without being destroyed by the constant avalanches (Johnson, Hogg, and Carlson 1985, Johnson 1987).

The analysis of conifers in avalanche tracks demonstrates the importance of the small size and slow growth rates of these trees. Because the trees are slow growing, they can live a relatively long time before reaching a size where they are likely to be destroyed by an avalanche. For example, a tree growing at .15 cm/year dbh that was 10 years old at breast height will be 77 years old when it reaches 10 cm dbh. The persistence of conifers, a function of their slow growth rates and small size, helps maintain the community despite frequent avalanche occurrence.

The relationship between avalanche frequency and conifer size and growth rates explains how conifer persistence can vary with avalanche frequency. Avalanches affect the average size of conifers in a community in two ways (Figure 17). They directly affect the average tree size of a stand through the constant removal of trees larger than 10 cm dbh. This type of thinning occurs almost continuously at a high avalanche frequency, removing only one or two trees at a time rather than causing extensive damage within the stand. Avalanches also appear to indirectly affect average tree size by reducing growth rates, potentially as a result of repeated stress from disturbance. As avalanche frequency increases, average growth rates decrease, so that trees remain at small sizes for longer periods of time. Because conifer damage is size related, these stands of small trees are less likely to be damaged or show changes in stand structure, thus less change occurs in communities where avalanche frequency is high. Longer lived conifers also have more time for seed production. This leads to the possibility that selection for slow growth genotypes could occur in avalanche tracks, although I have no data to support this speculation.

The idea that the maintenance of stand structure is related to avalanche frequency is not new. Others have demonstrated that communities are maintained where avalanche frequency is high and that periodic destruction is more likely to occur in areas of lower avalanche frequency (Cushman 1981, Butler 1985, Johnson 1987). The results presented here help explain how conifer stands can persist despite avalanche occurrence and how potential change in stand structure is related to avalanche frequency.

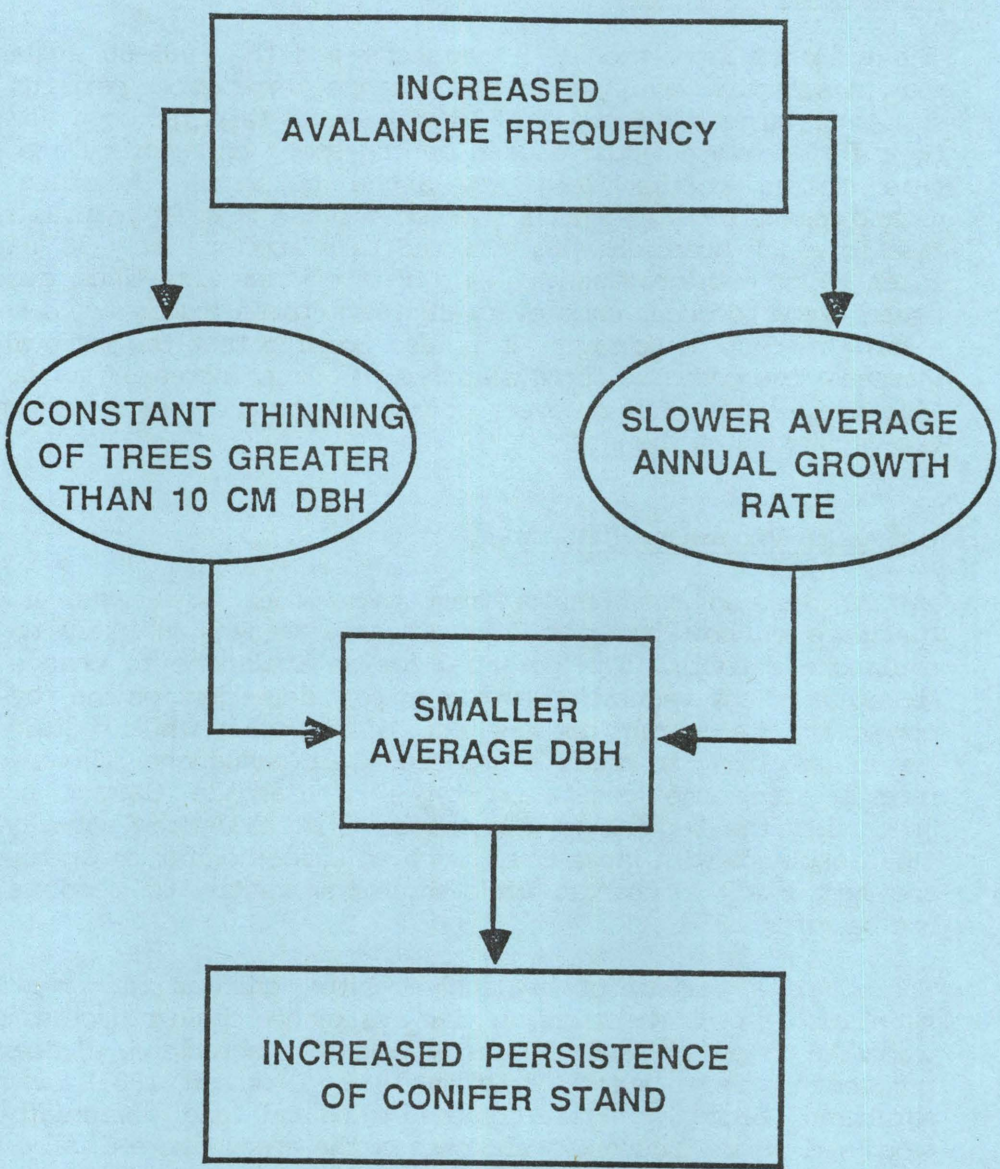

Figure 17. Summary of the relationship between the persistence of conifers within a stand and avalanche frequency. A high avalanche frequency causes both the average dbh and growth rate of conifers to decrease, reducing the potential for avalanche damage. Thus, conifers persist for a longer period of time in stands where the avalanche frequency is high.

Destructive Avalanches

The evidence from the 1971 avalanche and the 1985-86 avalanches indicates that destructive avalanches may change vegetation patterns by destroying stands of large conifers. How long it would take for such areas to return to their former state would depend on the speed of recovery and the interval of time before another large avalanche occurred. Assuming that seedling establishment occurs within a year or two and that 10 years is required for the tree to reach breast height, it would take approximately 30 years for trees to reach 10 cm dbh, growing at a rate of .6 cm/year dbh. Thus, even if destructive events were to occur once every 35 years, these stands would be susceptible to a large amount of damage. It is also possible that the removal of large trees increases the potential for avalanches to occur, increasing avalanche frequency. This might inhibit full recovery of the forests and create permanent changes in the vegetation at the site.

Change in Vegetation Pattern

By synthesizing the results from these four objectives, it is possible to speculate on how the mosaic of Cascade Canyon is likely to change due to avalanche activity. The potential for an avalanche to change the community structure of any vegetation type is in part dependent on the physiognomy of the community, i.e., shrubs are resilient to avalanches while conifers larger than 10 cm dbh are likely to break if impacted by an avalanche. This information can be used to rank the vegetation types of Cascade Canyon in terms of the probability the vegetation will change if an avalanche actually occurs (Figure 18). Woodlands with large trees, such as Large-conifer or Cottonwood woodlands are most likely to change, while shrub communities or meadows probably would not be affected.

There are a variety of avalanche-related changes that may occur in these vegetation types. Major destructive avalanches could reduce some Large-conifer woodland to either Small-conifer woodland or shrubland. Succession might then proceed in these areas (Stauffer 1976, Cushman 1981), with possibly Low shrubland becoming Small-conifer woodland and eventually Large-conifer woodland. More frequent avalanches in the areas where Small-conifer woodlands occur would maintain these stands by constantly removing trees larger than 10 cm dbh. This does not mean that tree damage in Small-conifer woodlands never occurs, or that stand structure is constant, but the vegetation type would remain the same. If an avalanche did not occur for a number of years in an area of Small-conifer woodland, it is possible some of this type would grow large enough to be classified as Large-conifer woodland. The conifers in avalanche areas, even in runout zones, grow at most around .2 cm/year dbh. At this rate the trees in the Small-conifer woodland could grow from 10 cm dbh to 20 cm dbh in 50 years. This is not likely to occur given the present avalanche frequency in areas of Small-conifer woodland, yet it is possible that some Small-conifer woodland might become Large-conifer woodland with time.

Although some vegetation types are not directly affected by avalanches, they may still change with time. Establishment of conifers in some areas might cause

RANK	COVER TYPE
1.	LARGE-CONIFER WOODLAND
2.	COTTONWOOD WOODLAND
3.	SMALL-CONIFER WOODLAND
4.	ASPEN-CONIFER WOODLAND
5.	MATTED-FIR WOODLAND
6.	ASPEN SHRUBLAND
7.	ASPEN WOODLAND
8.	TALL SHRUB
9.	LOW SHRUB
10.	RIPARIAN MEADOW
11.	TALUS
12.	BEDROCK

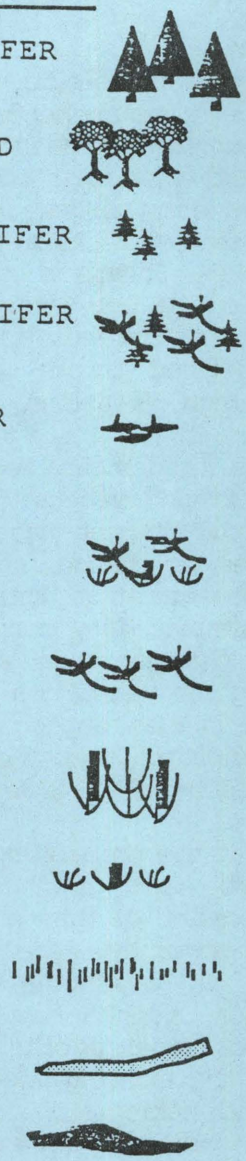

Figure 18. The vegetation types of Cascade Canyon ranked in order of the probability of change if impacted by an avalanche. The symbols are the same as those used in Figures 19 and 20.

shrublands to become Small-conifer and Aspen-conifer woodlands. Some talus might be stabilized and covered by Low shrublands or Matted-fir woodlands, and aspen establishment in Low shrublands might increase the area of Aspen shrubland type. These changes could occur but probably would not affect large areas.

Elevation is also important in considering how vegetation patterns may change, as it is directly related to avalanche frequency. Stand structure is more stable at higher elevations on avalanche tracks where avalanche frequencies are greater (Figure 17), and therefore communities at upper elevations are less likely to change than communities in runout zones. It also appears that avalanches have more stable tracks at higher elevations, with less variation in their path on upper slopes. If this is true, the forests outside established tracks at high elevations would be less likely to be affected by an avalanche than forests outside of tracks on the valley floor. The combination of high avalanche frequency and well defined tracks would result in less overall change in vegetation patterns at high elevations.

Cascade Canyon can be divided into regions of relative probability of change in vegetation, based on existing vegetation types and elevation (Figure 19). The south-facing slope of the Canyon has more area covered by vegetation types with lower probabilities of change, and site conditions other than avalanche frequency often control vegetation distributions on this aspect. In contrast, the north-facing slope is dominated by conifer woodlands, a vegetation type with a higher potential for change, thus avalanche frequency is probably more important in structuring the vegetation on this slope as other conditions are less limiting. Less change is also expected at upper elevations on both aspects. These considerations indicate that the valley floor is most likely to change while the upper south-facing slope is least likely to change through time.

This is not to imply that the probability of change due to avalanche occurrence is constant throughout each of the five zones. Topographic position is important, since the possibility that an avalanche can even occur is largely a function of existing topography. Areas under snow-collecting basins are more likely to be hit by an avalanche that areas under a cliff face, i.e., Large-conifer woodlands under a basin are more likely to be destroyed than Large-conifer woodlands under a cliff. The probability of change also varies within zones based on the existing vegetation. This variation can be seen in a transect along the south-facing slope of Cascade Canyon (Figure 20). Spatial changes in overlying topography and existing vegetation create variation in the potential for change. This is a simple example, as many factors are involved in both the potential for an avalanche to occur and the probability that vegetation will change, but it illustrates the variation found within any of the five designated zones of Cascade Canyon.

Cross-sections of Cascade Canyon at 50 year intervals demonstrate how these potential changes might actually occur through time (Figure 21). The cross section in Figure 21A illustrates the existing community types across one section of Cascade Canyon. The asymmetry of the valley is apparent, with a lower cliff face and rocky, drier conditions on the south-facing slope is an avalanche track with Small-conifer woodlands in the runout zone. The small

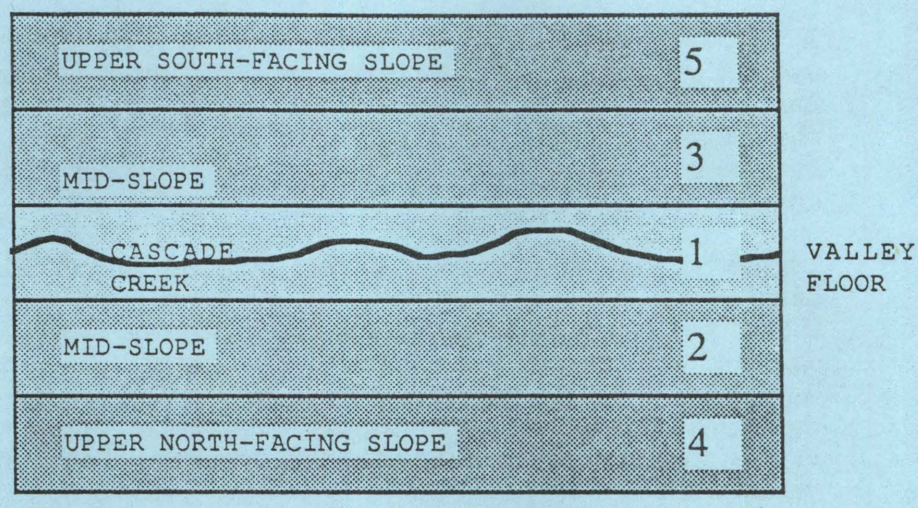

Figure 19. A conceptual aerial view of Cascade Canyon showing the valley divided into five regions based on slope aspect and avalanche frequency. These regions are ranked from 1, the most likely to show vegetation changes, to 5, the least likely to change. The valley floor has the highest probability of change due to low avalanche frequencies. The upper south-facing slope is least likely to change due to high avalanche frequencies and an abundance of low shrub and aspen communities.

area of Large-conifer woodland on the south-facing slope is part of the 1% of this vegetation type found in avalanche areas, consisting of a small patch of Douglas fir. The north-facing slope has frequent avalanches down to approximately 2380 m. This track is vegetated by Small-conifer woodland.

A possible cross-section 50 years later (Figure 21B) shows changes in the vegetation near the valley floor. A destructive avalanche has destroyed the Large-conifer woodland. Some growth has occurred in the small conifers at low elevations, but they have not reached a size where they will break with avalanches. Growth has been slow in trees on upper slopes, and they show little change.

Further change may occur in another 50 years (Figure 21C). Small conifers now exist where Large-conifer woodland had been. The trees in the runout zone of the south-facing avalanche track have been destroyed after exceeding 10 cm dbh, and a few trees in the north-facing track have broken, also after growing beyond the critical diameter. Throughout this time no change has occurred in the vegetation of the upper south-facing slope, where the dominant vegetation is low shrubs and small aspen. The greatest change has taken place on the valley floor.

It is possible to speculate on how changes related to avalanche occurrence might affect the vegetation cover of the entire Canyon mosaic, assuming no change in the present disturbance regime. By examining the Cascade Canyon vegetation map, the location and area of potential changes were identified, based on the discussion above. The changes in actual cover by each vegetation type were then calculated for two 50-year intervals (Table IV). Two major, destructive avalanches were assumed to occur within each time period, along with frequent avalanches within established avalanche tracks. The end result shows little change in the vegetation cover of Cascade Canyon due to avalanche activity. Even after 100 years, the most any vegetation type changes is 1%. It appears that the frequency and abundance of avalanches in the Canyon, and the fact that avalanches tend to recur in the same position due to topographic controls, results in a fairly stable landscape. Avalanches are important in maintaining the landscape mosaic and, although small changes in vegetation result from their occurrence, they do not cause major changes in the existing vegetation mosaic.

Avalanches are not the only disturbance that occurs in Cascade Canyon. Debris flows are common (Fryxell and Horberg 1943) and often occur in the same tracks where avalanches run. Summer storms may create flash floods. There is no evidence of major fires in the Canyon, but small fires do occur, with the largest recorded since 1924 affecting only .1 ha. Other factors which may be unrelated to disturbance, such as moisture and nutrient availibility, are also important to the vegetation in Cascade Canyon. While avalanches may not be the only factor in structuring this landscape, the results of this study indicate they are important.

A final consideration on the significance of avalanches in Cascade Canyon is their contribution to the habitat quality of the area. Because avalanches are significant in structuring the landscape, they help to maintain the diversity of

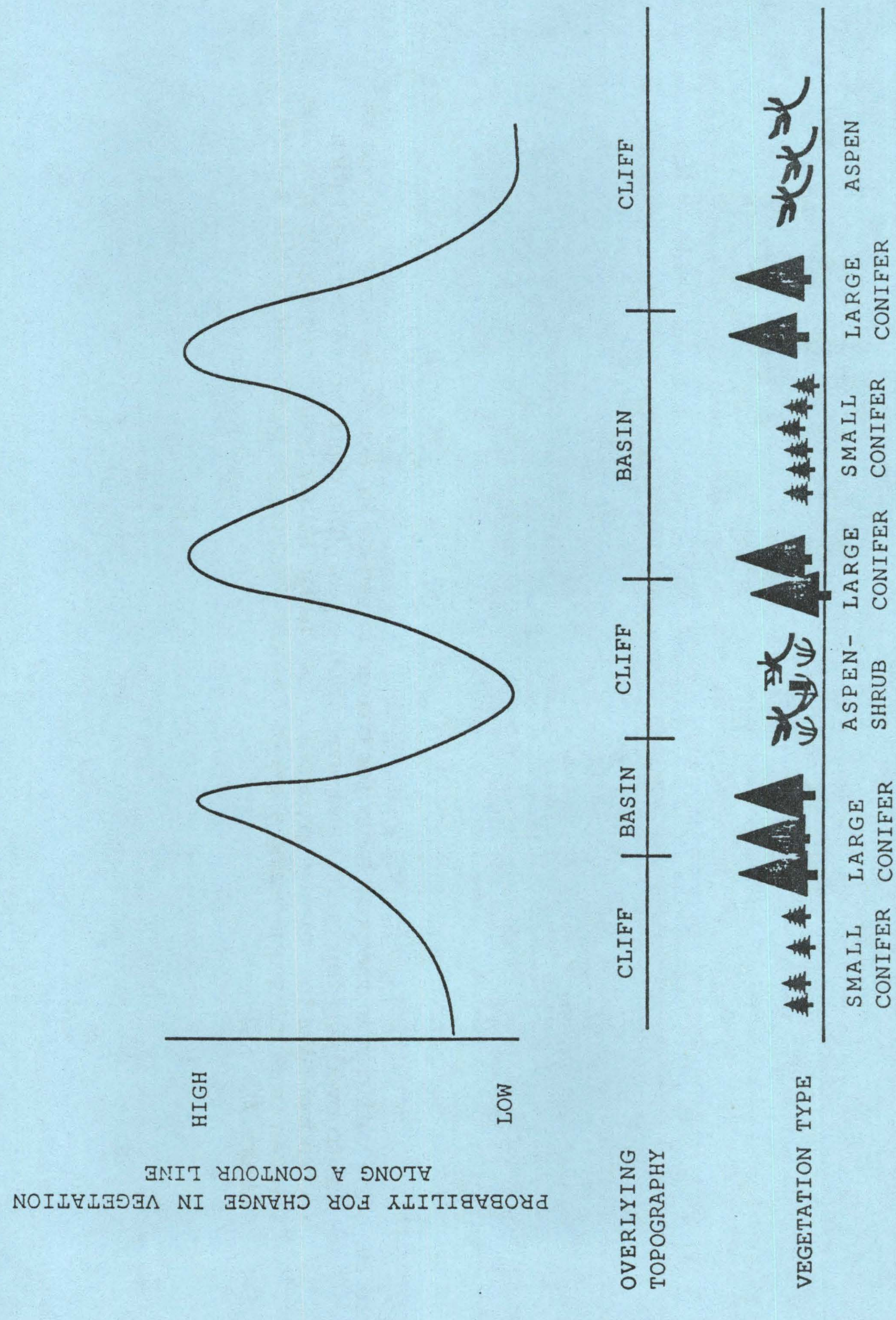
PROBABILITY FOR CHANGE IN VEGETATION
ALONG A CONTOUR LINE
HIGH
LOW
OVERLYING
TOPOGRAPHY
CLIFF
BASIN
CLIFF
BASIN
CLIFF
VEGETATION TYPE
SMALL
CONIFER
LARGE
CONIFER
ASPEN-
SHRUB
LARGE
CONIFER
SMALL
CONIFER
LARGE
CONIFER
ASPEN

Figure 20. The variation in the probability for change in vegetation across the slope that occurs due to overlying topography and vegetation types. The graph above the vegetation types indicates the relative probability for change at any point along the contour line. (Taken from the south-facing slope of Cascade Canyon, perpendicular to line A-B on Figure 7).

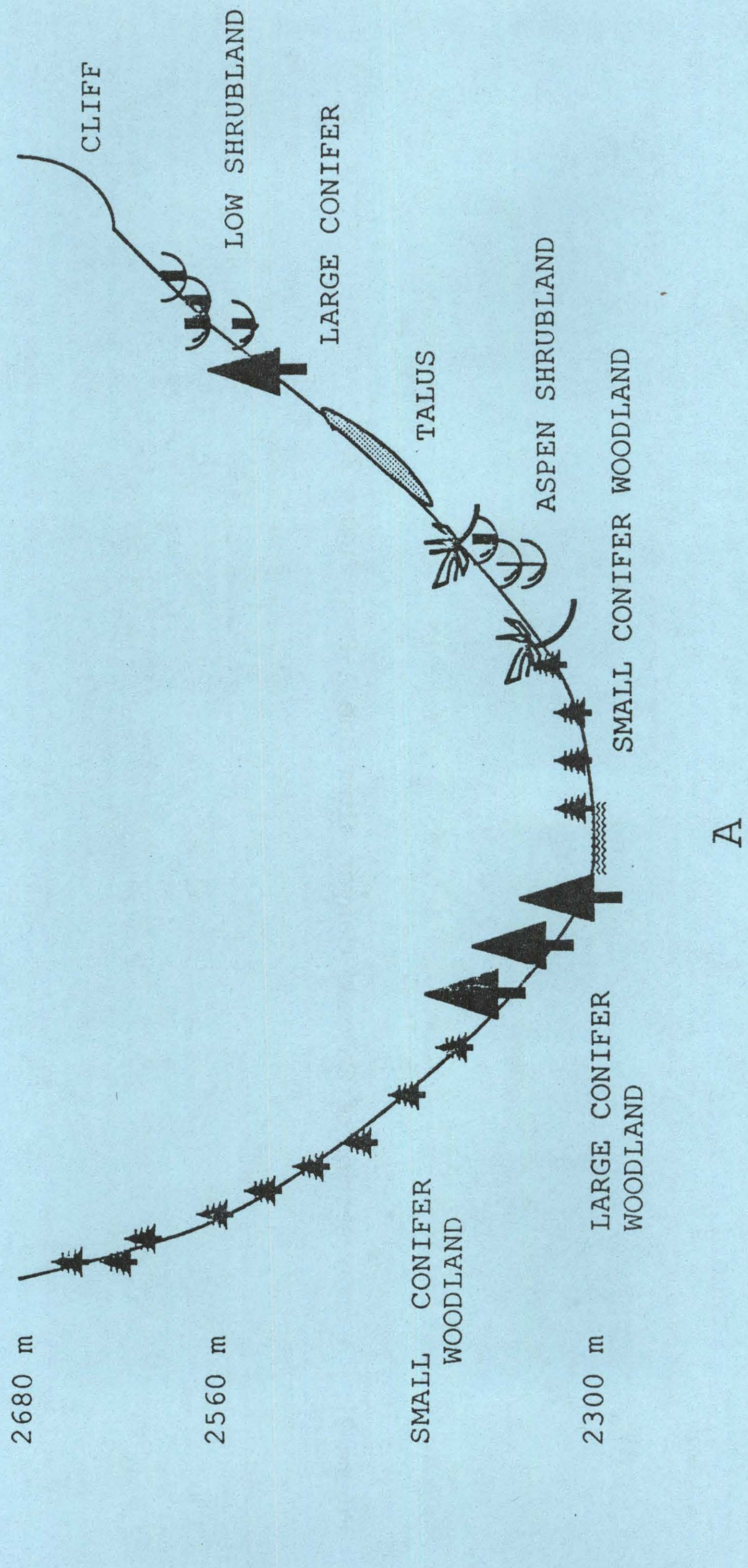

Figure 21A. Existing conditions in Cascade Canyon and changes that might occur.

Figure 21. A cross-section of Cascade Canyon, from line A-B on Figure 2.

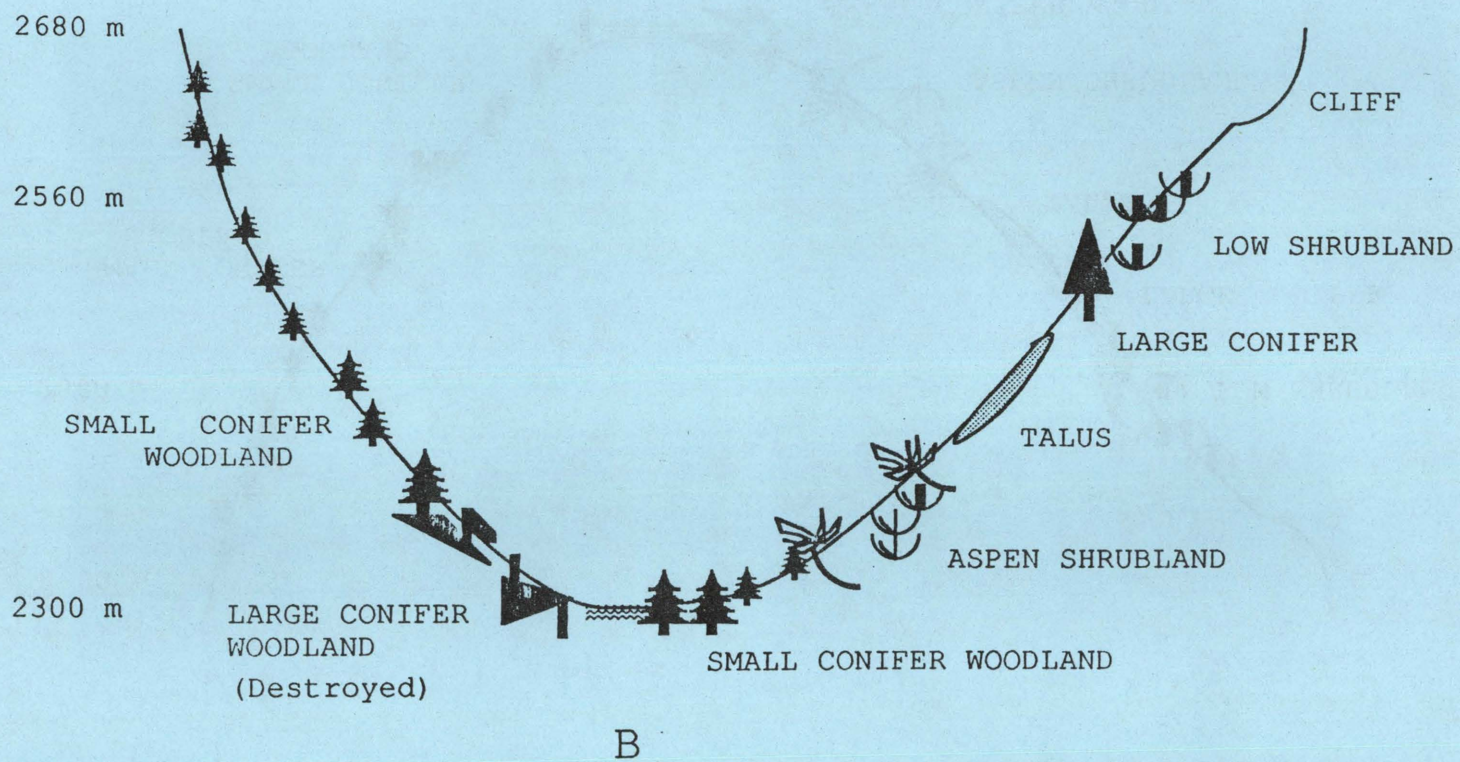

Figure 21B. 50 years after.

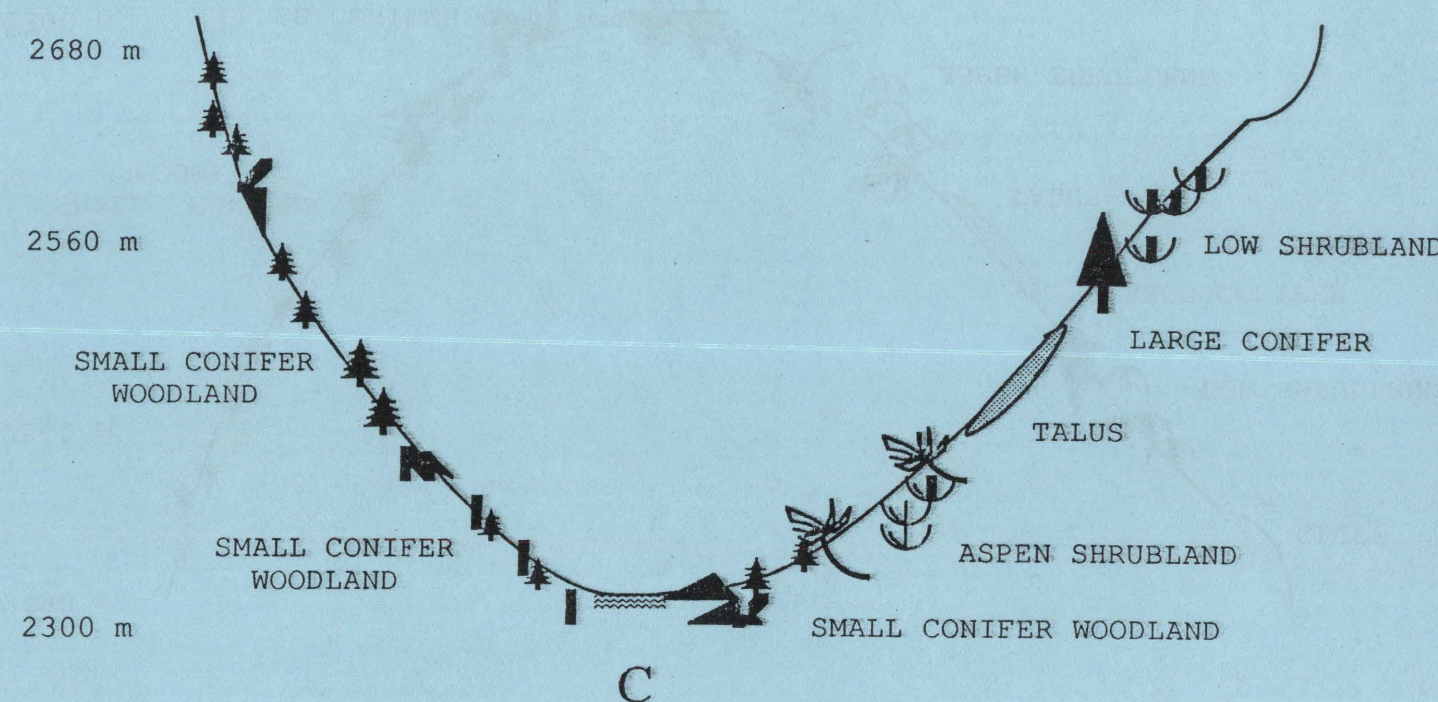

Figure 21C. 100 years after.

Table IV. Potential changes in percent cover of each vegetation type due to avalanche occurrence. See text for description of how changes might occur. The landscape of Cascade Canyon is fairly stable, with little change in vegetation cover through time.

COVER TYPE	PRESENT	% OF TOTAL AREA 50 YEARS FROM PRESENT	100 YEARS FROM PRESENT
Large-conifer woodland	35	35	34
Small-conifer woodland	28	28	28
Talus	13	13	13
Low shrubland	5	5	5
Aspen shrubland	5	5	4
Bedrock	4	4	4
Aspen-conifer woodland	3	4	4
Matted-fir woodland	2	2	2
Tall shrubland	2	1	2
Riparian meadow	2	2	2
Aspen woodland	1	1	1
Cottonwood woodland	<1	<1	<1

vegetation found in the Canyon. This diversity is important to the wildlife that depend on a variety of vegetation types, e.g., the moose in the Canyon that often browse the shrubby vegetation in avalanche tracks while using the neighboring forests for cover. This is further evidence of the importance of avalanches in the landscape of Cascade Canyon.

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