In: Vegetatio v.19 p. 192-207. 1969

VEGETATIONAL PATTERN NEAR ALPINE TIMBERLINE AS AFFECTED BY FIRE-SNOWDRIFT INTERACTIONS[1])

by

W. D. BILLINGS

Department of Botany,
Duke University, Durham, North Carolina, U.S.A.

Unexplored and almost uninhabited until scarcely more than a century ago, the central Rocky Mountains today provide an opportunity to assess the impact of modern man on mountain environments and vegetation. Side by side with areas which have been burned, grazed, or lumbered are remnants of essentially undisturbed ecosystems which can serve as baselines for the evaluation of change. Such a situation exists in the Medicine Bow Mountains of Wyoming (41°15'N, 106°15'W) where climax spruce-fir (*Picea-Abies*) subalpine forests adjoin large areas of successional vegetation which have followed great forest fires of the 19th century.

These mountains extend northward from the mountain complex of Colorado as a forested peninsula some 85 km long surrounded by semi-arid grasslands and shrub steppe. It is a narrow range (ca. 32 to 35 km wide) which rises abruptly from the high plains (elev. ca. 2,450 m) to a maximum elevation of 3,660 m. The upper, or alpine, timberline characterized by krummholz is at ca. 3,350 m and is not sharply defined. The lower, or arid, timberline coincides with the base of the mountains at ca. 2,450 m. Thus, the forests occur only in this relatively narrow montane belt of ca. 900 m between alpine vegetation above and the dry grasslands below.

The climate of the Medicine Bow Range is cold and continental. While there are no long-term climatic data available from the upper part of the range, short-term records (BLISS 1956, LINDSAY 1967) show that the winters are very cold (minima down to at least —45° C) and the summers cool (daytime maxima 10°—20° C, minima often below freezing especially in subalpine valleys). Precipitation increases with elevation, the subalpine zone receiving about 650 to 750 mm per year; most of this is in the form of winter and spring snowfall. Summer thundershowers occur almost daily, but rainfall from these showers is generally light; and as the summer progresses soil moisture decreases rapidly, the air becomes very dry, and drought stress is usually present by August except below snow-

[1]) The research was supported by National Science Foundation Grant GB-1219 and the Duke University Council on Research.

banks. Westerly winter and spring winds are especially strong, often averaging 40 to 50 km per hour for weeks at a time (LINDSAY 1967). Such winds blow the snow off exposed ridges and pile it in great drifts on the lee slopes and in the forests and subalpine meadows. Summer winds are usually lighter and less steady but still have a strong westerly component. They are often very dry, can be gusty, and contribute to the spread of forest fires.

Such fires have always been a part of the Rocky Mountain forest environment even in Indian times. Over periods as long as two or three thousand years, almost no areas have remained untouched by fire. However, there are forested areas which have escaped burning for periods of many centuries; these are occupied by spruce-fir forests in which the trees are 300—500 years old. Since spruce-fir forests follow earlier successional stages, this would indicate a fire-free period of at least 6 or 7 centuries. Other nearby forests, however, have been destroyed by fire more than once in that same period of time. Prehistoric fires were started mainly by lightning although the Indians were probably responsible for some. With the coming of trappers, miners, and lumbermen in the latter half of the 19th century, the incidence of fires increased remarkably. Large areas were devastated during this time. The 20th century has brought increased numbers of people to these mountains, and therefore more fires. However, forest fire control provided by the U.S. Forest Service has kept the fires smaller and has saved the forests from being completely destroyed. The effects of fire in the Medicine Bow have not been confined to the destruction of the forests but have extended to changes in snowdrift pattern, energy balance, and local hydrologic budgets.

FOREST VEGETATIONAL TYPES

Given two or three thousand years protection from completely destructive forest fires (this does not rule out occasional ground fires which do not kill the trees), the forest vegetation of the Medicine Bow Mountains would be largely a subalpine forest of spruce (*Picea engelmannii*) [1]) and fir (*Abies lasiocarpa*) with some admixture of lodgepole pine (*Pinus contorta*). The structure of this climax *Picea-Abies* forest has been described by OOSTING & REED (1952). Moister places may have clonal patches of *Populus tremuloides* while dry, south-facing slopes are usually dominated by *Pinus flexilis*. Only *Picea* and *Abies* go to timberline where they both form a wind krummholz a meter or two high. *Populus* reaches its upper

[1]) Nomenclature in this paper is that of WEBER (1961) insofar as the species are included by him.

limit at about 3,050 m while the two pine species drop out within the next hundred meters. Occasional seedlings of the pines occur above 3,200 m but are very rare and apparently do not survive.

Below 3,000 m, except in very rocky or very wet places, the forest forms an almost continuous cover. Above this elevation, both wet and dry subalpine meadows become more numerous. However, there are still extensive areas of closed forest up to about 3,300 m on steep slopes. Above this latter elevation on gentle slopes or plateaus, the forest tends to occur in elongated strips (Fig. 1) which have a north-south alignment approximately perpendicular to the direction of the westerly winds. The strips are usually 10 to 50 m

Fig. 1. Ribbon-forest and snow-glade patterns on West Flat Top Mt. (elev. 1,950 m) in Glacier National Park, Montana, Lat. 48°50′ N. Top of picture is west. Photograph by Ernest Hartley.

across but may be several hundred meters long. Between the forest strips are narrow bands of moist or wet subalpine meadow ranging from 25 to 75 m across (Fig. 2). I have been calling this type of forest "*ribbon forest*" and the meadow strips "*snow glades*" since these meadows appear to be the result of snow piling up in great drifts in the lee of each ribbon forest strip. In typical subalpine ribbon forest, the oldest spruce trees have trunks up to 1 meter in diameter and heights up to 15 to 18 meters.

ARNO (1966) has observed a similar phenomenon in the Bitterroot Mountains along the Idaho-Montana boundary. Here, a single ribbon-forest stand ca. 3 m wide and up to 9 m high extends for several hundred meters along a windswept ridge. Snow accumulates behind this ribbon in a large drift and prevents forest growth. ARNO described this stand as an "arborescent hedge-row".

With increasing elevation and wind-exposure, the ribbon forests give way to very open and disjointed ribbons of spruce and fir krummholz separated by moist alpine tundra replacing the subalpine snow glade meadows. The ribbon pattern is visible at timberline but more vaguely than below. Moist alpine tundra, dominated by *Geum rossii*, *Polygonum bistortoides*, *Deschampsia caespitosa*, and many other species, thus surrounds the krummholz "islands" as a matrix and represents the lowest alpine vegetation. Above this indistinct timberline of krummholz islands is a variety of alpine vegetational types which have been described by BLISS (1956).

VEGETATIONAL CHANGES AFTER FIRE

When fire sweeps through the closed spruce-fir forests of the middle mountain slopes, it usually destroys everything above ground. Such fires have burned through a hundred or more km² of these subalpine forests in the Medicine Bow region within the last century or two. HANNA (1934) states that the largest of these fires was set by the Ute Indians during the Indian wars of the late 1860's and that as a result large areas "are still destitute of trees". These treeless burned areas are near timberline and my dendrochronologic evidence (from cross-sections of fire-scarred living trees) indicates that these areas were burned earlier (ca. 1766, 1774, 1809) by smaller fires probably caused by lightning. There may have been Indian caused fires in the late 1860's since from 1865 to 1868 there were many severe Indian attacks in the region (HOMSHER 1965). However, it seems more likely that the largest fires occurred in the summer of 1871 when because of smoke the Medicine Bow Mountains could not be seen from Laramie for a period of two months (*Laramie Daily Sentinel*, Sept. 8, 1871). Because of the continuous nature of the forest, fires on the lower and middle slopes

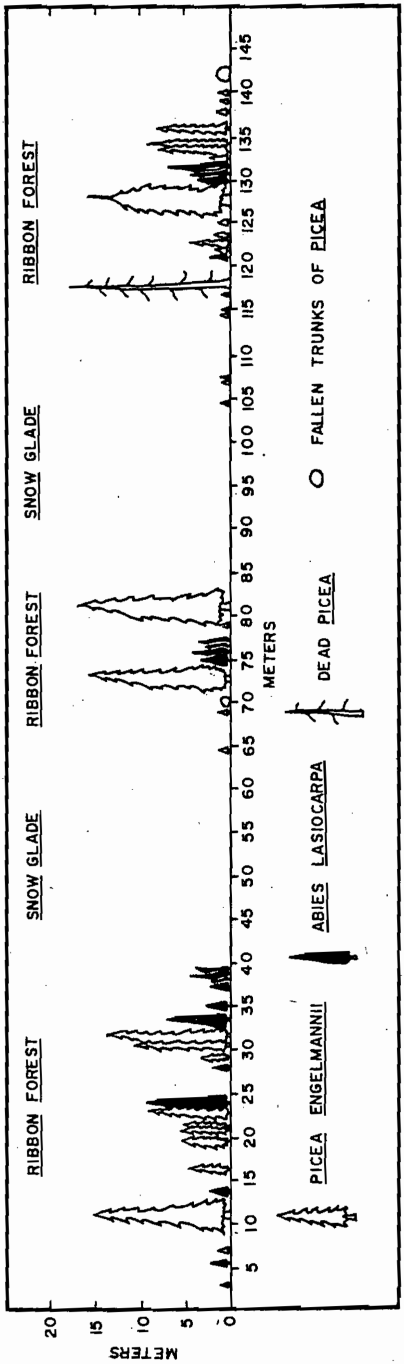

Fig. 2. Profile of ribbon forests and snow glades at an elevation of 3,260 m near East Telephone Lake, Medicine Bow Mts., Wyoming. True azimuth of line: 80°.

of the mountains are likely to be larger than those nearer timberline where ribbon forests prevail and the moist snow glade subalpine meadows provide natural firebreaks.

Extensive fires on the lower and middle slopes are followed rather quickly in a few years by a re-invasion of lodgepole pine (*Pinus contorta*). This species dominates the successional forest in the first 50 to 100 years almost to the exclusion of other species. If seed trees are close and abundant, these pine stands can be even-aged and dense to the extent of severe stunting, e.g., trees 80 years old, 2 to 3 cm in diameter, less than 3 m tall, and spaced as many as 20 trees per m^2. The usual situation, however, is for the seeding to occur over a period of several years and with wider spacing of seedlings. Such a forest after 80 to 90 years will consist usually of pines ranging from 10 cm to 30 cm in diameter and up to 15 to 20 m tall, spaced 2 to 3 m apart. Under these situations, *Picea* and *Abies* seedlings normally appear under the pine and within two or three centuries these species become dominant throughout most of the forest. Lodgepole pine does remain as a minor constituent of the spruce-fir forest; these pines act as seed trees after nearby fires. Below 3,000 m where aspen (*Populus tremuloides*) was present in or near the original forest, the aspen sprouts from its roots and is co-dominant in the successional forest with pine. However, the present climate does not allow aspen seedlings to become established.

Above 3,000 m, lodgepole pine does not regenerate and therefore burned areas remain open much longer. For 50 to 100 years, the land may be covered with wet or dry subalpine meadow as spruce and fir become established very slowly as scattered seedlings. After a century or two, the drier meadows usually are covered by young spruce-fir forest without the pine successional stage. Wet meadows above 3,000 m usually remain open indefinitely and may remain for centuries dominated only by tall herbs and shrubby willows. Climax forest, thus, from 3,000 m to ca. 3,300 m on slopes steeper than 5 or 6° is essentially a closed forest of spruce and some fir surrounding open wet meadows which occupy the topographic depressions. Succession after fire throughout this whole 3,000—3,300 m zone lacks the pine stage which is prevalent below 3,000 m. Consequently, succession is very slow and subalpine dry meadows persist for a century or more even in the lower part of the zone. In the upper parts of the zone, succession is even slower and the burned forest may be replaced by alpine tundra which will occupy the land indefinitely. STAHELIN (1943) ascribes this to relative lack of seed trees and the development of grass-sedge turf which prevents spruce and fir seed from reaching mineral soil. However, even where mineral soil is exposed, conifer reproduction is very rare.

THE RIBBON FORESTS

In contrast to the closed spruce-fir forest occurring up to 3,300 m on relatively steep or protected slopes is the open "ribbon forest" which characterizes exposed gentler slopes and flat areas between about 3,150 m and 3,325 m in the Medicine Bow. As described earlier, the "ribbons" are roughly normal to the direction of the prevailing winter winds and are relatively independent of slope direction. However, they are almost restricted to flattish areas or gentler slopes, and with their lee "snow glades" make up the vegetation of such windswept level areas just below timberline. The ribbon-forest phenomenon is fairly extensive in the Rocky Mountains occurring in similar topographic situations as far apart as Colorado and Montana (see Fig. 1).

I can only hypothesize as to the origin of ribbon forest. On a plateau or slope, the oldest ribbon would appear to have the best chance of originating as a small group of seedlings on shallow mineral soil toward the windward edge of the open area. As this forest patch grows taller, it spreads laterally by seedlings and also vegetatively. During the winters, a snowdrift will build up in the quieter air in its lee. This drift may eventually be 50 m or more across. As it melts back in the summers, it provides ideal moisture conditions for tree seedling establishment wherever its far edge happens to be late in June or early July. The part of the drift melting later than mid-July favors the moist or wet meadow vegetation of a snow glade. During the winter, tree seedlings are protected by the drift produced by the next ribbon-forest stand to windward. Because of such seedling establishment, it seems obvious that ribbon forest stands cannot be farther apart than about half the maximum width of the winter drift. The eventual effect on a windswept plateau is a series of natural "snowfences" consisting of continuous or discountinuous ribbon forests piling up snowdrifts in their lees. Immediately adjacent to the forest, the snowdrift is too deep and long-lasting for tree seedling establishment.

If old trees die in places where the ribbon forest is narrow, the wind funnels through causing a "blowout" in the drift (as in a sand dune) which allows tree seedling establishment in the snow glade. This results eventually in the creation of a bend or angle in the ribbon forest. This may be an indication that through the centuries the ribbons may break and heal, and slowly move to leeward to be replaced to windward by new ribbons. Fig. 3 is a somewhat diagrammatic map of an actual "blowout" and seedling establishment area in the ribbon forests southeast of East Telephone Lake at 3,260 m.

In the Medicine Bow, ribbon forest rarely occurs above 3,350 m.

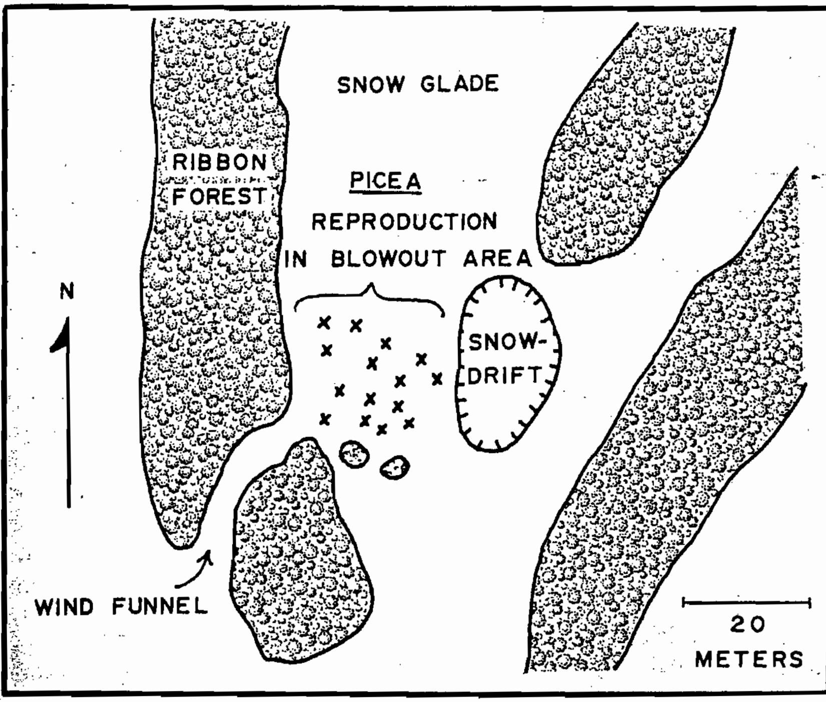

Fig. 3. Diagram showing effect of opening in ribbon forest causing wind removal of snow thus allowing spruce reproduction. East Telephone Lake, Medicine Bow Mts. Elevation 3,260 m.

Above this elevation, and even below in severely windswept places, the forest is replaced by krummholz patches with or without dwarfed flag-form trees. On relatively level areas, there is some tendency for these krummholz patches to be arranged in discontinuous ribbons as beads on a series of strings. The subalpine snow glades are replaced between krummholz strings by the more mesic types of true alpine vegetation. These inter-krummholz alpine meadows are somewhat wider than the subalpine snow glades. Isolated krummholz patches in this pattern may occur as high as 3,500 m.

Fire Effects on Ribbon Forest

Both ribbon forest and krummholz are subject to fires. Most of these are probably started by lightning. My dendrochronologic evidence from sections and cores of fire-scarred trees indicates that such fires are of fairly frequent occurrence through the centuries but that the fires are usually quite localized. They do not spread far (because of intervening snow-glade meadow or tundra) and, therefore, there is little cross-correlation of fire dates from one ribbon forest or krummholz patch to another.

Both ground fires and crown fires occur in ribbon forests; but because of the nature of krummholz, a fire there is almost always a crown fire. Ground fires may open up the understory in a ribbon forest but succession leads back to typical forest floor vegetation; the canopy of trees still dominates the environment. With this protection, *Ribes montigenum* soon provides a shrub border around the edges of the stand, snow accumulates, and within a relatively few years the vegetation and microenvironment within the ribbon forest are back to normal.

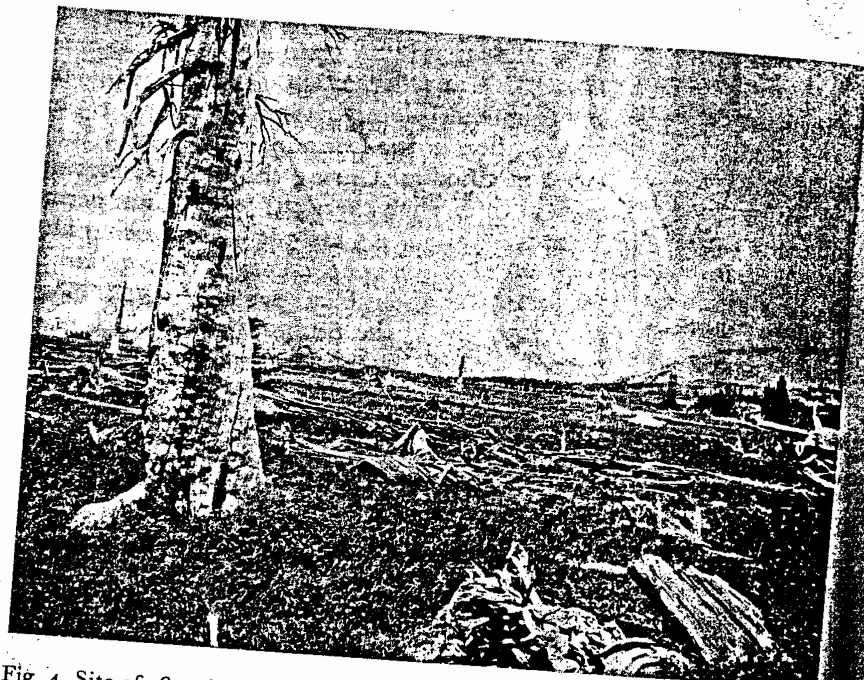

Fig. 4. Site of 1809 fire on South Libby Flats, Medicine Bow Mts., showing tre killed by fire and replacement of forest by mesic tundra. Elevation: 3,200 m 1 August 1967.

This early recovery is not the case after ribbon forest or krumm holz patches are destroyed by crown fire. The destruction of th foliage cover and the killing of the trees opens the site to the impac of the severe tundra environment. The whole radiational energy budget is changed; but this is not so important as the lack of pro tection against the full force of the wind. The principal wind effec is in winter and spring when almost constant winds, with gusts u to 150 km per hour, blow much of the snow off the burned area to new resting places farther down the mountain. The new, relatively snowless, microenvironment at soil level provides no protection fo tree seedlings against cold and winter desiccation. Moreover, summer soil moisture conditions are less favorable to forest plants without the snow meltwater — and the drying summer winds also have greater access to the site. In 1956, we installed totalizing anemometers at heights of + 65 cm in an unburned ribbon forest at 3,240 m and in an open tundra 130 m to the southeast at the same elevation. They were operated for the month 23 June to 23 July. The average wind speed for this month in the forest was 0.61 km per hour while that in the open was 11.70 km per hour, 19 times greater. LINDSAY (1967) obtained similar results in a year-long microenvironmental comparison between +1.5 m anemometers in an open station in the krummholz zone at 3,300 m and in a spruce-fir forest at 2,990 m. During the summer months, wind speeds in the open at timberline averaged 13 to 15 km per hour while those in the forest were about 1.5 km per hour. During December and January, wind speed in the open averaged over 35 km per hour while that in the forest was about 6 km per hour. Gusts of over 120 km per hour were frequent at the timberline station. It is no surprise that open tundra stations on the windward sides of ridges and plateaus are almost snow-free in winter (MARR 1961) and that this snow forms large drifts in and behind the ribbon forest.

Succession back to ribbon forest or krummholz is almost impossible in the windswept environment left after fire in such places. Instead, the site is invaded by various species of alpine and subalpine herbaceous plants which may dominate the vegetation for centuries (STAHELIN 1943, BILLINGS 1957). This occurs even though some slight protection is given by standing dead trees or fallen burned logs. These logs and standing snags themselves may remain for a century or two, relatively undecayed, because of the cold dry environment; but these are not enough to stay the wind and prevent the snow from blowing away.

The composition of this replacement herbaceous vegetation varies with substratum, elevation, and time after fire. In places, it has many of the characteristics of climax fell-field or mesic tundra vegetation. Table I presents the results of point-intercept coverage sampling in unburned vegetational types near timberline compared with data from identical samples taken nearby in successional vegetation following fire in krummholz or ribbon forest. Column A shows the composition of a fell field at 3,300 m which has never been forested or covered with krummholz. Column B lists the composition of a successional fell field nearby on the site of a fire in krummholz ribbon forest of at least a century ago. The few still-standing dead trees indicate a forest height of 9 to 10 m with trees up to 60 cm in diameter. The present vegetation is typical fell field; the species at B which are not listed in column A are common at other fell-field sites. In contrast, there is almost no species overlap of A or B with column C, the composition of forest floor vegetation at a nearby unburned ribbon forest at 3,250 m. The site of a ribbon forest fire at the slightly lower elevation of 3,200 m (column D) is covered with a more mesic type of tundra than that at site B. This site, illustrated in Fig. 4, is more protected by being on the lee side of a gentle flat ridge at the south end of Libby Flats. As a result of its topographic position, a little more snow remains. The

TABLE I

Composition (cover percentage) of herbaceous vegetation near timberline on unburned and burned sites. Determined by point-intercept method (MOONEY & BILLINGS 1961) using 283 points along diagonals of a 5×5 m. plot.

Species	A	B	C	D	E	F
Arenaria obtusiloba	12.4	3.2		0.4		
Erigeron pinnatisectus	9.5					
Trifolium parryi	6.7	24.7				
Silene acaulis	5.7	2.5				
Carex scopulorum	4.9			4.2		
Geum rossii	2.5			1.1		
Calamagrostis purpurascens	2.5	0.7				
Poa glauca	2.1	P		1.4		
Festuca brachyphylla	1.8	3.2		0.4		
Luzula spicata	1.4	1.8				
Sedum lanceolatum	1.1	1.8				
Draba sp.	0.4					
Poa alpina	P				8.5	
Phlox pulvinata	P					
Artemisia scopulorum		5.3	0.4	7.1		
Trisetum spicatum		1.4				
Polygonum bistortoides		1.4	P	7.8	11.3	
Achillea lanulosa		1.4		0.7		
Saxifraga rhomboidea	P				2.1	
Arenaria rubella	0.4					
Agrostis humilis		1.8		0.4	0.	
Potentilla diversifolia		1.4	P	2.1	4.	
Arnica cordifolia			1.4			
Sibbaldia procumbens			P	5.3	2.8	
Thlaspi alpestre			0.7	P	0.4	
Erigeron peregrinus			P	3.9	P	
Ribes montigenum			6.7			
Androsace septentrionalis			P			
Ranunculus eschscholtzii			P			
Poa reflexa			6.0			
Festuca sp.			0.4			
Cerastium arvense			1.1			
Carex sp.			0.4			

snow enables moisture-requiring species such as *Polygonum bistortoides*, *Sibbaldia procumbens*, *Ranunculus alismaefolius*, *Deschampsia caespitosa*, and *Caltha leptosepala* to dominate the site. However, a few fell-field species have invaded. The site is intermediate in wind and snow accumulation between a fell field and a snow glade (Column E). Snow accumulation at D is aided by numerous logs remaining on the ground from the fire and some dead trees still standing.

Site D was covered originally with a series of four or five ribbon-

TABLE I (continued)

Species	A	B	C	D	E	F
Angelica sp.			P	0.4		
Phleum alpinnum				3.2	0.4	
Ranunculus alismaeefolius				4.2	6.7	18.7
Lewisia pygmaea				3.2	1.1	
Carex elynoides				0.7	1.1	1.8
Deschampsia caespitosa				5.7	20.1	12.7
Juncus drummondii				3.6	2.8	0.4
Senecio crocatus				4.6	2.8	
Moss				0.7		1.1
Caltha leptosepala				5.3	6.7	27.2
Viola adunca					1.1	
Carex sp.					P	
Erigeron melanocephalus					P	
Taraxacum ceratophorum					5.3	
Plantago tweedyii					11.0	
Arnica mollis					0.7	
Veronica sp.					0.7	
Epilobium alpinum					1.1	
Erythronium grandiflorum					P	
Draba sp.						0.4
Litter	8.1	4.6	78.1	21.6	4.2	33.2
Bare soil	6.4	14.8		12.0	3.5	0.4
Rock	34.6	29.3			0.4	
Wood		0.4	4.9	0.4		1.1
Water						2.5

Column
- A — climax fell-field vegetation (Sta. No. 67—3)
- B — successional fell-field vegetation after krummholz fire (Sta. No. 67—4)
- C — forest floor vegetation in climax ribbon forest (Sta. No. 67—6)
- D — successional tundra meadow following ribbon forest fire of 1809 (Sta. No. 67—2)
- E — climax snow-glade meadow vegetation (Sta. No. 67—5)
- F — successional snow-glade vegetation developing in forest due to snowdrift from 1809 fire site (Sta. No. 67—1)

All stations in Libby Flats area of Medicine Bow Mts., Wyoming forest stands. These stands were on the windward edge of a relatively closed spruce forest. Only the four or five windward ribbons were burned, leaving untouched an area of forest (and a little snow-glade vegetation) of ca. 3 hectares. A few trees in the burned area were not killed by the fire, only scarred on one side. We cut down one of these living trees to date the fire. Instead of only one fire, there were two fires; both pre-date the coming of European man. One occurred in 1766 and was probably a ground fire; the second fire in 1809 was apparently a severe crown fire and destroyed most of the forest. After almost 160 years, the dead trees and logs still remain. There is no spruce reproduction, and the site is covered with mesic alpine tundra.

Changes in Snowdrift Patterns

There is a secondary effect of timberline fires which is well-illustrated at the site of the 1809 fire. With the opening of the site to windward by fire, snow removal by wind has permitted the development of tundra. Since well-developed, but open, spruce forest was immediately adjacent to leeward, this snow now accumulates in the forest. The principal zone of snow accumulation is from 80 to 100 m in from the windward unburned edge. Here, the snow piles up in great drifts around the trees. Even in relatively dry years, these drifts do not melt until August and in snowy years, they can persist into September. On 13 July 1956, this drift was 2 m deep after a relatively dry year; on 1 August 1967, it was still 3 m deep in a relatively wetter year. Not only is spruce reproduction impossible under such a late-lying drift but the drift is killing mature trees and producing a new snow glade within the forest. Every mature tree (some up to 30 m high and as much as 1 m in diameter) which is surrounded by or touched by this drift as late as 20 July in an average year is dead. Beyond the limits of the drift on this date, the mature trees are alive. Comparable examples are numerous in the region. The conclusion is clear: forest fire near timberline not only allows replacement of the burned forest by alpine tundra vegetation but changes the snowdrift pattern enough that trees in an unburned area to the lee of the burn are killed by late-lying snow during the summer. The dead trees are replaced by a wet type of snowglade meadow (Column F) in which *Deschampsia caespitosa*, *Ranunculus alismaefolius*, and *Caltha leptosepala* dominate. This effect of the fire of 1809 on snowdrift pattern provides a good clue as to the origin of snow glades and thus of ribbon forest.

It is well to make the distinction between initial cause of the great amount of drifting snow and the ultimate effect of this snow on the forest pattern. In the example above, the snow was made available by the destruction of a forest by fire. There are other places in the Medicine Bow Mountains where the bare subalpine snow-source area may be caused by a factor other than fire — perhaps edaphic effects. An example is Cinnebar Park at 2,940 m, a subalpine meadow ca. 1.25 km long by 0.75 km wide, in which there is no evidence of any pre-existing forest, and which is surrounded by a mature forest of *Pinus contorta.* The entire eastern edge of the park or meadow is a ribbon forest unbroken for more than 1 km and about 60 to 65 m across. Behind this ribbon is a snow glade of the same length and breadth as the ribbon forest. Here in the snow glade rests much of the snow blown off the park during the winter. This one long drift prevents any development of forest. On 4 July 1965, there was no snow remaining in the open park or in the forest, but the drift in the snow glade was more than 1 km long and had a maximum depth of 6 m (see Fig. 5). The initial cause of the treelessness of the park is unknown but the effect is to supply snow for the maintenance of a snow glade and its ribbon forest.

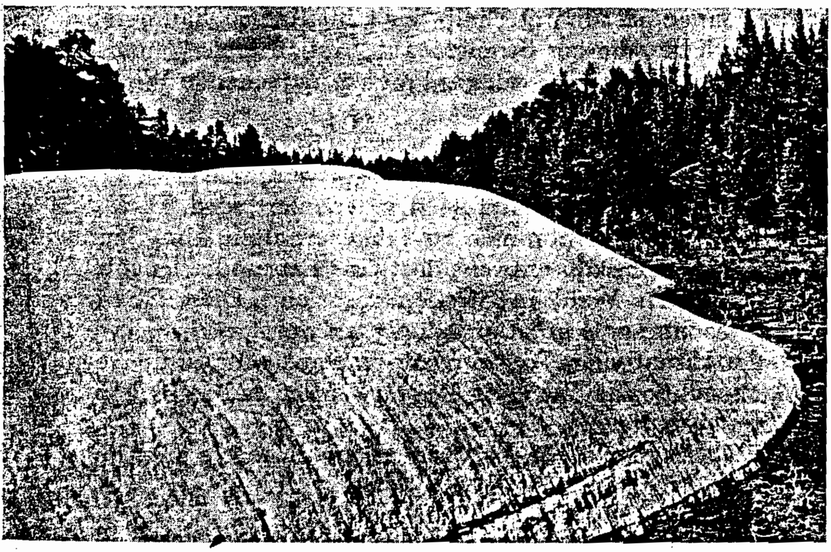

Fig. 5. Large snowdrift (6 m deep)in the snow glade east of ribbon forest at Cinnebar Park, Medicine Bow Mts. Elevation: 2,940 m. 4 July 1965.

CONCLUSIONS

In the central Rocky Mountains, flat areas or gentle slopes just below climatic timberline exhibit a vegetational pattern consisting of ribbon forests and snow glades lying across the path of the prevailing winds. The pattern is the result of removal of snow by wind from the open areas and its deposit in a great drift about 60 to 100 m in from the windward edge of the forest. This drift remains too long during the summer for tree growth. Consequently, the vegetation in the drift area is a wet or moist subalpine meadow occupying the snow glade and, in effect, breaking the forest into ribbon-like patches. The source area for the snow may be natural climax tundra, tundra which has replaced burned subalpine forest, or subalpine meadow of edaphic origin. The ribbon-forest and snow-glade pattern can be expected just below climatic timberline wherever plateaus or gentle slopes are exposed to heavy snowfall, strong winter winds, and cool summers. Destruction of such ribbon forests by fire or cutting will result in new snowdrift patterns and the long-lasting replacement of the forest by alpine or subalpine meadow vegetation.

ZUSAMMENFASSUNG

In den zentralen Rocky Mountains zeigen flache Gebiete oder sanfte Hänge gerade unterhalb der klimatischen Baumgrenze eine Pflanzendecke, die aus Streifenwald "ribbon forests" und Schnee-Lichtungen besteht, die quer auf die vorherrschende Windrichtung stehen.

Dieses Muster wird dadurch verursacht, daß der Schnee durch den Wind von den offenen Stellen weggeweht, und etwa 60—100 m vom Wald gegen den Wind wieder deponiert wird. Diese Schneehaufen bleiben im Sommer zu lange erhalten, um Baumwuchs zu erlauben. Deshalb entsteht dort eine nasse oder feuchte Alpenwiese, die den Wald in Streifen zerbricht. Diese Streifenwald-Schnee-Lichtung Vegetation kann man dort erwarten, wo unterhalb der klimatischen Baumgrenze Plateaux oder sanfte Neigungen starkem Schneefall, heftigen Winterwinden und kühlen Sommern ausgesetzt sind.

Durch Feuer oder Schlag wird dieser Waldtyp in Alpine oder Subalpine Wiese umgewandelt.

REFERENCES

Arno, S. F. 1966 — Interpreting the timberline. M. F. thesis, Univ. Montana, Missoula. 206 pp.

Billings, W. D. 1957 — Replacement of spruce-fir forest by alpine tundra as a result of fire. (Abstract) *Bull. Ecol. Soc. Amer.* 38: 70.

Bliss, L. C. 1956 — A comparison of plant development in microenvironments of arctic and alpine tundras. *Ecol. Monographs* 26: 303—337.

Hanna, L. A. 1934 — The major plant communities of the headwater area of the Little Laramie River, Wyoming. *Univ. Wyoming Publ. Sci., Bot.* 1, 10: 243—266.

HOMSHER, LOLA M. 1965 — The history of Albany County, Wyoming. Privately printed, Lusk,, Wyoming 110 pp.
LINSDAY, J. H. 1967 — The effect of environmental factors on the leaf water balance of conifers. M. Sci. thesis, Univ. Wyoming, Laramie. 60 pp.
MARR, J. W. 1961 — Ecosystems of the east slope of the Front Range in Colorado. *Univ. Colorado Stud., Ser. Biol.*, No. 8. 134 pp.
MOONEY, H. A. & BILLINGS, W. D. 1961 — Comparative physiological ecology of arctic and alpine populations of *Oxyria digyna*. *Ecol. Monographs* 31: 1—29.
OOSTING, H. J. & REED, J. F. 1952 — Virgin spruce-fir forest in the Medicine Bow Mountains, Wyoming. *Ecol. Monographs* 22: 69—91.
STAHELIN, R. 1943 — Factors influencing the natural restocking of high altitude burns by coniferous trees in the central Rocky Mountains. *Ecology* 24: 19—30.
WEBER, W. A. 1961 — Handbook of plants of the Colorado Front Range, rev., Univ. Colorado Press, Boulder. 232 pp.