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INVASION OF SUBALPINE MEADOWS BY TREES IN THE CASCADE RANGE, WASHINGTON AND OREGON

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ABSTRACT

In the forest-tundra ecotone region of the Washington and Oregon Cascades, massive invasion into subalpine meadows by a variety of tree species, especially *Abies lasiocarpa* and *Tsuga mertensiana,* has been noted. The most intense period of establishment in most areas was during 1928 to 1937. Little invasion has been noted in the Cascade Range since about 1945. We consider fire, grazing, and forest edge effect as possible factors influencing the massive establishment of trees during this time but suggest that climatic change is the most probable causative factor. At Paradise Valley on the slopes of Mount Rainier, trees invaded meadows during the period when the mass budget of the Nisqually Glacier was generally negative; after 1945, this mass budget was positive or balanced. The snow-free period in certain subalpine meadow communities is probably the most critical factor affecting tree establishment. Invasion densities were low on tall-forb-dominated (*Valeriana sitchensis*) and grass (*Festuca viridula*) communities and were high on low-forb-dominated (*Potentilla flabellifolia*) and shrub (*Phyllodoce empetriformis-Vaccinium deliciosum*) meadow types. However, growth rates of established trees appeared greatest on the tall-forb and grass communities.

INTRODUCTION

The forest-tundra ecotone has a special fascination for ecologists. Changes in relative dominance between trees, shrubs, and herbs may represent sensitive responses to subtle changes in climate. Furthermore, shifting boundaries between subalpine meadows[1] and adjacent forests in mountain areas have important implications in land management. The meadows are often prime recreational attractions or are prized as sources of game or livestock forage, so that shifts toward forest dominance merit considerable attention.

Recent invasion of subalpine meadows has been widely reported in mountainous areas of the Pacific Coast of North America from British Columbia to the Sierra Nevada, although the tree species involved and probable causes vary. In

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[1]Our terminology is based upon recommendations by D. Löve (1970). In particular, usage of the term "subalpine" refers to that belt between upper altitudinal tree line and the lower closed-canopy, more or less continuous coniferous forest. The term "subalpine meadow" refers to herb- or shrub-dominated communities in the forest-tundra ecotone where trees do not, at present, dominate.

1966, we surveyed and dated meadow invasion by trees at Mount Rainier National Park, Washington, with the support and encouragement of the National Park Service. Investigations centered on Paradise Valley, where subalpine meadows are a major visitor attraction, but other parts of the park and Cascade Range were also reconnoitered. Additional ages of invading trees were obtained in 1968 and 1969 and these substantiated conclusions from the earlier study. This report contains results of both studies and our interpretations of the cause of the invasion.

STUDY AREAS

The Paradise Valley study area is at 1,600- to 1,800-m elevation on the south slope of Mount Rainier in the Washington Cascade Range (46°47'N, 121°44'W). Topography varies from gentle and undulating to moderately steep, reflecting the surface of the Paradise debris flow which it occupies. The age of the debris flow is about 5,000 years (Crandell and Mullineaux, 1967). The maritime subalpine climate is characterized by mean temperatures of −3°C in January and 12°C in July. Yearly precipitation averages 2,795 mm, with total snowfall of about 1,480 cm (U.S. Department of Commerce, n.d.).

The vegetation of the study area is a mosaic of subalpine forest and meadow communities typical of the Parkland Subzone, *Tsuga mertensiana* Zone (Franklin and Dyrness, 1969). Forest stands are dominated by *Tsuga mertensiana* (Bong.) Carr. and *Abies lasiocarpa* (Hook.) Nutt. and occur mainly as stringers and small tree groups with subalpine meadows between. Meadow communities are varied including heather-huckleberry (*Phyllodoce empetriformis* (J. E. Sm.) D. Don. and *Vaccinium deliciosum* Piper) and herbaceous (e.g., *Valeriana sitchensis* Bong.) types. The percentage of the landscape occupied by forest tends to decrease with increasing elevation—at the upper edge of the forest-tundra ecotone in the Paradise Valley vicinity, the trees are confined to upland ridges and convex surfaces.

Meadow invasion was also studied at other locations in Mount Rainier National Park (e.g., Yakima Meadows) and in Goat Rocks Wilderness southeast of the park, at Mount Hood and Mount Jefferson in Oregon, and in the Mount Baker (Skyline Divide and Winchester Mountain) and Harts Pass areas in the North Cascades (Table 1).

TABLE 1

Average and range in ages of invading tree seedlings and saplings in subalpine meadows of Washington and Oregon

Location	Species	Number of Trees Sampled	Age in Years	
			Average	Range
Paradise Valley (1966 and 1969)	*Abies lasiocarpa*	150	36	17-54
Skyline Divide	*Tsuga mertensiana*	10	39	30-48
	Abies lasiocarpa			
Winchester Mountain	*Tsuga mertensiana*	10	60	47-72
Harts Pass	*Larix lyallii*	10	45	33-54
Goat Rocks Wilderness	*Abies lasiocarpa*	10	38	20-48
Mount Hood	*Tsuga mertensiana*	10	35	28-48
Mount Jefferson	*Tsuga mertensiana*	10	39	31-55

METHODS

At Paradise Valley, major areas of subalpine forest-meadow mosaic were first reconnoitered to determine the extent and intensity of meadow invasion. A small valley at about mid-elevation in the mosaic (1,700 m) and average in degree of meadow invasion was then selected for quantitative sampling (Figure 1). An area of about 0.8 ha, extending from closed forest to a small stream

FIGURE 1. Dense patches of invading *Abies lasiocarpa* seedlings in study area at Paradise Valley, Mount Rainier National Park, Wash.

in the center of the valley, was laid out and gridded in 15-meter-square segments. Closed forest, older tree groups, meadow, and invading trees were mapped within this area. Where invading seedlings and saplings were isolated, they were mapped as individuals; most occurred in patches of varying density and were mapped as clumps. Line transects were run through several clumps to determine density. Seedlings and saplings from each transect, covering the full range of height classes present, were cut off at ground line, measured for height and diameter, and aged by counting rings with a hand lens. An older tree group within the sample area was also analyzed by increment borings and height and diameter measurements to determine its developmental history. In 1969, the National Park Service provided butt sections from 100 additional seedlings and saplings cut from a slightly lower meadow area. These were cleaned, sanded, and counted in the laboratory with a dendrochronograph. The data from 1966 and 1969 are essentially identical, but the latter are reported in more detail, as the 1969 ring counts are believed to be more accurate.

Qualitative data on meadow invasion was obtained by studying old photographs of Paradise Valley, several of which were rephotographed, and by reconnaissance sampling of other areas in the park and Cascade Range. At these other locations, relations between meadow community type and degree of meadow invasion received special attention. Representative invading trees (including the smallest and largest which could be found) were measured for dimensions and age at most sites.

RESULTS

The reconnaissance data and detailed study at Paradise Valley confirm the obvious—coniferous seedlings have invaded significant portions of subalpine meadows (Figure 1). This is particularly true in the lower and middle portions of the Parkland Subzone, *Tsuga mertensiana* Zone. For example, in the area mapped at Paradise Valley, all 15-meter-square grid segments contain at least some seedlings and saplings (Figure 2).

CHARACTERISTICS OF INVADING TREES

Abies lasiocarpa is the major invading tree species at Mount Rainier and in Goat Rocks Wilderness—at Paradise Valley, 99% of the trees sampled. In the western half of the North Cascades (Mount Baker area) and in Oregon, *Tsuga mertensiana* is usually the most abundant and often the sole invader. In the drier eastern North Cascades, one area (Harts Pass) was sampled in which *Larix lyallii* Parl. is the major invader.

In most areas examined, invading trees occur in clumps with isolated seedlings and saplings often scattered between (Figures 1 and 2). At Paradise Valley, tree densities in the clumps range

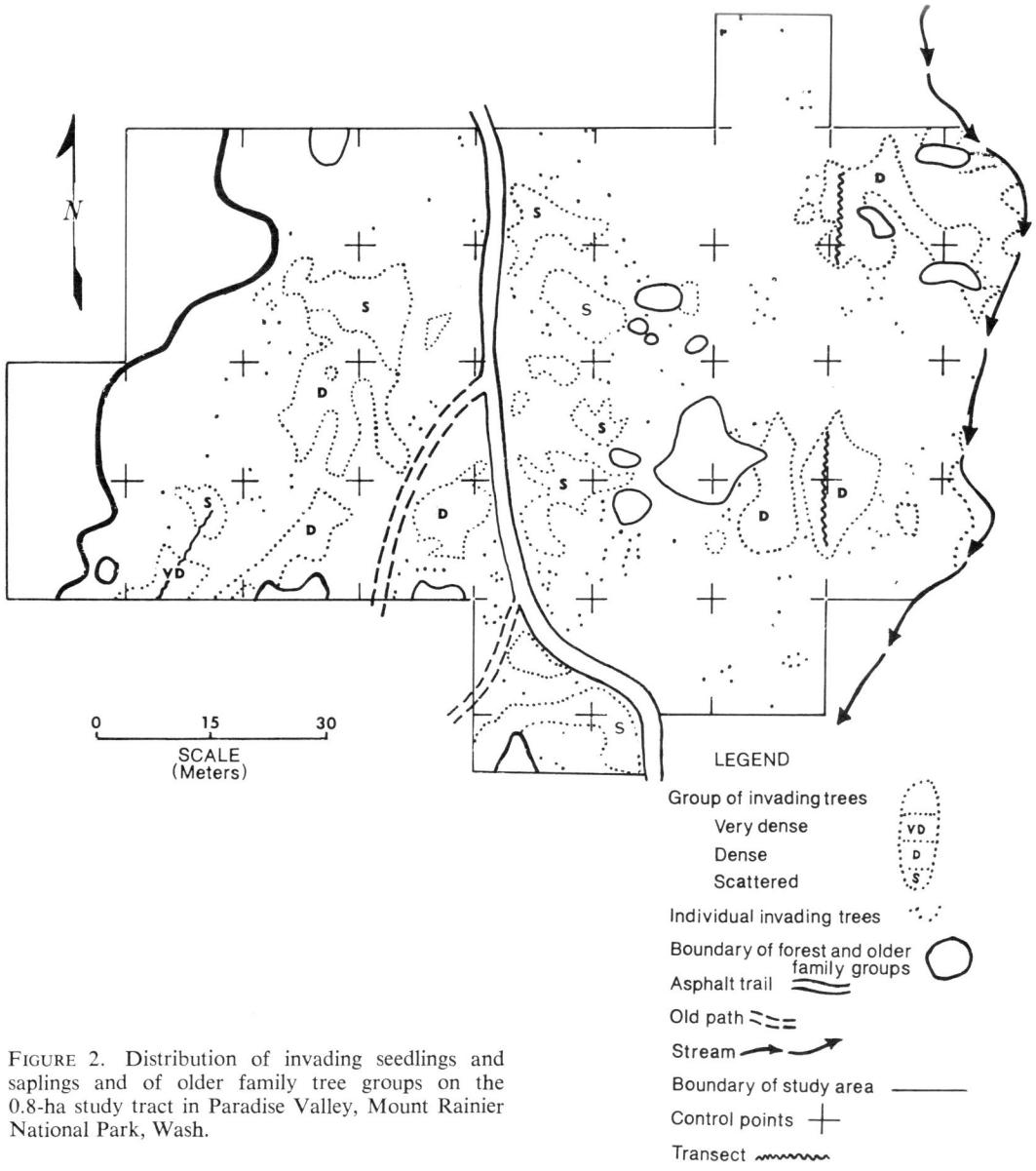

FIGURE 2. Distribution of invading seedlings and saplings and of older family tree groups on the 0.8-ha study tract in Paradise Valley, Mount Rainier National Park, Wash.

from about 110,000 to 490,000 ha^{-1}. Total heights and diameters range from 0.2 to 2.6 m and 8 to 70 mm, respectively.

The most interesting feature of the invading trees is their age span, which is truncated at both younger and older ages (Table 1, Figure 3). Trees younger than 20 years (and often 30) and older than 55 are absent from most sample sites. At Paradise Valley, where the largest sample is available, over 90% of the trees became established during a 21-year period between 1923 and 1944, with a peak between 1928 and 1937 (Figure 3). Except for Winchester Mountain, where trees are consistently older than at the other sites, the average age of invading trees in all areas is between 35 and 45 years, again emphasizing the late 1920s and early 1930s as a major period of establishment.

There is no correlation between seedling and sapling ages and heights when the data are plotted or analyzed statistically. A specimen 0.5 m tall is often as old or older than one 2.0 m tall.

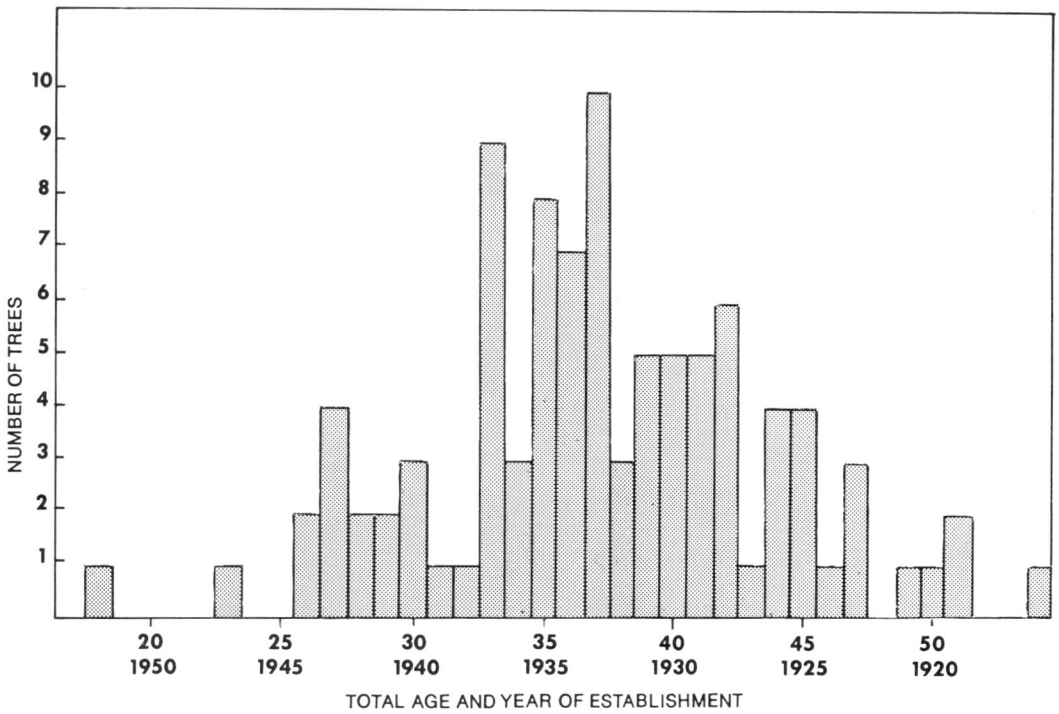

FIGURE 3. Number of seedlings and saplings by age and year of establishment; sample of 100 trees collected near Fairy Pool, Paradise Valley subalpine meadows (Mount Rainier National Park, Wash.), by the National Park Service in 1969.

CHARACTERISTICS OF OLDER TREE GROUP

In the Mount Rainier area, invasion of meadow areas by tree groups has been typified as a gradual process (Franklin and Mitchell, 1967). Development of tree groups would begin with the establishment of one or two seedlings of a pioneering species. Around these tree foci, additional trees would be established from seed or by layering as the first specimens ameliorate the meadow microenvironment, particularly by accelerating snowmelt and extending the growing season. In this way, tree groups, or copses, would gradually extend over meadow areas by expanding their margins (Figure 4). In his studies in the subalpine region of the northern Rocky Mountains, Patten (1963) suggested that seeds of *Picea engelmannii* Parry falling in the open at the forest margin, where spring temperatures are higher than within the forest, would have enhanced germination stimulus and thus caused forest advance into meadows.

The development of the largest tree group within the 0.8-ha study area at Paradise Valley follows the pattern of slow and gradual expansion into the surrounding meadow (Figure 5). The oldest tree (160 years) is at the south edge, and there is a gradation in age and size toward the north and east margins. The youngest tree (74 years) is at the east edge of the copse. Sample borings of other tree groups in Paradise Valley and Goat Rocks Wilderness indicate a generally similar developmental history.

INVASION AND MEADOW COMMUNITY TYPE

Intensity of conifer invasion (measured by density of trees and percentage of meadows invaded) and growth rate of seedlings and saplings vary markedly by subalpine meadow type. For this work, in the absence of any previous meadow community classifications for the study areas, we stratified the important meadow communities into four general categories at Paradise Valley: (1) a *Potentilla flabellifolia* Hook. type combining a variety of flowering forbs with a dense turf of *Carex* spp.; (2) a *Phyllodoce empetriformis-Vaccinium deliciosum* type in which either species may be the exclusive dominant; (3) a *Valeriana sitchensis* type, the most luxuriant of the flowering meadows and, typically, a dense community of flowering forbs 0.5 to 1.0 m in height; and (4) a *Festuca viridula* Vas.-*Lupinus latifolius* Agardh type, which is more typical of Sunrise Ridge but

FIGURE 4. The meadows at Yakima Park on the northeastern slopes of Mount Rainier are dominated by *Festuca viridula* and *Lupinus latifolius*. Massive tree invasion during 1920 to 1945 is not evident, but copses developed around trees established during a much earlier period are gradually and slowly extending into the grass meadows.

occurs in small stands on some drier and warmer south-facing slopes at Paradise Valley.

A subjective appraisal of the relation between invasion intensity, tree growth rates, and these community types is given in Table 2. Invasions of *Phyllodoce-Vaccinium* and *Potentilla* meadows are often massive, involving large numbers of invading trees. Invasions of *Valeriana* meadows are less frequent; some meadows are entirely free from invasion, and even where they are invaded, seedlings and saplings are not so abundant as in adjacent *Phyllodoce* and *Potentilla* communities. At Paradise Valley, *Festuca* communities occupy only small landscape segments, but invasion of these fragments is rare and usually consists of a few scattered trees. At Sunrise Ridge, where extensive tracts of *Festuca-Lupinus* meadow occur, almost no recent invasion is noted (Figure 4). The growth rate of established seedlings appears to be the reverse, with the fastest rates in the *Valeriana* and *Festuca* communities.

TABLE 2

Relation between invasion intensity, tree growth, and community types

Community type	Intensity of invasion	Growth rate of established trees
Phyllodoce-Vaccinium	High	Low
Potentilla	Medium	Medium
Valeriana	Low	High
Festuca-Lupinus	Very low	High

DISCUSSION

Several significant features of meadow invasion are revealed in this study. First, the invasion occurred during a restricted time span earlier in this century and has essentially ceased for about the last 20 years. Second, it was a massive invasion unrelated to the gradual expansion of forest onto meadow areas normally expected. Finally, it has occurred in many subalpine areas along the coast

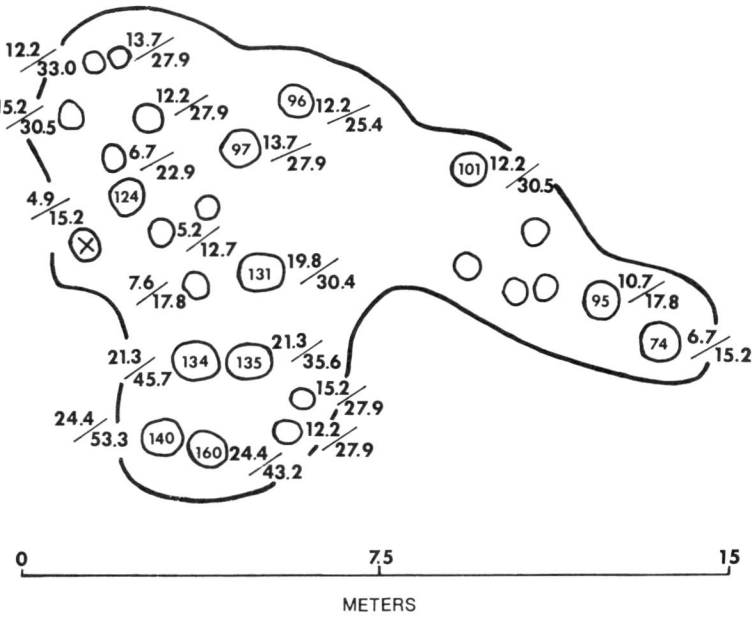

FIGURE 5. Spatial distribution, height, and diameters of trees in one of the older copses at Paradise Valley, Mount Rainier National Park, Wash. Numbers within circles are ages; numbers outside of circles are total heights and diameters at breast height, e.g., 24.0/43.0 = 24 m tall and 43 cm d.b.h. Trees marked with "X" are dead.

of the northwestern United States and adjacent British Columbia. Before considering possible causes for the invasion, we will briefly discuss each of these features.

The widespread and massive nature of subalpine meadow invasion is confirmed by both our reconnaissance data and published accounts. Brink (1959) reported extensive invasion of heather communities by *Abies lasiocarpa* and *Tsuga mertensiana* in coastal British Columbia. Douglas (1970) found it to be widespread in heather communities in the northern Cascades of Washington. Fonda and Bliss (1969) and Kuramoto (1968) encountered the phenomenon in the Olympic Mountains, with *Abies lasiocarpa* the major invader in drier northeastern areas and *Tsuga mertensiana* more common on western slopes. Van Vechten (1960) and Swedberg (1961) reported invasion of subalpine meadows by *Tsuga mertensiana* in two portions of the Oregon Cascade Range.

Our data clearly show that establishment of invading seedlings and saplings was essentially limited to a 20- to 30-year period in the first half of this century. Establishment reached a peak in the late 1920s and early 1930s, and seedlings younger than 25 years in age are rarely seen. These ages correlate well with those reported by other investigators. For example, Brink's (1959) trees were mostly 20 to 40 years old, indicating a similar chronology. The only significant exceptions are the data reported by Fonda and Bliss (1969) who found age groups of 8 to 15, 20 to 25, and 35 to 45 years in their invading trees. The 8 to 15 group and 1- and 2-year-old seedlings which they report are found only rarely in our study areas.

POSSIBLE CAUSES FOR MEADOW INVASION

The gradual successional encroachment of forest on meadow is often encountered in subalpine areas, but massive changes of the type reported here are not expected. Several possible causes have been suggested, including fire control programs, grazing, modifying effects of adjacent forest, and climatic changes.

Fire is often considered an important factor in creating and maintaining meadow areas. For example, Kuramoto (1968) felt that fire was the major factor responsible for subalpine meadows in the Olympic Mountains. The microclimate of the fire-created opening would determine whether or how fast trees would reinvade. At Paradise Valley there are large open areas in the lower part of the subalpine zone which were created during the last century by extensive fires (Haines, 1962). However, these are, in general, easily identified as potentially forested sites by old logs and snags, presence of several herbs and shrubs typical of forested sites (e.g., *Vaccinium membranaceum* Dougl.), and an abundance of charcoal. Tree regeneration on these fire-created openings is generally dense and vigorous and exhibits a full range of age classes down to 1- or 2-year-old seedlings, all of which indicates a strong and continuing successional pressure toward forest.

We conclude that fire has had little to do with

the creation and maintenance of the subalpine meadows considered in our study. There is little or no evidence that the meadow sites studied have been forested in postglacial time—neither charcoal nor rotten wood is common in soils except near older tree groups and forest. Consequently, fire control programs instituted in this century could have little to do with the tree invasion reported here.

Excessive grazing of meadow areas often encourages tree invasion by reducing herbaceous competition. Many of the meadow areas examined have no grazing history, however, except for an occasional native herbivore. The only case observed where grazing was felt to have had a significant effect was in the Goat Rocks Wilderness. There, extensive tracts of what were probably *Festuca viridula-Lupinus latifolius* meadows were heavily grazed by domestic livestock earlier in this century. Tree invasion is quite common on these degraded meadow types in contrast to the nearly pristine *Festuca-Lupinus* communities examined in Mount Rainier National Park, where cattle grazing permits were issued for only three summers during and after World War I (McIntyre, 1952).

Conditions on the study area at Paradise Valley (Figure 2) suggest that the modifying influence of adjacent forest or tree groups was of little importance in aiding seedling establishment. Invading clumps of seedlings and saplings are not closely associated with older trees. This situation generally agrees with that described by Fonda and Bliss (1969), who found greatest densities of invading trees to be within 5 to 8 m of the center of treeless areas. Perhaps if the meadows we studied had had larger segments free of older trees, we would have observed an edge effect, which could reflect both increased seed supply and more favorable microenvironments.

The simultaneous, temporary occurrence of conditions favorable for conifer invasion over such a widespread area strongly suggests a climatic flux favorable for conifer seedling establishment. Snowpack, through its influence on length of growing season, is known to be one of the most important factors in determining the position of forest-meadow ecotones in subalpine zones. A climatic flux which reduced duration of snow cover (i.e., increased the length of the growing season) would favor conifer invasion (Brink, 1959). Fire control programs and livestock grazing could have made only localized contributions to the phenomenon.

There is abundant meteorological (Hamilton, 1965; Veryard, 1963), oceanographic (Stewart *et al.,* 1958), and glaciological (Meier, 1965) evidence that a period of warmer, drier climate did occur, beginning late in the nineteenth century and extending into the 1940s. The health of Nisqually Glacier on Mount Rainier provides the most convincing local evidence. The terminus of Nisqually Glacier retreated irregularly from about 1840 until 1910, and steadily from 1910 to 1953 (Sigafoos and Hendricks, 1961), when a new front began to overrun the stagnant ice of the former terminus (Mr. Donald Richardson, U.S. Geol. Surv., Tacoma, Wash., pers. comm., 1970). Annual net budget studies of the glacier to 1962 (Meier and Post, 1962) showed that the glacier was in a better state of health in some years than terminal recession indicated. From 1945 to 1952, the glacier was accumulating mass; and from 1952 to 1961, no large changes could be measured. The agreement between invading tree ages (established mostly between 1923 and 1944) and the health of the glacier (as indicated by recessional and net budget studies) is very good.

We attempted to use the climatic records from Paradise Valley (U.S. Department of Commerce, n.d.) to correlate tree invasion with the length of the snow-free season, seasonal snowfall, and other climatic parameters. Unfortunately, data were too fragmentary and insufficient in duration to allow statistical analyses. They did provide a basis for some conjecture, however.

Meadow invasion would require at least one other major element in addition to one or several favorable growing seasons—an adequate supply of tree seed. Good seed crops are not produced annually, but generally at 3- to 6-year intervals in the case of *Abies lasiocarpa* (Franklin, 1968). Consequently, we would expect significant tree establishment only in years when a good seed crop (produced the previous summer) coincided with a favorable growing season. With adjustments for probable underestimation of ring counts, some peak years of establishment are strongly suggested —1928, 1933, and 1937. If we go back in 3- or 6-year increments from the bumper *Abies lasiocarpa* seed crop experienced in 1968 (data on file, Forestry Sciences Laboratory, Corvallis, Oregon), we can hypothesize abundant seed production in 1932. This seed would germinate in the spring of 1933. The growing season that year began late (snow-free about July 15), but the snow-free period was one of the longest on record, and the snow-free season in 1934 began exceptionally early. There could, therefore, have been a combination of factors favorable for conifer establishment at that time. The snow-free seasons in 1928 and 1937 were similarly longer than average. These interpretations and extrapolations of cli-

matic, seed production, and seedling age data are less than definitive but are interesting nevertheless.

Relation to Community Type

The greater abundance of invading conifers in *Phyllodoce* and *Potentilla* communities but greater growth of established trees on *Valeriana* and *Festuca* types may have considerable ecological significance and is worthy of further detailed study. Kuramoto (1968) noted a similar pattern in the Olympic Mountains. Both the *Valeriana* and *Festuca* communities typically have a dense, herbaceous cover 0.5 m or more in height and are on sites with somewhat warmer and longer snow-free seasons. The minimal amounts of tree invasion in these communities suggest that one important factor limiting conifer establishment may be herbaceous competition. Under these conditions, increased tree invasion in response to a longer, snow-free season should be minimal, as seems to be the case. Once competition is overcome and trees are established, however, seedling growth rates would logically be superior on these somewhat warmer habitats and better drained soils.

Management Implications

Conifer seedlings have invaded large portions of subalpine meadows in the Pacific Northwest, including many sites where the meadows are key recreational attractions. Except in the case of overgrazed meadow areas, this appears to be an entirely natural phenomenon. Although the invasion was essentially completed two decades ago, trees are only now reaching sufficient size to be conspicuous and to significantly alter meadow composition and scenic vistas.

The land managers responsible for these landscapes must decide whether they will remove invading seedlings from all or a portion of the affected area or will allow developments to proceed unhindered. If control of tree encroachment is deemed desirable, removal of seedlings and saplings by cutting should be very effective. Successional pressures are not great, and reinvasion will not occur until favorable environmental conditions again exist for establishment of conifer seedlings. Even if reinvasion were to take place again the next year, which seems most unlikely, it would be 20 to 30 years before trees were again sufficiently large to constitute a threat to meadow communities.

If tree removal is not carried out, some subalpine meadow area will undoubtedly be lost to forest. This is not necessarily serious, however, as the higher subalpine meadows and some of the most luxuriant types (e.g., *Valeriana*) are least affected.

References

Brink, V. C.
1959 : A directional change in the subalpine forest-health ecotone in Garibaldi Park, British Columbia. *Ecology*, 40: 10-16.

Crandell, Dwight R. and Mullineaux, Donal R.
1967 : Volcanic hazards at Mount Rainier, Washington. U.S. Geol. Surv. Bull., 1238. 26 pp.

Douglas, George Wayne
1970 : A vegetation study in the subalpine zone of the western North Cascades, Washington. Unpublished M.S. thesis, Univ. of Washington. 293 pp.

Fonda, R. W. and Bliss, L. C.
1969 : Forest vegetation of the montane and subalpine zones, Olympic Mountains, Washington. *Ecol. Monogr.*, 39: 271-301.

Franklin, Jerry F.
1968 : Cone production by upper-slope conifers. Pacific Northwest Forest & Range Exp. Sta. USDA Forest Serv. Res. Pap., PNW-60. 21 pp.

Franklin, Jerry F. and Dyrness, C. T.
1969 : Vegetation of Oregon and Washington. Pacific Northwest Forest & Range Exp. Sta. USDA Forest Serv. Res. Pap., PNW-80. 216 pp.

Franklin, Jerry F. and Mitchell, Russel G.
1967 : Successional status of subalpine fir in the Cascade Range. Pacific Northwest Forest & Range Exp. Sta. USDA Forest Serv. Res. Pap., PNW-46. 16 pp.

Haines, Aubrey L.
1962 : *Mountain Fever*. Oregon Historical Society, Portland, Oregon. 255 pp.

Hamilton, Thomas D.
1965 : Alaskan temperature fluctuations and trends: An analysis of recorded data. *Arctic*, 18: 104-117.

Kuramoto, Richard Tatsuo
1968 : Ecology of subalpine meadows in the Olympic Mountains, Washington. Unpublished Ph.D. thesis, Univ. of Illinois. 150 pp.

Löve, D.
1970 : Subarctic and subalpine: Where and what? *Arctic and Alpine Res.*, 2: 63-73.

McIntyre, Robert N.
1952 : Short history of Mount Rainier National Park. Unpublished report in reference library, Mount Rainier National Park, Washington. 361 pp.

Meier, Mark F.
1965 : Glaciers and climate. *In* Wright, H. E., Jr. and Frey, David G. (eds.), *The Quaternary of the United States.* Princeton Univ. Press, Princeton, 795-805.
Meier, M. F. and Post, A. S.
1962 : Recent variations in mass net budgets of glaciers in western North America. Int. Ass. Sci. Hydrol., Obergurgl Symp. Publ., 58: 63-77.
Patten, D. T.
1963 : Light and temperature influence on Engelmann spruce seed germination and subalpine forest advance. *Ecology,* 44: 817-818.
Sigafoos, R. S. and Hendricks, E. L.
1961 : Botanical evidence of the modern history of Nisqually Glacier, Washington. U.S. Geol. Surv. Prof. Pap., 387-A. 20 pp.
Stewart, H. B., Zetler, B. D., and Taylor, C. B.
1958 : Recent increases in coastal water temperature and sea level—California to Alaska. U.S. Coast & Geod. Surv. Tech. Bull., 3. 11 pp.
Swedberg, Kenneth C.
1961 : The coniferous ecotone of the east slope of the northern Oregon Cascades. Unpublished Ph.D., thesis, Oregon State Univ., Corvallis. 118 pp.
U.S. Department of Commerce
n.d. : Mount Rainier National Park, Washington. Climatography of the United States, 20-45 R60-18. 4 pp.
Van Vechten, George Wendell
1960 : The ecology of the timberline and alpine vegetation of the Three Sisters, Oregon. Unpublished Ph.D. thesis, Oregon State Univ., Corvallis. 111 pp.
Veryard, R. G.
1963 : A review of studies on climatic fluctuations during the period of the meteorological record. *In: Changes of Climate,* Proc. Rome Symposium, 1961. UNESCO & World Meteorol. Organ. Proc., 3-15.

Ms submitted November 1970