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FOREST EXPANSION IN THE SUBALPINE ZONE DURING THE PAST HUNDRED YEARS, MOUNT BAKER, WASHINGTON, U.S.A.

With 6 figures, 2 photos and 2 tables

Olavi Heikkinen

Zusammenfassung: Waldexpansion in der subalpinen Zone während der letzten hundert Jahre, Mount Baker, Washington, U.S.A.

Die subalpine Zone, ein Übergangsgürtel zwischen dem geschlossenen Bergwald und der baumlosen alpinen Tundra, ist am Mount Baker, wie allgemein in den maritimen Gebirgen des pazifischen Nordwestens Amerikas, exzeptionell breit ausgebildet. Der untersuchte Bergrücken, 1400–1600 m ü. M. gelegen, ist in jüngerer Zeit auffallend stark von Bäumen besiedelt worden, und zwar von folgenden Spezies: *Tsuga mertensiana* [Bong.] Carr., *Abies amabilis* [Dougl.] Forbes und *Abies lasiocarpa* [Hook] Nutt. Von den 100 untersuchten Exemplaren, die in der Zeit zwischen 1886–1960 ihr Wachstum begannen, stammen 47% aus den Jahren 1925–1945. Wegen der günstigen Exposition der unteren Teile des Bergrückens sind die Bäume dort im Durchschnitt älter, größer und gesünder als die, die auf den oberen Hängen und auf dem Scheitel selbst wachsen, wo starke Winde die Bäume zerzausen und einzelne Äste absterben, was zu fahnenförmigen und krummholzähnlichen Wuchsformen geführt hat. Die rezente Baumkolonisation wurde jedoch primär von einem verhältnismäßig warmen und teils trockenen Klima während der ersten Hälfte dieses Jahrhunderts gefördert. Diese Klimaverbesserung verlängerte die schneefreie Saison, was die Ausbreitung der Bäume begünstigte.

The subalpine zone, also referred to as the upper timberline and forest-tundra ecotone, between closed forest and treeless alpine tundra is exceptionally broad in the Pacific Northwest of North America (Fonda a. Bliss 1969, Kuramoto a. Bliss 1970, Franklin a. Dyrness 1973, pp. 248–284). In many places, this altitudinal belt, studded by mosaics of clumps and ribbons of trees, meadows, snow patches, and bedrock outcrops, can reach a vertical dimension of 300–500 metres. Abundant snowfall, particularly on the western flanks of the mountains, results in snowdrifts which persist late into the summer and are probably the main causes of the well-developed subalpine forest-meadow mosaic or parkland in Washington and Oregon (Franklin a. Dyrness 1973, pp. 248–250), and in British Columbia (Brink 1959).

The elevation of the upper timberline as well as the position of the polar timberline is primarily determined by air temperature (Troll 1973, Tuhkanen 1980, pp. 67–72). The duration of the growing season, and the severity of the winter and wind-related damage (Wardle 1968, Baig a. Tranquillini 1976) are some of the most important factors in controlling the upper timberline. Topography, soil, fires, plant diseases, insect damage, and human activity may play an important role, at least on a local scale (e.g. Billings 1969, Kuramoto a. Bliss 1970). Because of changing conditions in the subalpine zone the forest-tundra ecotone is a dynamic environment.

Changes in the distribution of meadows and forested areas in the upper timberline region have tended to be gradual (Franklin a. Mitchell 1967, Lowery 1972). In this century, however, many subalpine meadows have experienced a massive invasion by trees, e.g. throughout the Pacific Northwest: from British Columbia (Brink 1959) and Washington (Fonda a. Bliss 1969, Franklin et al. 1971, Lowery 1972) to Oregon (e. g. Vale 1981). Besides, the phenomenon has been described from California (LaMarche 1973) and Wyoming (Dunwiddie 1977). Simultaneous forest expansions also occured at the polar timberline in northern Europe (Hustich 1958) and in Canada

(Hansell et al. 1971). In all, it seems that the recent tree invasion is primarily a result of climatic conditions (e. g. Franklin et al. 1971, Franklin a. Dyrness 1973, p. 282).

Purpose of the study

The aim is to study the intensive tree invasion during the past 100 years in the subalpine zone on a ridge of Mount Baker, the state of Washington (Fig. 1). The background information given above permits the *a priori* hypothesis that climatic events, at least, are involved in the current forest advance. With this assumption as starting point, answers are sought to the following questions:

(1) What were the climatic changes that triggered and maintained the tree invasion?

(2) To what extent is the tree expansion due to other factors such as fires, grazing of livestock, and insect and disease damage? Also growth forms and state of health of the trees are described and explained.

Study area and its surroundings

The study area of approximately 3.6 hectares is situated at 48°48′N and 121°52′W at an elevation of 1400 to 1600 m a.s.l. on the west flank of Mount Baker. This ice-clad stratovolcano (Easterbrook 1975), which has currently intensified its thermal activity (Easterbrook 1980, Krimmel a. Frank 1980), towers to a hight of 3285 m a.s.l. in the western North Cascades, Washington. One of the Mount Baker glaciers, the Coleman Glacier, lies almost immediately east of the study area and terminates nowadays at close to 1200 m a.s.l. Small branches of Glacier Creek, the discharge channel of the Coleman Glacier, nearly enclose the study area (Fig. 2). The area was selected on the basis of tentative observations that the recent tree invasion towards the alpine zone was intensive within a vertical belt of 200 metres at this point.

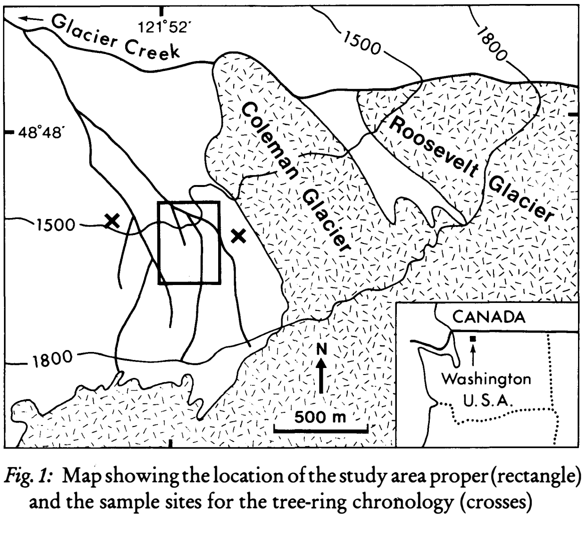

Fig. 1: Map showing the location of the study area proper (rectangle) and the sample sites for the tree-ring chronology (crosses)

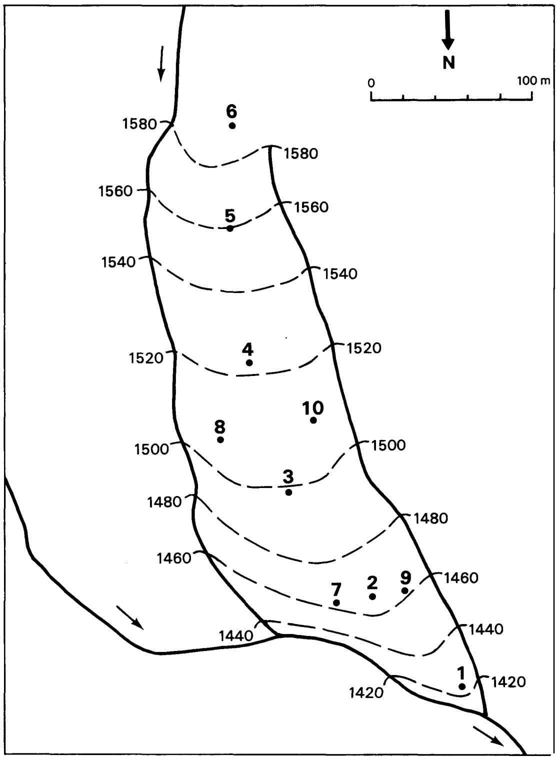

Fig. 2: The study area with contour lines (in metres), and numbered sample sites

The climate in the area is distinctly maritime with wet and relatively mild winters and cool, comparatively dry summers (Franklin a. Dyrness 1973, p. 42). No accurate climatic data are available on the study area. The subalpine Mount Baker Lodge station, 1265 m a.s.l. and 16 km to the northwest, appears to be fairly representative of the climatic conditions of the study area (see Douglas a. Bliss 1977, p. 116), even though weather conditions and the snow cover may vary over short distances in mountain areas (e.g. Baig a. Tranquillini 1976). The following information is for the Mount Baker Lodge station for 1927–51 (*U.S. Weather Bureau,* no date). Most of the mean annual precipitation of 2790 mm falls as snow and sleet in autumn and winter. The snow cover normally reaches its greatest depth (4.5 to 6.1 m) at the end of March or beginning of April. Summer (June-August) rainfall is restricted to 285 mm, c. 10% of the total annual precipitation. The mean temperature for the whole year is 4.5°C, and for August, the warmest month of the year, 13.7°C.

Topographically the study area is a north-sloping ridge with a slightly convex top and precipitous side slopes (Fig. 2). The soil is predominantly coarse till but in places contains sand and finer substrate. Bedrock exposures are common in the lower part of the area. Because of its topography, the composition of the surface material, and the proximity of creeks, the terrain is well-drained.

The timberline region marginal to the study area ranges from 1400 to 1650 metres. Mature conifers in adjacent forest stands consist of mountain hemlock (*Tsuga mertensiana* [Bong.] Carr.), Pacific silver fir (*Abies amabilis* [Dougl.] Forbes) and subalpine fir (*Abies lasiocarpa* [Hook] Nutt.). All these species are common in the subalpine zone in the western North Cascades (Franklin a. Mitchell 1967, Lowery 1972) and constitute a typical combination of tree-species, particularly in a habitat characterized by ridges and bedrock outcorps (Douglas 1969). Mountain hemlock and Pacific silver fir are especially characteristic of cool and moist maritime conditions, whereas subalpine fir is usually most typical of cold and relatively dry environments (e.g. Fonda a. Bliss 1969, pp. 290–291).

Methods

The study area was mapped with a tape measure and an altimeter, using a grid of longitudinal and transverse lines. To examine the progress of recent forest expansion, ten sample plots were chosen: six on the crest and four on the side slopes of the study area (Fig. 2). Every sample site is a circle with a radius of 5 m. The ten largest trees in each sample circle, 100 trees altogether, were cored with a Finnish increment borer not more than 2–8 centimetres above ground level. Annual rings were counted with a microscope in the laboratory, and only actual pith dates were used in determining the ages of the trees.

The history of forest fires and livestock grazing as well as variations in local temperatures and precipitation were elucidated to explain the recent tree invasion. Because meteorological measurements at the nearby subalpine Mount Baker Lodge station began as late as 1926, the ages of the trees are compared with Sedro Woolley's records *(U.S. Weather Bureau).* This station (48° 30′ N, 122° 13′ W, 17 m a.s.l.) lies nearly 45 km southwest of the study area and, in the regional climatic division, belongs to the "Puget Sound Lowlands". The station has produced precipitation data since 1896 and temperature records since 1898.

Indirect tracing of climatic changes back to 1800 was attempted by means of tree-ring width variations of samples extracted from ten old mountain hemlocks growing in two subalpine stands on each side of the study area, 1400–1500 m a.s.l. (Fig. 1). The tree-ring cores collected were mounted, sanded and cross-dated according to standard dendrochronological techniques (Stokes a. Smiley 1968). Ring widths were measured with a Bannister's incremental machine to the nearest 0.01 mm. Absolute ring-width values of each core were standardized by fitting an exponential, polynomial, or linear curve to the measured ring-width series, and each true ring-width value was then divided by the corresponding curve value. The computed ring-width indices of individual trees were then averaged according to year to obtain the site chronology in which each sampled tree is equally weighted and relatively free of biological trend and partly of other nonclimatic growth variations as well (Fritts et al. 1969, Fritts 1976).

Furthermore, the forest invasion in time is related to simultaneous variations in the regional and hemispheric climate and finally also to the pattern of recent glacier fluctuations. The results of this study are compared with conclusions reached in corresponding investigations in western North America.

Direct results

Invading conifer species are the same as in the adjacent old stands: mountain hemlock, Pacific silver fir, and subalpine fir, all of which are distributed throughout the study area. Mountain hemlock occurs most frequently at least at the three highest sample sites (Sites 4, 5, and 6 in Fig. 2); Pacific silver fir predominates or is nearly as abundant as mountain hemlock in the lower part of the ridge (Sites 1, 2, 7, and 9); and subalpine fir is mostly found in the middle section of the area but is dominant only at Site 9.

Fig. 3, which shows the age distribution of the sampled 100 seedlings without reference to species, provides a general illustration of the establishment dates of the seedlings for the whole of the study area and for the crest (Sites 1 to 6 in Fig. 2) and the side slopes (Sites 7 to 10 in Fig. 2) separately. The oldest tree dates back to 1886 and the two youngest to 1960, the average germination year being 1930. The most distinct concentrations in the age distribution, depicted in 5-year age classes, fall within 1925–34 and 1940–44. On average, forestation continued longer on the slopes than on the ridge crest. Fig. 3 does not permit an overall view of forest expansion since only the ten largest trees in each sample site were cored. The proportions of young seedlings would probably be emphasized if a systematic rather than a selective sampling technique had been applied.

Fig. 4 shows the minimum establishment years of individual seedlings separately for each of the sample sites. The average ages are greatest at Sites 2 and 9, which lie on the west and northwest slopes in the lower portion of the area (Fig. 2). The trees here are symmetrical, sharp-spired and healthy.

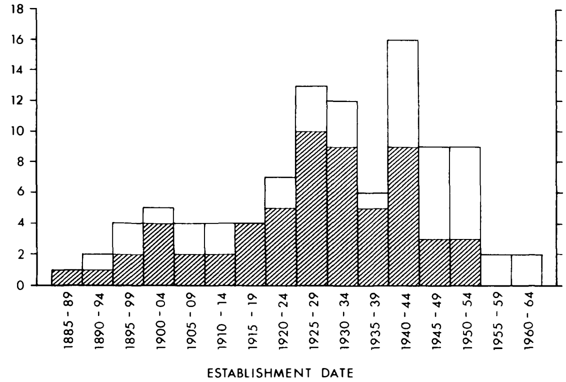

Fig. 3: Age distribution by pentads for the 100 trees dated
Shaded portions of columns represent 60 trees on the crest, and the white portions 40 trees on the side slopes of the ridge

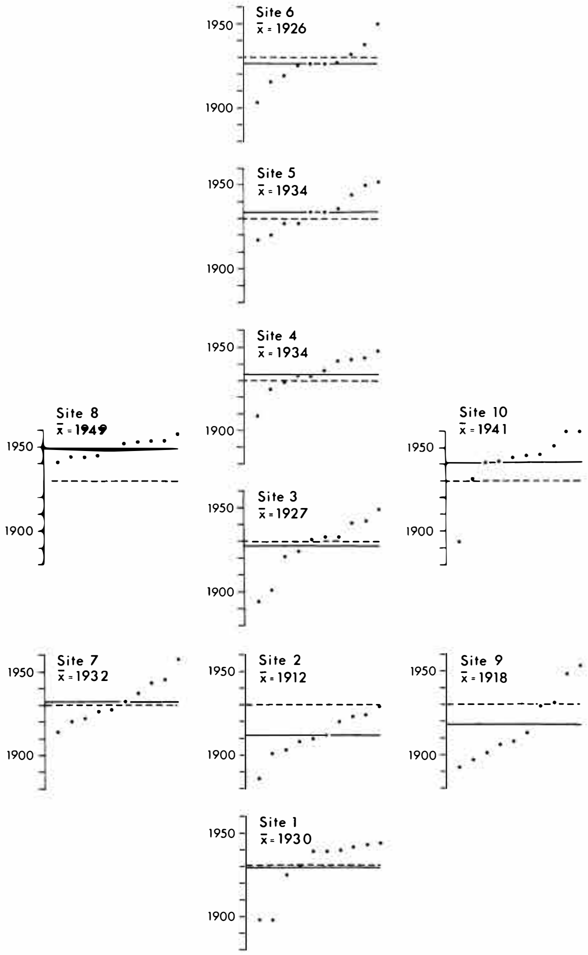

Fig. 4: Establishment years for individual trees at each of the ten sample sites, separately
Average establishment year for each site is shown by solid line and numbers. Average establishment year for all trees studied is 1930 (broken line)

These localities receive abundant solar radiation, so the winter snow cover melts relatively early, giving a prolonged growing season (cf. Brink 1959, Lowery 1972, p. 26). Furthermore, surrounding ridges shelter these sites from strong wind. However, at the lowest sample location (Site 1) trees are younger, probably because of the shaded aspect that shortens the snow-free season. Also temperature inversions are very likely on the base of the slope, close to the deep creek valley.

The most recently established trees are found at the sites lying on the sides of the ridge studied, so that trees on the shady eastern slope are younger than on the light western flank, and the age of trees declines uphill. Despite the high altitude, the stunted trees at Site 6 on the ridge top started growing suprisingly early, in 1926 on average. The bush-like growth form of these uppermost trees are a result of their position on a knoll, unprotected from the harsh winds which sweep down from ice-capped Mount Baker and impair the tree growth. On the other hand, the knoll with the modest winter snow cover and the resulting lengthened growing season has enabled early tree establishment.

The age distribution of the trees implies that the convex crest has been a suitable habitat for pioneer saplings. The creek bottoms and slopes both in and near the study area are largely treeless even nowadays (Photo 1).

Growth forms and condition of invasive trees reveal the diversity of the impact of environmental stress factors in this subalpine area. Excluding those at the three uppermost sites, the trees are rather symmetrical, with one dominant trunk and a tapering form. On the top of the ridge, many trees tower up to 10 m, but on the slopes the hight averages 2.5 to 5 m. Though most of the trees seem to be healthy, many dead or dying Pacific silver firs were found on Site 3. Perhaps insect infestation or disease damaged these conifers, or perhaps the climatic conditions, which nowadays are less favourable than in preceding decades, were detrimental to Pacific silver fir.

Above the 1500 m contour (Sites 4 to 6 in Fig. 2), trees decrease from 4 m to about 1 m in height, become stunted and resemble krummholz bushes. Trees growing in small clumps also tend to reproduce by layering or rooting, when the lateral branches of parent trees touch the ground, take root, and become independent individuals. The crowns of some of the uppermost trees are clearly flagging downhill, because the branches on the opposite side of the stem are damaged or dried (Photo 2). The topmost dwarfed conifers have been abraded at the "flagging height", approximately 1.3 m from ground level, so that only withered and inferior shoots with partly brownish needles rise above this level.

The flagging and truncated growth forms apparently indicate the depth of the winter snow. Wind, possibly

Photo 1: Ridge crests are the most favourable aspect for invasive trees in the subalpine zone on Mount Baker, whereas heavy, late-lying winter snow and wetness delay or prevent seedlings from becoming established in valleys and depressions. The uppermost part of the study area in the foreground, termini of the Coleman and Roosevelt Glaciers in the background. Photo: O. Heikkinen, July 21, 1981

Photo 2: Because of exposure to icy winds blowing from Mount Baker some of the uppermost trees, here mountain hemlock, are flagging downhill. Photo: O. Heikkinen, June 27, 1981

katabatic, blowing down from Mount Baker with snow and ice particles as its tools, abrades the parts of trees that protrude from the snow pack at the upper section of the timberline. What is more, the limbs of trees which are not protected by snow during the cold winter months may suffer water stress and desiccation (cf. Wardle 1968, Lindsay 1971, Baig a. Tranquillini 1976).

Most of the tree trunks curve downslope at their base. This phenomenon, which frequently occurs on steeply sloping terrains, may primarily be caused by winter snow pushing and pressing saplings down to the ground. Snow creep is evidently rather widespread at the timberline in the western North Cascades (Lowery 1972). Besides, the base bending of younger seedlings may indicate that these plants have become established by layering from the lowest branches of pioneer trees. Finally, mass movements on steep slopes may have contributed to tree trunk deformations.

The small scars found in numerous stems are concentrated on the uphill side of bases or trunks at various heights. The scars on the bases presumably testify to rocks rolling down the slope, those on the trunks to the pressure of the snowpack.

Factors contributing to the tree invasion

Non-climatic agents apparently played only a minor role in the recent forest expansion process. There is no evidence for fires nor reports of grazing by domestic animals (Raddon 1982). Browsing by wild animals is probably of minor importance at most. Moderate utilization by cattle, if present, might aid tree establishment (Dunwiddie 1977) by reducing the herbaceous competition (see Franklin et al. 1971), whereas sheep would obviously lessen or prevent tree establishment (Vale 1981).

The adjoining forests have not assisted the forest advance, either, because the area is separated from old-growth stands by creeks. In principle the forest edge effect, discussed by Franklin et al. (1971), could promote tree establishment through a favourable microenvironment and ample seed supply.

Thus, it seems that the forest expansion investigated is primarily attributable to climate. Within the scope of this study, however, it is difficult to assess on a long term how exceptionally favourable the climate of the last hundred years has been to tree establishment because, for instance, the deglaciation of the area has not been dated.

It is widely known that, on the Earth as a whole, the last hundred years or so were preceded by a long, predominantly cold interval representing the latest Neoglacial state (Porter a. Denton 1967), frequently called the Little Ice Age. This period has been dated in various ways between about 1300 and 1920 (see Porter 1981a). However, air temperatures in western North America (Blasing a. Fritts 1976) and in the entire Northern Hemisphere (Mitchell 1961) obviously started rising towards the warmer climate characteristic of the first half of the present century in the 1890s, or possibly already in the 1880s (cf. Fig. 6:B). Some support for this view is given by the tree-ring chronology (Fig. 5) built up for the ten mature mountain hemlocks growing on either side of the study area (see Fig. 1). Accordingly, the initiation of the climatic warming in the late 19th century appears to coincide with the beginning of forest expansion studied (Fig. 6).

The comparison of the age distribution of recently established trees with climatic variations at Sedro Woolley shows that the intensive forestation phase is fairly consistent with

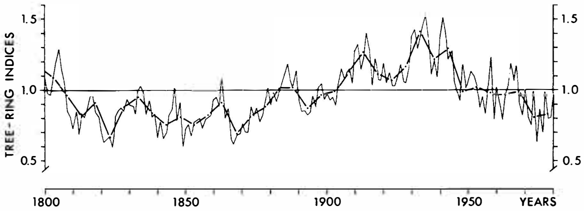

Fig. 5: Tree-ring chronology for ten mountain hemlocks growing in the subalpine zone close to the study area (Fig. 1)
Time-series plots describe the annual (thin line) and pentad (thick line) values so that the averaged index value 1.0 refers to 1633 to 1980

a temperature peak spanning the early 1920s to the late 1940s (Fig. 6: A and E). That episode, excluding the pentad 1930 to 1934, was also dry. The years 1940 to 1944, which represent the warmest and driest pentad of the present century at Sedro Woolley correspond to the period of most intense tree invasion. Because another dry, though not quite as warm pentad, 1925 to 1929, also matches the tree establishment ages, high air temperatures together with a decline in precipitation rates may have effectively contributed to the forest advance.

Table 1: Correlation coefficients (R) between ring-width indices and average temperatures at Sedro Wooley in 1898-1971 (see Fig. 6: A and C)

Time*⁾	R
Winter	+0.129
Spring	+0.370
Summer	+0.141
Autumn	+0.089
Year	+0.260

*⁾ The seasons refer to the months as follows: winter - previous December to February, spring - March to May, summer - June to August, autumn - September to November.

The growth pattern of mountain hemlock in itself (Figs. 5 a. 6: C) as well as the correlations of its ring-width indices with Sedro Woolley's meteorological data (Tables 1 a. 2) imply that annual rings are wide if the climate is relatively warm and dry, whereas wet, cool weather reduces the gradial growth.

Because the plot of ring-width indices manifests a considerable similarity to the age distribution of invasive seedlings (Fig. 6: C and E) one can deduce that warm and dry

Table 2: Correlation coefficients (R) between ring-width indices and total precipitations at Sedro Woolley in 1898-1971

Time	R
Winter	-0.149
Spring	-0.155
Summer	-0.255
Autumn	-0.075
Year	-0.251

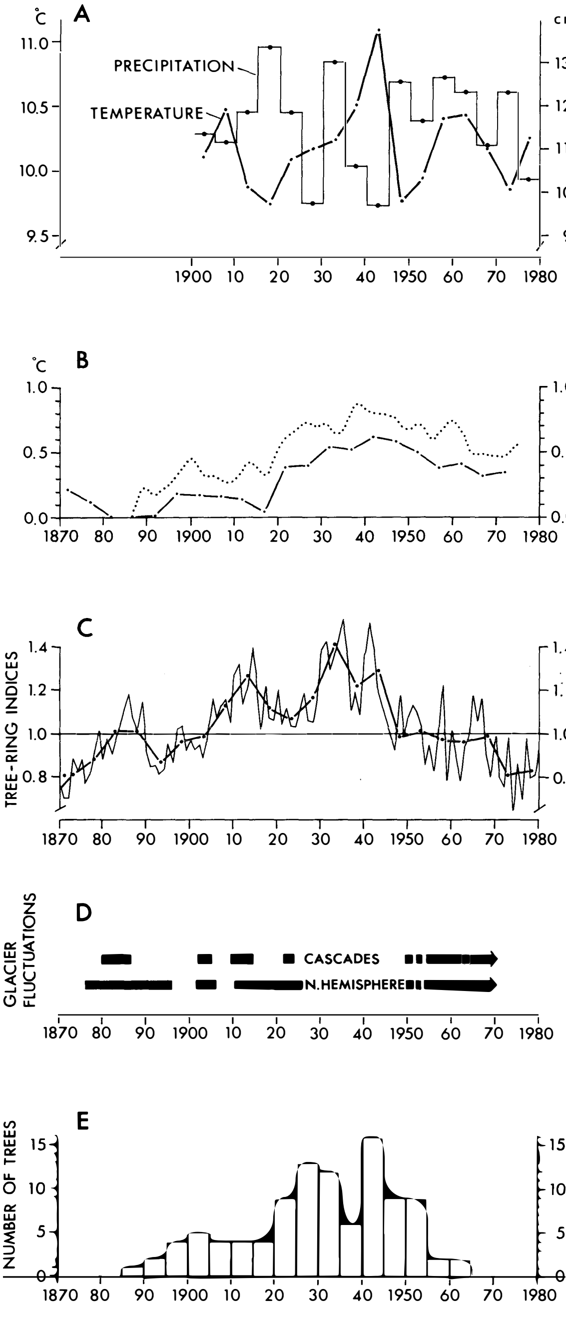

Fig. 6: Variations in climate and climate-related phenomena compared with the age distribution of invaded trees
A: Mean annual temperature and total annual precipitation as pentad averages at Sedro Woolley this century
B: Annual temperature changes in the Northern Hemisphere: broken line connects pentad values determined by Willet, Mitchell, Reitan and Brinkmann (Brinkmann 1976), dotted curve shows mean annual surface temperature variations smoothed by a nine-term bionomial filter (Ingram et al. 1981, according to Jones and Wigley 1980). Both plots have been adjusted so that temperatures are deviations from the lowest value of the time considered
C: Local tree-ring chronology. For details see Fig. 5
D: Recent glacier oscillations in the Cascades and in the Northern Hemisphere. Black bars indicate years when glacier expansions culminated or glaciers started retreating. Description is based mainly on Porter's (1981b) presentation with some contributions from Long (1955), Bengtson (1956), Burbank (1981), and Heikkinen (1984)
E: Age distribution by pentads for 100 trees dated here. See Fig. 3

climates also promoted tree establishment. This conclusion appears convincing, even if there are some uncertain factors in the data sets involved. For instance, climatic inferences are based on Sedro Woolley's records, although this station lies 17 m a.s.l. in the "Puget Sound Lowlands", whereas the study area is located at 1400 to 1600 m a.s.l., in the "Cascade Mountains West". Furthermore, neither the temperature nor precipitation data utilized here are completely continuous. Still, both the tree growth and tree establishment exhibit a certain time lag in relation to climatic events. However, all of these uncertainties obscure rather than clarify proved relationships between climatic changes and forest invasion.

Hemispheric results have a high conformity with the climatic changes derived from Sedro Woolley's records and local tree-growth variations. The northern hemisphere temperatures (Fig. 6: B), which started increasing in the 1880s or 1890s, rose conspicuously from about 1920 to 1940. In spite of a cooling trend from about 1940 to 1965 (Reitan 1974, Ingram et al. 1981, p. 12) the climate was still relatively warm up to the 1950s or 1960. Very recently, temperatures have possibly risen slightly (Brinkmann 1976), though this change appears to be too small to be statistically significant (Ingram et al. 1981, p. 12). The age distribution of invaded trees on Mount Baker corresponds suprisingly well with the hemispheric temperature curves (Fig. 6).

Regional investigations also support the conclusions drawn here. For instance, when studying sea level pressure patterns over the North Pacific and western North America Blasing a. Lofgren (1980) divide the 20th century into three different periods: a cold period to the early 1920s, a warm period from the mid-1920s to the mid-1950s, and an "average" period after about 1955. According to tree-ring analyses in the Pacific Northwest (Brubaker 1980, p. 804), the years 1919 to 1940 were also drier than usual.

Glacier-front variations, which usually reflect climatic fluctuations with a variable time lag (e.g. Porter 1982), correspond quite well to the climatic pattern and age distribution of the trees established in the past 100 years. The youngest prominent terminal moraine of the Coleman Glacier was formed in about 1886–87 (Heikkinen 1984), i.e. at the same time as the oldest invading saplings took root in the study area. In the first half of this century, Mount Baker glaciers receded one to two kilometres (Long 1953), being at their minimum extent for centuries in about 1950 (Long 1955, Bengtson 1956). The rapid glacial retreat coincided with the most massive forestation. Since 1950, when these glaciers reactivated and started to expand (Harrison 1970, Heikkinen 1984), forest invasion has slowed down. Glaciers on Mount Rainier, Washington, behaved in much the same fashion as those on Mount Baker (Sigafoos a. Hendricks 1972, Burbank 1981). In fact, fluctuations of the Northern Hemisphere glaciers in general have followed largely the same pattern in the last 100 years (Porter 1981b, Fig. 6: D). Consequently, the dates of climate-induced glacier oscillations indirectly confirm the view that the recent forest expansion is attributable to a warm (and dry) climate.

Discussion and comparisons

Inferences drawn in earlier studies on the invasion of meadows by trees in western North America are fundamentally in accordance with the present results. The period from 1920 to 1940 in particular appears to have favoured tree establishment. Most of subalpine seedlings studied by Brink (1959) in British Columbia date back to these decades, although the oldest ones had germinated in the second half of the 19th century. In the North Cascades of Washington, near Mount Baker, the recent forestation started intensively in about 1920 and largely came to an end in the 1950s (Lowery 1972). Likewise, Paradise Valley subalpine meadows on Mount Rainier, Washington, were invaded by saplings between the 1910s and the 1950s, culminating in the 1920s and 1930s (Franklin et al. 1971). In the Olympic Mountains of the Coast Range, seedlings became established in the timberline region from the 1920s to the 1960s (Fonda a. Bliss 1969). According to LaMarche (1973), the recent ascent of treelines commenced in the White Mountains of California as early as 1850 and lasted approximately 100 years.

In all the cases mentioned above the forest advance has been connected directly or indirectly with a simultaneous warm, in part also dry climate (Franklin et al. 1971). Increased air temperatures (e.g. Lowery 1972, LaMarche 1973) and diminished depth and duration of winter snow cover (Brink 1959, Fonda a. Bliss 1969) are assumed to have lengthened the growing season and enabled the intensive tree invasion (Franklin et al. 1971). This conclusion is based on either correlations with the behaviour of local glaciers, or on relatively short climatic records of nearby meteorological stations, or on general information on climatic variations.

Some results depart from the above-mentioned trend. Vale (1981) reports that Oregon's montane (!) meadows were mainly invaded by saplings as late as 1950–59. Additionally, all trees studied there started growing after 1920 and the recent forestation seems to have continued up to the present, or at least until the 1970s. Fires and particularly sheep grazing up to 1940 probably delayed the establishment of trees, as Vale assumes. Vale's explanation, however, that the cool moist weather since 1950 contributed to the intensive tree invasion is not supported by either the conclusions quoted above or results of the present study.

Also in the Wind River Mountains, Wyoming, an overwhelming majority of subalpine seedlings became established relatively late, 1940 to 1963, although tree invasion of meadows had already started in about 1890 (Dunwiddie 1977), as on Mount Baker. Dunwiddie concludes that moderate cattle grazing, which improved tree establishment by reducing the rival meadow vegetation, was the major reason for the accelerated forest expansion.

Almost all the tree invasions referred to above experienced some delay with respect to the warmest and driest climatic period, about 1920 to 1940. This might, in part, have resulted from those microenvironmental changes that the pioneer trees induced. Being dark objects, the first seedlings absorbed more solar radiation than the ambient white snow did, which accelerated snowmelt and locally improved thermal conditions (Franklin a. Mitchell 1967, Lowery 1972, p. 16). The pioneer trees also protected subsequent saplings from abrading and desiccating winds. The pioneers thus provided sheltered habitats for tree juveniles even when the climate turned less favourable. This view is backed by the present results from Mount Baker, where tree invasion on the side slopes of the ridge started and continued later than on the ridge crest, where the first trees were established.

The subalpine tree invasion on the studied flank of Mount Baker, and probably in many other locations in the maritime Pacific Northwest, is basically attributed to high temperatures and low precipitation rates, both of which lessen the winter snow cover, promote its melting and lenghten the growing season. Wide subalpine meadows, the relatively low altitude of the timberline, the lack of real krummholz forms and the scarcity of wind-battered trees obviously indicate that the heavy snow cover rather than the direct impact of the temperature or desiccating winds, for instance, controls the meadow-forest pattern in the study area and its surroundings.

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DIE BEDEUTUNG VON INNOVATION UND DIFFUSION NEUER TECHNOLOGIEN FÜR DIE REGIONALPOLITIK

Mit 10 Abbildungen und 1 Tabelle

Ernst Giese und Josef Nipper

Summary: The impact of innovation and diffusion of new technologies for regional policy in the Federal Republic of Germany

Regional policy in the Federal Republic of Germany has, above all, formerly concerned itself with the assumption of a high regional mobility of firms and capital. Attempts have been made with the help of regional development measures to direct this mobility readiness towards structurally weak, underdeveloped marginal areas of the Federal Republic of Germany. These attempts were still showing signs of success up to the beginning of the 70s, so that the results of earlier efficiency analyses as well as the development of the international division of labour led to the conclusion that a change in regional policy is essential in order to strengthen the competitiveness of the development areas so that a more comprehensive estimation than before will have to be established. This aims at using the capacity of the region to achieve its optimal development, especially for the strengthening of each area of production, and aims at the manufacture of what were originally called "intelligent products" and aims at the development of new technologies. Knowledge of requirements, influencing factors and the consequences of innovation and diffusion processes is an essential basis for an adequate regional policy. In the Federal Republic of Germany, therefore, large numbers of regional policy makers are calling for a strategically new orientation of regional policy in the direction of a stronger, "innovation – orientated regional policy". Before carrying out the new regional policy, however, the question should be raised whether its basis is theoretically and above all empirically secured. This will be done in the investigation based upon the results to hand of innovation and diffusion research into technological innovations.

I

Die auf Arbeiten von Marx (1972, 1973, 1975) zurückgehende „Regionalpolitik des mittleren Weges" hat die Raumordnungspolitik in der Bundesrepublik Deutschland in den 70er Jahren in entscheidender Weise beeinflußt. Angesichts der in den letzten Jahren aufgetretenen wirtschaft-