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A Comparative Study of Spruce Growth Rates in Four Different Regions of the World

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ABSTRACT

Coniferous forests in which some member of the genus *Picea* (spruce) is present as a dominant or codominant species occur throughout the Northern Hemisphere. During the period of 1985-89, quantitative data on composition and structure of the vegetation and soil chemical and physical characteristics were obtained for forest communities containing red spruce (*Picea rubens* Sarg.) in the Appalachian Mountains of central West Virginia, Engelmann spruce (*P. engelmannii* [Parry] Engelm.) in the Swan Mountains of northwestern Montana, white spruce (*P. glauca* [Moench] Voss) in central Alaska, and Himalayan spruce (*P. smithiana* [Wallich] Boiss.) in the Himalayan Mountains of northwestern India. In order first to determine and then to compare general patterns of growth and ages of the species of spruce at each study site, increment growth cores also were collected. The importance value (%) recorded for spruce ranged from 7.0 for Himalayan spruce in India to 63.1 for white spruce in Alaska. Spruce shared dominance with an admixture of eight species of hardwoods in the tree stratum at the study area in West Virginia; at the three other study areas, dominance was shared with only one or two other species. Mean number of rings ±SE for cored trees ranged from 96 ± 6.5 to 220 ± 13.3. Total radial growth for the period 1900-79 varied considerably (76.0 to 194.8 mm), with the highest value recorded for Himalayan spruce (youngest overall) and the lowest value for white spruce (highest latitude).

INTRODUCTION

Coniferous forests in which some member of the genus *Picea* (spruce) is present as a dominant or codominant species commonly occur at higher latitudes and higher elevations throughout the Northern Hemisphere. In eastern North America, red spruce (*Picea rubens* Sarg.) is the most characteristic species of the subalpine coniferous forests that occupy higher peaks and ridges of the Appalachian Mountains. Dendroecological (tree-ring) data from several studies (e.g., Adams et al., 1985; McLaughlin et al., 1987) recently conducted in spruce and spruce-fir forests of the Appalachians indicate that a reduction in average ring widths (radial increments) has occurred in red spruce during the past 20 to 25 years. Several hypotheses have been proposed to explain this growth-trend decline, including climatic factors (e.g., Cook et al., 1987; Cook and Johnson, 1989; Hamburg and Cogbill, 1988), disease (e.g., Mielke et al., 1986), community dynamics (e.g., Federer and Hornbeck, 1987; Hornbeck et al., 1986, Reams and Huso, 1990; Van Deusen, 1990; Zedaker et al., 1987), atmospheric pollution (McLaughlin et al., 1987), or possible combinations of some of the preceding (e.g., Van Deusen et al., 1991). A general consensus was developed by the several authors in the last chapter of *Ecology and Decline of Red Spruce in the Eastern United States* (Eagar and Adams, 1992), concluding "... that airborne pollutant chemicals have provided the principal impetus for red spruce decline" (p. 410). However, these same authors also point out that many gaps in information still remain. One of the major difficulties associated with objectively evaluating this recent reduction in red spruce radial growth is determining whether, in fact, it does represent a substantive departure from what might be considered "normal" for spruce. Norway spruce (*Picea abies* [L.] Karst.) in western Europe has exhibited widescale decline (a general syndrome referred to as *Waldsterben*) (Shutt and Cowling, 1985), but there appear to be few data available for other species of spruce in the Northern Hemisphere for comparison of growth rates. Consequently, it would seem worthwhile to compare the recent (i.e., since 1900) growth pattern of red spruce with those of several other species of spruce found elsewhere in the Northern Hemisphere.

The primary purpose of this paper is first to describe and then to compare the general patterns of radial growth since 1900 for four different species of spruce found in widely separated regions of the Northern Hemisphere. In addition, very general quantitative data on vegetation and soils are provided for the forest communities in which these four species of spruce occur as canopy dominants or codominants.

THE STUDY AREAS

The increment growth cores and quantitative data upon which this paper is based were collected during the period of 1985-89 from four different study areas: (1) the Gaudineer Scenic Area on Cheat Mountain in central West Virginia (38°40′ N latitude, 81°30′ W longitude), elevation 1220 m, old-growth red spruce (*Picea rubens*)-northern hardwood forest; (2) the Swan Mountains in northwestern Montana (48°09′ N latitude, 114°56′ W longitude), elevation 2040 m, subalpine spruce (*Picea engelmannii* [Parry] Engelm.)-fir forest; (3) the Bonanza Creek Experimental Forest near Fairbanks in central Alaska (64°55′ N latitude, 146°10′ W longitude), elevation 300 m, upland old-growth white spruce (*Picea glauca* [Moench] Voss)-quaking aspen forest; and (4) near the village of Narkanda in the Himalayan foothills of Himachal Pradesh, northwestern India (31°16′ N latitude, 77°27′ E longitude), elevation 2700 m, montane Himalayan spruce (*Picea smithiana* [Wallich] Boiss.)-fir forest.

Geological substrata exposed at the surface on Cheat Mountain in central West Virginia are predominantly coarse sandstones and conglomerates. Annual precipitation at higher elevations in this region of West Virginia usually exceeds 150 cm and is generally well distributed throughout the year with no pronounced dry season (Core, 1966). Lower elevations within the Swan Mountains of northwestern Montana receive an average of about 75 cm of precipitation annually; although detailed climatic data are lacking, somewhat higher values would be expected for higher elevations in the same region. The winter months and June are relatively moist, but only 3-5 cm/mo occurs during July and August (McCune, 1982). The underlying geological substrata of the general study area are primarily quartzites and argillites (Pfister et al., 1977). Average annual precipitation for the study area in central Alaska is approximately 30 cm, about 35% of which falls as snow. The bedrock consists of schist overlain by a layer of micaceous loess of varying thickness (Van Cleve et al., 1986). Total annual precipitation for Himachal Pradesh in northwestern India usually exceeds 150 cm, with the major portion (>70%) occurring during the monsoon months of July to September. The major geological formations of this region of the Himalayas consist largely of calcareous shales and limestones, with some quartzites, slates, and sandstones also present (Gansser, 1964).

METHODS

In each study area, the unit of forest vegetation (stand) selected for sampling met the following criteria: (1) typical of the general study area with respect to both general composition and floristics, (2) a relatively homogeneous unit of vegetation, (3) located in an area of essentially uniform topography, and (4) no evidence of appreciable recent (<30 yrs) disturbance by humans or other causes. For the study areas in Montana and Alaska, quantitative data for the tree stratum were obtained from a single 20 by 50 m (0.1 ha) rectangular plot laid out with its long axis parallel to the contour of the slope; two such plots were used for the study area in West Virginia. In India, the tree stratum was sampled using the point-centered quarter method (Mueller-Dombois and Ellenberg, 1974). Species and diameter were recorded for all woody stems 10 cm DBH (diameter at breast height; 1.37 m).

Field data were converted to absolute measures. Density (number of stems per hectare) and basal area (m^2 per hectare) were determined for all species. These data were then used to calculate species importance value indices (Curtis and McIntosh, 1951). As used in this paper, importance values are one-half the sum of relative density and relative basal area.

Increment growth cores were collected from at least twelve representative larger (i.e., canopy dominants or codominants), healthy (i.e., without obvious visible damage) spruce trees in each study area. Trees selected for coring occurred both within and outside the plot or area actually sampled. Cores from the India, Alaska, and Montana localities originally were collected only for the purpose of determining the ages of the largest trees in stands, rather than for the data we are sharing in this report. Consequently, no effort was made to establish comparable conditions (e.g., obtain cores from the same number of trees) in all stands.

Cores were extracted at breast height using a standard Swedish-made increment borer. In the laboratory, cores were air-dried, mounted on grooved boards, and sanded. Cores from each region were crossdated to assure that measurements were made for comparable time periods. In order to determine the general trend of growth, total ring widths for each five-year period were measured to the nearest 0.1 mm. Measurements from all cores for a particular study area were grouped and a mean value for each five-year interval was calculated. Further, growth of each species in the present century, 1900 through 1979, was determined in twenty-year intervals in order to detect any obvious differences in growth over longer periods of time. Since no attempt was made to control age/maturity or competitive status of trees at the various sites and our data are limited, we have chosen to make only general comparisons of growth patterns among sites.

Soil samples were collected from four or more locations in each study area and brought back to the laboratory for analysis. In the laboratory, samples were oven-dried at 100° C for 48 hours and then passed through a 2-mm sieve to remove gravel. Soil pH values were determined in a 1:1 soil:water mixture with a glass electrode pH meter, organic matter was determined by loss on ignition (Cox, 1990), and soil texture was analyzed with the Bouyoucos hydrometer method (Bouyoucos, 1951). Later, analyses of phosphoric acid, calcium, magnesium, potassium, zinc, nitrate nitrogen, and total soluble salts were conducted by the Soil Testing Laboratory at Virginia Polytechnic Institute and State University, using the procedures outlined by Donohue and Friedericks (1984).

RESULTS AND DISCUSSION

Composition of the tree stratum in each of the four study areas is given in Table 1. The importance value recorded for spruce in the stands we sampled varied widely, ranging from 7.0 for Himalayan spruce in India to 63.1 for white spruce in Alaska. Spruce shared dominance with eight other species (an admixture of northern hardwoods) in the tree stratum at the study area in West Virginia; at the three other study areas, dominance was shared with only one or two other species.

The mean number of rings for cored trees ranged from 96 (India) to 220 (Montana) (Table 2). Since pith was not reached in all cored trees and stem growth to breast height occurred over innumerable years, these ages should be considered conservative estimates. Ages of spruce at the West Virginia and Montana sites were comparable and are in a range probably considered representative of mature trees for both species. In contrast, spruce at the Alaska and India study sites were younger and thus cannot be considered "mature" (even though they were canopy dominants). Maximum number of rings recorded for any one tree (368) was from a red spruce in West Virginia.

Total radial growth for the period 1900-1979 (Table 2) varied from 76.0 mm for white spruce in Alaska (presumably the site with harshest environmental conditions) to 194.8 mm for Himalayan spruce in India (on average, the youngest trees we sampled). As a general observation, subalpine spruce in Montana exhibited the most consistent growth during the past century, whereas Himalayan spruce displayed the most erratic growth. Both red and white spruce evidenced slower growth beginning in 1940. The period 1960-1979, constituting twenty-five percent of the total period of growth since 1900, is the time interval for which a considerable reduction in radial growth has been reported for red spruce throughout its range in the Appalachian Mountains of the eastern United States (Siccama et al., 1982; Johnson and Siccama, 1983; McLaughlin, 1985; Adams et al., 1985; McLaughlin et al., 1987; Adams et al., 1990). Interestingly, the data presented in Table 2 show that radial growth during the 1960-1979 interval exceeded twenty percent of the total growth since 1900 for all but red spruce in West Virginia. In fact, radial growth for each of the other twenty-year time intervals since 1900 (i.e., 1900-1919, 1920-1939, and 1940-1959) exceeded twenty percent of the total growth for all species except Himalayan spruce during the 1900-1919 time interval, when these trees presumably were growing under suppressive subcanopy conditions. Only rarely did radial growth for any of the four species of spruce in a given twenty-year time interval exceed thirty percent of the total growth since 1900. The highest value was recorded

TABLE 1. Composition of the tree stratum (stems ≥10 cm DBH) for each of the four study areas. Nomenclature follows Radford et al. (1968) for West Virginia, Hitchcock and Cronquist (1973) for northwestern Montana, Hultén (1968) for Alaska, and Polunin and Stainton (1984) for northwestern India.

Species	Density (N/ha)	Relative density (%)	Basal area (m^2/ha)	Relative Basal area (%)	Importance value
WEST VIRGINIA					
Picea rubens	140	30.8	17.29	45.8	38.3
Betula lutea	115	25.3	7.13	18.9	22.1
Fagus grandifolia	100	22.0	5.09	13.5	17.7
Prunus serotina	15	3.3	4.19	11.1	7.2
Acer rubrum	20	4.4	3.02	8.0	6.2
Acer pensylvanicum	30	6.6	0.32	0.9	3.7
Magnolia acuminata	15	3.3	0.48	1.3	2.3
Magnolia fraseri	15	3.3	0.20	0.5	1.9
Liriodendron tulipifera	5	1.1	0.01	0.1	0.6
Total	455	100.0	37.73	100.0	100.0
NORTHWESTERN MONTANA					
Abies lasiocarpa	910	96.8	25.83	79.1	87.9
Picea engelmannii	30	3.2	6.83	20.9	12.1
Total	940	100.0	32.66	100.0	100.0
CENTRAL ALASKA					
Picea glauca	620	58.5	30.19	67.6	63.1
Populus tremuloides	320	30.2	11.46	25.7	27.9
Betula papyrifera	120	11.3	3.01	6.7	9.0
Total	1060	100.0	44.66	100.0	100.0
NORTHWESTERN INDIA					
Abies pindrow	282	92.5	75.34	93.6	93.0
Picea smithiana	23	7.5	5.18	6.4	7.0
Taxus baccata	—	—	—	—	P*
Total	305	100.0	80.52	100.0	100.0

*not encountered during sampling but present in the general study area

for red spruce during the 1920-1939 time interval when 31.8 percent of its total radial growth between 1900 and 1979 occurred.

Inspection of the radial increment patterns (based on five-year means) presented in Figure 1 reveals that growth of both Himalayan spruce and red spruce increased rapidly in the early 1900s. A rather interesting release which occurred at the West Virginia site in the 1860s-1870s (possibly in response to Civil War activities) was followed by a fairly severe decline beginning in the 1880s. This decline, which coincided with a period of high spruce mortality, was reported by Millspaugh (1891) and Hopkins (1899) and is discussed in more detail by Adams and Stephenson (1989).

TABLE 2. Summary data on spruce trees from which increment growth cores were collected in spruce and spruce-fir forests in four different regions of the world. Values given for DBH, radial growth, and number of rings are sample means ±SE.

Parameter	West Virginia	Montana	Alaska	India
Number of trees cored	21	26	15	12
DBH(cm)	60.3 ±7.9	70.9 ±2.9	36.8 ±1.1	62.4 ±2.4
Number of rings	200 ±9.6	220 ±8.5	159 ±2.6	96 ±6.5
Maximum number of rings	368	344	171	129
Radial growth (mm):				
1960-1979	23.5 ±2.8	25.0 ±2.5	16.4 ±1.7	55.2 ±4.1
1940-1959	30.4 ±2.9	26.9 ±2.7	16.2 ±1.14	55.2 ±4.1
1920-1939	44.4 ±4.2	24.7 ±2.0	23.1 ±1.3	54.3 ±6.4
1900-1919	41.4 ±3.4	26.0 ±2.2	20.3 ±1.4	38.9 ±2.5
Radial growth for the 1960-1979 interval/total radial growth from 1900 (%)	16.8	24.4	21.6	28.3

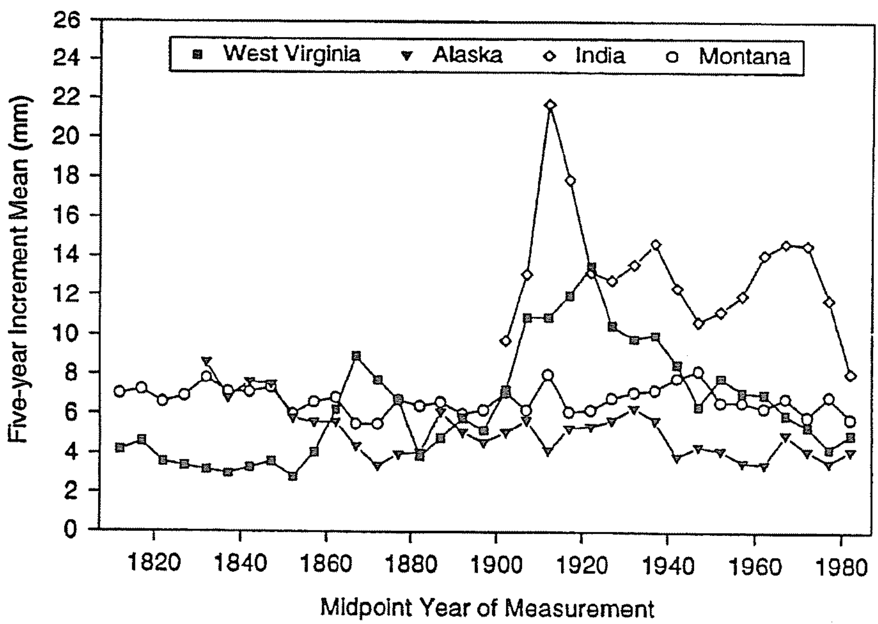

FIGURE 1. Incremental growth (based on five-year means) for cored spruce trees in the four study areas.

A pre-1950 period of increased growth for red spruce (which, in our data, became apparent following the late 1800s decline) has been reported by other researchers in the northern Appalachians (e.g., Reams and Huso, 1990; Van Deusen, 1990). Van Deusen (1990) suggested that possible stand disruption during

TABLE 3. Summary data on soils associated with spruce and spruce-fir forests in four different regions of the world. Values given are sample means (n = 4).

Parameter	West Virginia	Montana	Alaska	India
Organic matter (%)	56	20	2	14
pH	3.1	4.1	5.3	6.5
Calcium (ppm)	131	194	406	1200 +
Magnesium (ppm)	27	39	120 +	120 +
Potassium (ppm)	62	65	27	80
Phosphorus (ppm)	26	7	3	16
Zinc (ppm)	4.7	4.6	0.3	3.6
Nitrogen (ppm)	22	9	4	22
Soluble salts (ppm)	768	226	< 100	234

the 1930s and 1940s by insects, disease, or anthropogenic factors may have been responsible for a period of release that resulted in abnormally fast growth. This, in turn, established conditions for the recent period of decline. The disruption in the West Virginia stand occurred much earlier (i.e., late 1800s), with the increased growth beginning just after 1900. During the early part of the present century, extensive logging operations were still ongoing in the general vicinity of the study area in West Virginia. However, such operations would not have affected this study area, since it is considered to be an old-growth forest that has not been subjected to extensive human disturbance (Core 1966). Another type of disturbance, birch dieback, has been documented in some stands of red spruce in Maine by Reams and Huso (1990). Yellow birch (*Betula lutea* Michx. f.) does share dominance with spruce in the West Virginia study area. However, such a scenario is doubtful for our stand, since any associated dieback of birch was never mentioned in the well-documented decline of red spruce in the late 1800s.

A fairly severe reduction in growth of red spruce, commencing in the 1920s and continuing until around 1950, followed the earlier period of increased growth (Figure 1). The decline is not apparent in Table 2 since 1920-1939 included the period of maximal growth of these trees in the early 1920s. This decline most likely can be attributed to natural intrastand competition following survival and subsequent release of this cohort of trees from prior disturbance. It would appear that the pattern of decreasing growth had leveled off in the 1940s and 1950s. However, trees at this site then entered another period of consistent (though gradual) diminishing growth until 1980. McLaughlin et al. (1990) have suggested that high atmospheric inputs of SO_4 and NO_3 to soils already very acidic can reduce levels of both calcium and magnesium, while raising levels of aluminum to the point of potential toxicity to red spruce. The combination of these factors may be adversely affecting growth and physiology of red spruce trees at high elevation sites in the Great Smoky Mountains National Park. Interestingly, our data (Table 3) indicate that considerably lower values of pH, calcium, and magnesium exist for soils at the West Virginia site than for soils at the other sites. Conversely, values for soils in

India (where growth for the most recent time period was greatest) were the highest of any site we studied. Acid deposition is well-documented in West Virginia (Helvey and Kunkle, 1986; Helvey and Edwards, 1987; Edwards and Helvey, 1991) and our own recent analyses of soils from this region of West Virginia often show relatively high levels of aluminum (unpublished data). Given this information, our data would tend to support the hypothesis of McLaughlin et al. (1990).

Data from the 1980s and into the 1990s (Adams and Stephenson, 1992) do suggest an amelioration of the recent growth decline of red spruce in the mid- and southern Appalachians. It is interesting to note that many of the red spruce trees included in our study were growing at a similar and even slower rate during the early 1800s as compared to their growth during the mid- and late 1900s. Perhaps these trees merely are returning to their pre-1860s growth rate. In any case, and not surprisingly, the results of the present study (although based on limited data) clearly demonstrate that the pattern of growth for each of the four species of spruce we studied is indeed unique.

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