United States
Department of
Agriculture

Forest Service

Rocky Mountain Forest and Range Experiment Station

Fort Collins,
Colorado 80526

General Technical Report RM-117

Silvical Characteristics of Blue Spruce

Gilbert H. Fechner

Abstract

This report summarizes information on distribution, botanical description, habitat conditions, life history, special uses, and genetics of blue spruce.

USDA Forest Service
General Technical Report RM-117

April 1985

Silvical Characteristics of Blue Spruce

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[1]This report was prepared under cooperative agreement between the Rocky Mountain Forest and Range Experiment Station (MFRWU-1252) and Colorado State University, both in Fort Collins, Colo.

Contents

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Blue spruce (*Picea pungens* Engelm.)[2] is one of seven species of spruce indigenous to the United States. Other common names include Colorado blue spruce, Colorado spruce, silver spruce, and pino real.

DISTRIBUTION

Blue spruce is primarily restricted to the central and southern Rocky Mountains of the western United States. Its range extends across 15° 04′ of latitude (33°50′ to 48°54′ N.), a distance of about 1,050 miles, and 9° 15′ longitude (104°45′ to 114°00′ W.). Blue spruce is found from southern and western Wyoming, southwestern Montana, and eastern Idaho, south to Utah, northern and eastern Arizona, southern New Mexico, and central Colorado. It also has been reported in isolated locations in north-central Montana (Strong 1978) and in north-central (Coconino County) Arizona (Jones and Rietveld 1974) (fig. 1).

Approximately one-half of the blue spruce distribution is in the mountains of Colorado. In Idaho it is restricted to the Wasatch and Caribou Mountains, the Snake River Range, and the extreme northeastern part of the state.

In addition to the recently reported locations in Arizona, blue spruce is found on the Kaibab Plateau and in the Lukachukai and White Mountains. In New Mexico, it grows from the Sacramento Mountains and the Sangre de Cristo Range westward in scattered locations. Blue spruce is not abundant in Utah, although it grows over a wide range from Iron County to the Uinta Mountains along the mountain backbone of that state, and also in the Deep Creek Mountains near its western boundary (Erdman 1970).

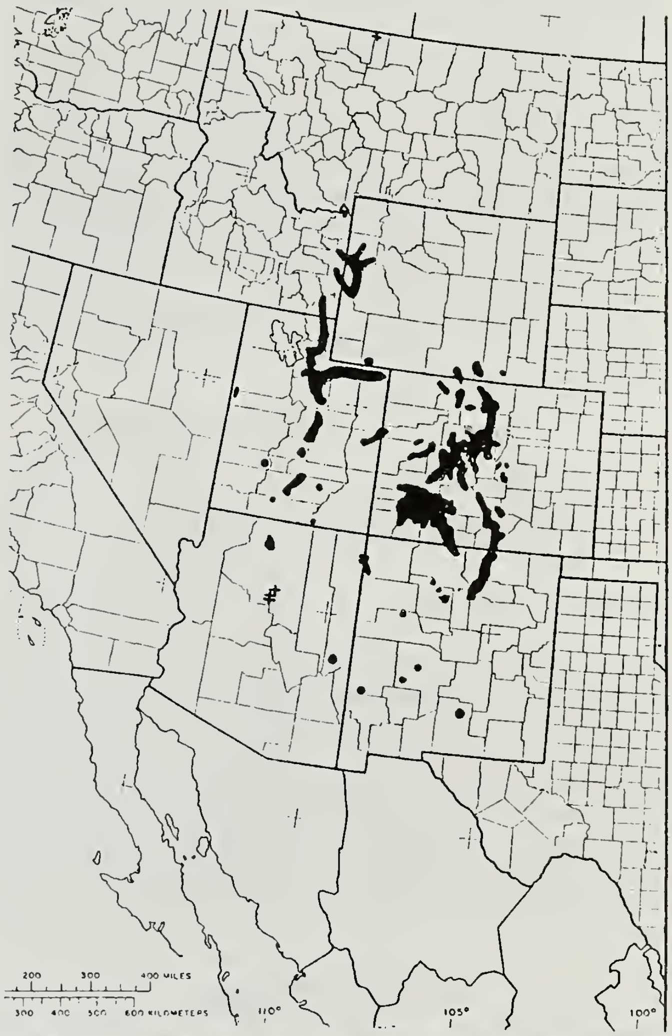

Figure 1.—Natural distribution of blue spruce (*Picea pungens* Engelm.). Adapted from Little 1971.

BOTANICAL DESCRIPTION

Leaves.—Leaves are straight, 4-angled, about 1 to 1–1/4 inches long; they are yellow green to bluish green to silvery-white, often with a glaucous bloom. The stiff, sharp-pointed leaves extend nearly at right angles to the twig. When chewed, they have a sharp, acid taste.

Twigs.—The stout, stiff, shiny twigs are greenish brown, becoming orange brown to grayish brown; they are usually glabrous.

Buds.—The buds are pointed, about 1/2 inch long, light chocolate brown; the scales are usually reflexed.

Conelets.—Blue spruce is monoecious. Male conelets are yellow, tinged with red, and the female, light pink to bright scarlet; occasionally conelets of both sexes are light yellow green.

Cones.—The cones are oblong to cylindrical, and usually 2–1/2 to 3–1/2 inches long, but sometimes up to 4–1/2 inches. They are green, tinged with red, but become straw-colored at maturity. The unstalked or short-stalked cones have scales that are thin, diamond-shaped, tough, wrinkled, with straight or ragged margins and flat tips, with the broadest point of the scale below the middle. Maturing in August and September, some cones fall during the first winter, but many remain on the tree for 2 to 3 years after seeds have been released. Cones are concentrated in the upper third or less of the crown.

[2] *Scientific and common names of trees used in this report are from Little (1979); names of other plants follow Nickerson et al. (1976). For plants not included in either of these publications, the name used by the author of the reference has been adopted.*

Bark.—The gray bark is tinged with red. It is scaly when young, becoming furrowed, with rounded ridges. Epicormic branches frequently develop along the trunk.

HABITAT

Climate

Blue spruce grows in a climatic zone that is generally cool and humid. It may be classified as a microthermal to taiga temperature province and a subhumid to humid moisture province, characterized by low summer temperatures and low winter precipitation (Thornthwaite 1948).

Local temperature data within the range of blue spruce are sparse. Mean annual temperatures, where blue spruce is most commonly found in Colorado and the Southwest, are as follows:

	Mean temperatures °F
Annual	39–43
January	25–27
January minimum	12–16
July	57–59
July maximum	70–72

The frostfree period from June to August is about 55 to 60 days (Bates 1924, Pearson 1931).

Precipitation data are also sparse. Average annual precipitation where blue spruce most commonly occurs varies from 18 to 24 inches. Winter precipitation is usually low; less than 20% of the annual moisture falls from December through March. Fifty percent of the annual precipitation falls as rain during the growing season (Baker 1944, Bates 1924, Pearson 1931).

Soils and Topography

The soils on which blue spruce is found vary considerably, but frequently they consist of rich, moist, fairly fertile, sandy to gravelly loams in streambottoms, in valleys, and on low, moist soils or on subirrigated, gentle slopes. Depending on the location, these soils may be alluvial or fluvial deposits derived from a variety of parent materials, including limestone, quartzite, sandstone, or shale. The soils are approximately neutral to slightly alkaline (pH 6.8 to 7.2) (Dixon 1935).

In Arizona and New Mexico, blue spruce is found on gentle upland slopes and in well-watered tributary drainages, extending down intermittent streams, and on lower northerly slopes. Soils there may consist of sponsellar loam, sponsellar gravelly silt loam, or deep alluvial soils derived from limestone (Moir and Ludwig 1979). Similarly, in many localities in Utah, blue spruce is found on loamy sands, loams, and clays, with some gravel present. Most of these soils are derived from calcareous parent materials (Mauk and Henderson 1984, Pfister 1972). In a few localities in Utah, blue spruce may be found on swampy sites; the species is considered to be the pioneer tree species in wet soils (Dixon 1935).

In general, the soils and the landforms of the mixed conifer forest of the central Rocky Mountains, of which blue spruce is often a part, are similar to those of the spruce-fir type at higher elevations and the ponderosa pine type at lower elevations, although the sites on which blue spruce grows are more moist than those of ponderosa pine and warmer than those of Engelmann spruce and subalpine fir (Alexander 1974) (fig. 2).

Blue spruce is characteristically found at elevations between 6,000 and 9,000 feet in the northern part of its range, and from 7,000 to 10,000 feet in the southern part. At the most northerly extent of its reported distribution in Montana, it occurs at 6,960 feet (Strong 1978). In northern Colorado, it is mostly found between 6,000 and 8,500 feet, occasionally to 9,000 feet (Fechner 1980). In Utah, most of the blue spruce usually grows between 6,560 and 8,530 feet, but an island population has been reported at 9,840 feet and occasional trees grow to timberline (Dixon 1935, Johnson 1970). In Arizona, this species commonly is found from 8,300 to 9,100 feet on the Kaibab Plateau; in the White Mountains, it occasionally grows up to 11,000 feet and down streams to 8,000 feet (Little 1950, Peattie 1953). In New Mexico, blue spruce is found between 7,800 and 8,100 feet, and it is found up to 9,100 to 9,500 feet in the Sangre de Cristo Mountains and similar elevations in the San Juan Mountains of southwestern Colorado (Moir and Ludwig 1979).

Associated Forest Cover

Blue spruce is characteristically a species of the montane zone in the central and southern Rocky Mountains. It is the principal species of the blue spruce cover type (SAF Type 216) (Society of American Foresters 1980) and is a minor associate in four other forest cover types:

SAF Type Number	**Type**
206	Engelmann Spruce—Subalpine Fir
210	Interior Douglas-fir
235	Cottonwood—Willow
237	Interior Ponderosa Pine

In the central and southern Rocky Mountains of Colorado, Utah, and southern Wyoming, where most of the blue spruce grows, Rocky Mountain Douglas-fir (*Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco) and Rocky Mountain ponderosa pine (*Pinus ponderosa* var. *scopulorum* Engelm.) are perhaps the most persistent tree associates of blue spruce. Blue spruce never grows in extensive stands, but it is often the only conifer present on streamside sites.

The most common hardwood associate of blue spruce in the central Rocky Mountains is narrowleaf cottonwood (*Populus angustifolia* James) (fig. 3). Quaking aspen (*Populus tremuloides* Michx.) is also a frequent associate, and blue spruce will invade quaking aspen stands, especially in moist, protected locations. Occasionally balsam poplar (*Populus balsamifera* L.) is found with blue spruce. Smaller streamside trees and common shrub associates of blue spruce in the central Rocky Mountains include water birch (*Betula occidentalis* Hook.), mountain alder (*Alnus tenuifolia* Nutt.), shrubby cinquefoil (*Potentilla fruticosa* L.), common snowberry (*Symphoricarpos albus* (L.) Blake), chokecherry (*Prunus virginiana* L.), and various species of willow (*Salix* L.). Herbaceous plants in the montane zone streambottom locations often include Richardson geranium (*Geranium richardsonii*) Fisch. & Trautv.) and grasses, such as foxtail barley (*Hordeum jubatum* L.), Kentucky bluegrass (*Poa pratensis* L.), timothy (*Phleum pratensis* L.), nodding brome or Porter brome (*Bromus anomalus* Fourn.), and bluejoint reedgrass (*Calamagrostis canadensis* (Michx.) Beauv.) (Hess 1981, Mauk and Henderson 1984).

On north-facing slopes adjacent to streambottom sites where blue spruce is found, Rocky Mountain Douglas-fir may form dense stands, and near the upper limits of the montane zone, that species may be replaced by lodgepole pine (*Pinus contorta* var. *latifolia* Engelm.). White fir (*Abies concolor* (Gord. & Glend.) Lindl. ex Hildebr.) is also associated with blue spruce on mesic sites in the central Rocky Mountains but not north of approximately 42°30′ N. latitude. On the north-facing slopes, blue spruce may extend somewhat up the slope in direct mixture with the above-named species, but is rarely found more than 30 to 40 feet above the streambottom or drainage bottom. Associated small trees and shrubs on these cool, moist sites include Rocky Mountain maple (*Acer glabrum* Torr.), western serviceberry (*Amelanchier alnifolia* (Nutt.) Nutt., common juniper (*Juniperus communis* L.), red-osier dogwood (*Cornus stolonifera* Michx.), and bearberry or kinnikinnick (*Arctostaphylos uva-ursi* (L.) Spreng.) (Fechner 1964, Hess 1981).

Forests of the south-facing slopes near the blue spruce streambottom sites of the montane zone in the central Rocky Mountains, or at the lower altitudinal extent of blue spruce, characteristically consist of open stands of Rocky Mountain ponderosa pine and perhaps Rocky Mountain juniper (*Juniperus scopulorum* Sarg.). Common shrubby vegetation on these sites include ante-

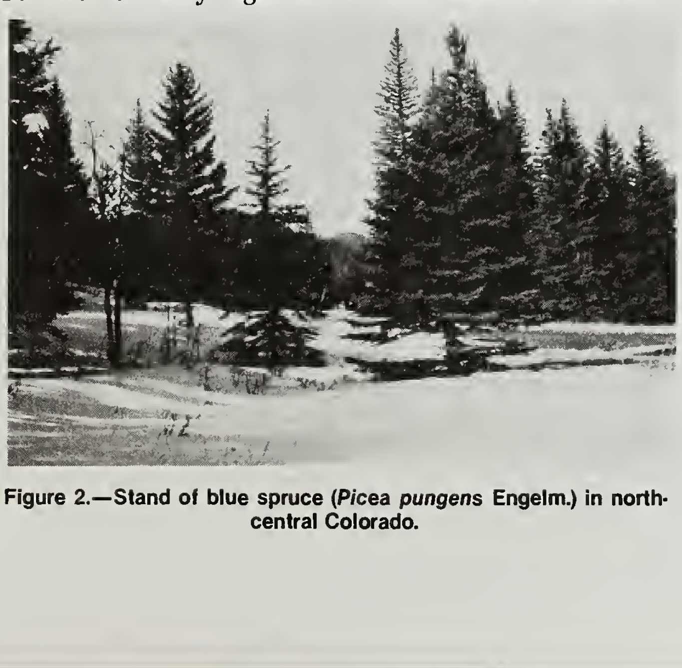

Figure 2.—Stand of blue spruce (*Picea pungens* Engelm.) in north-central Colorado.

Figure 3.—Typical streamside habitat of blue spruce in Colorado. Major hardwood associate shown is narrowleaf cottonwood.

lope bitterbrush (*Purshia tridentata* (Pursh) D.C.), alderleaf cercocarpus (*Cercocarpus montanus* Raf.), and wax currant (*Ribes cereum* Dougl.). Common herbaceous plants are hairy goldaster (*Chrysopsis villosa* (Pursh) DC.) and grasses, such as needleandthread (*Stipa comata* Trin. & Rupr.), blue grama (*Bouteloua gracilis* (H.B.K.) Steud.), and bottlebrush squirrel tail (*Sitanion hystrix* (Nutt.) J. G. Smith).

At 8,500 to 9,000 feet in the central Rocky Mountains of northern Colorado, blue spruce contacts the lower extent of the subalpine life zone, which is dominated by Engelmann spruce (*Picea engelmannii* Parry ex Engelm.) and subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.). Blue spruce may mingle with these two species on moist sites, such as lower, north-facing slopes, or with lodgepole pine on somewhat dry sites or on disturbed sites. Quaking aspen is also a common associate of blue spruce in the lower subalpine life zone on moist, disturbed sites. Rocky Mountain maple, common juniper, russet buffaloberry (*Shepherdia canadensis* (L.) Nutt.), bearberry honeysuckle (*Lonicera involucrata* (Richards.) Spreng.), and creeping mahonia (*Berberis repens* Lindl.) are common shrubs. Herbaceous associates in the lower subalpine zone include heartleaf arnica (*Arnica cordifolia* Hook.), sagebrush or wormwood (*Artemisia* spp.), cinquefoil (*Potentilla* spp.), and spreading thermopsis (*Thermopsis divaricarpa* A. Nels.); grasses may be bearded wheatgrass (*Agropyron subsecundum* (Link) Hitchc.) and Thurber fescue (*Festuca thurberi* Vasey) (Hess 1981, Mauk and Henderson 1984, Pfister 1972).

In the southern part of the blue spruce range (southwestern Colorado, Arizona, and New Mexico), blue spruce is a component of several habitat types, and it also occurs in the widespread and complex mixed conifer forest (Jones 1973, Moir and Ludwig 1979). These habitat types are relatively diverse, the blue spruce series constituting topoedaphic climaxes bordering meadows and in streambottoms. In general, blue spruce dominates in habitats that are too warm and dry for Engelmann spruce and subalpine fir and that are wetter than those typically occupied by ponderosa pine, although all three of these species are associates of blue spruce. Blue spruce forms ecotones with types dominated by subalpine fir, white fir, and Rocky Mountain Douglas-fir, and it also forms ecotones with the deciduous riparian forest and the woodland riparian types (Layser and Schubert 1979). Additionally, southwestern white pine (*Pinus strobiformis* Engelm.) is a common component of the mixed conifer forest containing blue spruce.

Typical shrub associates of blue spruce in the southern part of the range include alders and willows in the most moist situations, and Rocky Mountain maple, western serviceberry, chokecherry, common juniper, and Gambel oak (*Quercus gambelii* Nutt.) in somewhat drier situations. Western thimbleberry (*Rubus parviflorus* Nutt.), Utah honeysuckle (*Lonicera utahensis* Wats.), bearberry or kinnikinnick, and twinflower (*Linnaea borealis* L.) may also be found associated with blue spruce in some habitats.

Common herbaceous associates in various habitats of the southern part of the blue spruce distribution are fleabane (*Erigeron superbus* Rydb.), wild strawberry (*Fragaria ovalis* (Lehm.) Rydb.), groundsel (*Senecio cardamine* Greene) and sharpleaf valerian (*Valeriana acutiloba* Rydb.). Also associated with blue spruce may be sedges (*Carex* spp.) and grasses, such as Arizona fescue (*Festuca arizonica* Vasey), screwleaf muhly (*Muhlenbergia virescens* (H.B.K.) Kunth), fringed brome (*Bromus ciliatus* L.), and Kentucky bluegrass, the latter sometimes constituting up to 70% of the ground cover (Moir and Ludwig 1979).

In the northern part of the blue spruce range (northern Wyoming, Idaho, and Montana), the species occurs only in scattered locations. It may be found reproducing on cobble bars in the upper montane and lower subalpine zones, such as under established stands of narrowleaf cottonwood and among scattered ponderosa pines. Large shrub associates here include mountain alder, water birch, bearberry, honeysuckle, and various species of willow. Associated herbaceous plants include red baneberry (*Actea rubra* (Ait.) Willd.), sweetscented bedstraw (*Galium triflorum* Michx.), starry solomon plume or starry smilac (*Smilacina stellata* (L.) Desf.) and mountain bluebells (*Mertensia ciliata* (James) G. Don), especially in moist locations; Kentucky bluegrass and sedges are common grass and grasslike associates. Flats and benches may be dominated by big sagebrush (*Artemisia tridentata* Nutt.), whereas most adjacent slopes are predominantly covered with Engelmann spruce, and south-facing sites are dominated by lodgepole pine, as are disturbed Engelmann spruce forests (Mogren, personal communication 1981, Steele et al. 1979).

In the extreme northern extent of the blue spruce distribution, associates of this species are Engelmann spruce and white spruce (*Picea glauca* (Moench) Voss) (Strong 1978).

Blue spruce occurs in various seral stages, from pioneer to climax, in 32 currently recognized habitat types. These habitat types are summarized in the Appendix.

LIFE HISTORY

Reproduction and Early Growth

Flowering and Fruiting

Blue spruce is monoecious. Male strobili occur throughout the living crown of the tree, although they are usually more frequent in the upper one-half of the crown. They commonly develop in whorls of three to five at the base of the current vegetative growth, or singly in subterminal or terminal positions. Female strobili of blue spruce develop in the upper 10% to 25% of the live crown of mature trees. They usually occupy terminal positions on lateral branchlets (Fechner 1964, 1974).

The male strobili of blue spruce mostly are rose-red colored at the time that they emerge from the buds.[3] A single male strobilus, containing approximately 100 sporophylls, may produce about 370,000 pollen grains. The female strobili consist of 175 to 225 scales and thus have a potential to produce 350 to 450 seeds per cone. Pollen is shed in May and June, depending upon altitude (fig. 4) (Fechner 1964, 1974).

For a short period of time following emergence from the bud, the scales of the female strobili are greenish yellow. However, as peak receptivity is reached, the scales become light pink to red, the scales are reflexed 90 degrees or more toward the base of the strobilus, and the strobili become erect on the twig (fig. 5). Within approximately two weeks following initial receptivity, the female strobili change from erect to a position about +45° above horizontal. In another week, approximately 50% of the cones are −45° to pendent; during the fourth week, all remaining cones become pendent and reach approximate full size (Fechner 1964, 1974). Phenological events of blue spruce are summarized in table 1.

Seed Production and Dissemination

Blue spruce is generally considered to be a good to prolific seed producer; full crops of cones occur about every 2 or 3 years (Safford 1974, Sudworth 1916) but some intermediate years are complete failures (Fechner 1964). Seed production begins at approximately 20 years, and optimum seed-bearing age is reached between 50 to 150 years (Vines 1960). Cones mature in August of the first year, and seed shed begins from early to late September, depending on altitude, and continues into the winter (Fechner 1974, Safford 1974). Seed set may reach 198 sound seeds per cone, averaging about 85, on open-pollinated trees. However, self-pollination, which may reach 18% in natural stands, depresses seed set by as much as 75% (Cram 1983a, 1984b). The seed is wind-disseminated, and seedfall diminishes rapidly as distance from the source increases. Most seeds fall within 300 feet of the upwind timber edge (Alexander 1974).

[3]*Some trees bear yellowish-green strobili, but these trees occur in relatively low frequencies. Male and female strobili on a given tree are the same color, whether red or green.*

Figure 4.—Male strobili of blue spruce (*Picea pungens* Engelm.) at pollen shedding.

Figure 5.—Female strobili of blue spruce (*Picea pungens* Engelm.) at peak receptivity.

Table 1.—Notes on the phenology of blue spruce in the Bennett Creek area, Larimer County, Colorado (40°40′ N.; 105°30′ W.; 7,600 to 7,800 feet altitude) (Fechner 1964).

Date	Blue spruce: Male strobili	Blue spruce: Female strobile, cones	Blue spruce: Vegetative development	Associated species
April				
1-10	Internal and external growth becomes measurable	Strobilus buds appear dormant	Buds appear dormant	Quaking aspen (*Populus tremuloides* Michx.) male catkins begin to emerge from buds
10-20	Strobilus growth continues			Quaking aspen male catkins reach woolly stage
20-30	Strobilus growth continues			Quaking aspen pollen is shed. Wax currant (*Ribes cereum* Dougl.) vegetative buds burst
May				
1-10	Meiosis; strobilus growth obvious	Buds show measurable but not obvious growth	Buds show measurable but not obvious growth	American pasqueflower *Anemone patens* L. in full bloom. Quaking aspen and wax currant leaves emerging
10-20	Many strobili begin to emerge from buds; microspore stage; airsacs developing, but pollen sinks in water		Buds show definite internal development	American pasqueflower waning. Quaking aspen leaves 1/3 inch. Rocky Mountain ponderosa pine (*Pinus ponderosa* var. *scopulorum* Engelm.) shows obvious vegetative elongation
20-30	Most strobili have broken bud, most red (yellow-green on some trees); size increase is regular. Branches may be excised for pollen forcing	Strobili buds elongating; becoming erect, all scales intact; early free nuclear gametophyte stage. Time for flower isolation in breeding programs		Wax currant in full bloom. Rocky Mountain ponderosa pine vegetative elongation continues
June				
1-10	Strobili show sharp increase in length	Strobili elongating, bud scales pushing off, strobili scales greenish to reddish	Buds continue swelling	Wax currant still in bloom. Rocky Mountain ponderosa pine shows pronounced candling

Table 1.—Notes on the phenology of blue spruce in the Bennett Creek area, Larimer County, Colorado (40°40′ N.; 105°30′ W.; 7,600 to 7,800 feet altitude) (Fechner 1964).—Continued

10-20	Pollen is shed	Strobili become receptive; most red (yellow-green on some trees); erect, ca. 40 mm long, scales reflexed to about 90°; starch deposition heavy in nucellus; pollen tube emergence begins on nucellus	Buds burst, leaves unfold, and elongation begins after pollen is shed	Wax currant and American pasqueflower fruit begins to swell. Quaking aspen leaves reach 3/4 inch in diameter
10-30	Strobili desiccate and abscise	Strobili scales close, red; strobili begin to turn down	Elongation is rapid, new branchlets are green	
July				
1-10		Strobili become completely pendent, red color fading; egg forms in archegonium; sperm nuclei formed; penetration of nucellar cap by pollen tube is completed	New (current-year) growth completes elongation; new buds arise and scale differentiation begins	Quaking aspen vegetative growth nears completion; buds develop. Rocky Mountain ponderosa pine leaves extend about equal to length of basal sheath
10-20	New strobili become noticeable, but green	Cones double in length, and mature size is reached; fertilization occurs	New branchlets begin to show tan coloration; still quite succulent	
July				
20-30		Cones retain reddish cast	Tan coloration continues; hardening begins	
August				
1-10	Sporophylls begin to differentiate at base of strobili	Cones begin to harden	Coloration and hardening intensifies	
10-20	Sporophyll differentiation is essentially completed	Comes become very hard	Branchlets become tan and harden; new vegetative buds are still somewhat green	
20-30	Sporangia initiate	Cone scales show evidence of drying, becoming quite tan at tips		
September				
		Mature seeds are released; some cones fall from some trees, remain intact on others		Quaking aspen leaves color, but clonal variation is apparent. Wax currant fruit matures. Rocky Mountain ponderosa pine appears dormant
October[1]				
	Sporangial cell divisions very active early, differentiation completed by end of month; bud scales shiny, with very little reflexing		Buds show scale reflexing; this difference from male strobili persists throughout dormant period	Leaves of quaking aspen and other deciduous species have fallen

[1] *Trees appear dormant from November through March.*

It is unlikely that heavy cone crops will occur in successive years on an individual tree, because the female strobili usually occupy terminal positions on lateral branchlets. Such terminal positions are at a minimum in the year following one of high seed production, because once differentiated from an apical meristem, only development of the strobilus occurs at that position during the following growing season. If a whorl of new axillary buds is produced on the branchlet at the base of the developing cone, these buds ordinarily will produce vegetative shoots for one season before female strobili are again differentiated. Thus, although blue spruce cones occasionally occupy sessile, axillary positions, the likelihood of heavy seed crops occurring more frequently than every 2 years is remote (Fechner 1964). Late spring freezing weather may also reduce cone production.

Heavy crops of cones were produced on blue spruce trees in the Fort Collins and Bennett Creek areas of northern Colorado in 1961 and 1964. Poor cone crops were produced in both locations in 1962 and 1963. Data obtained from the Colorado State University weather station show that the heavy cone crops were preceded by years during which the July was warmer and drier than normal.

Seedling Development

Seeds of blue spruce will germinate on a variety of media, although most natural reproduction takes place on exposed mineral soil with side shade and overhead light in the vicinity of seeding trees. Natural reproduction is probably scanty because the lightweight seeds are prevented from coming into contact with mineral soil by the dense herbaceous, grassy, and other ground-cover vegetation that is usually abundant in the habitat of the species (Sudworth 1916).

Seeds of blue spruce were once thought to exhibit embryo dormancy. It is now known, however, that blue spruce seeds germinate in the laboratory promptly and completely without pretreatment, and under a wide range of temperatures, with or without light (Heit 1961).

Natural germination of blue spruce seed takes place the spring or summer following dispersal. In Arizona, where the spring and early summer is normally dry, blue spruce seeds germinate during the summer rainy season (early July); but if significant showers occur in June, some may start then (Jones 1974b). In most other parts of the blue spruce range, the spring and early summer months receive adequate moisture for seed germination.

In a spot seeding test in Arizona, soil in the seed spots was loosened with a mattock, and the seed was pressed in by foot June 27 to July 9. Germination was abundant; 36.6% of the seeds planted were known to have germinated, 64% of them within 3 to 4 weeks after planting. After 2 years, only two of the original 549 seedlings remained, and both of these were on one of the 300 seed spots planted (Jones 1974a). Some main known causes of mortality—frost heaving, predation, and burial from soil movement—could be identified; however, the causes of most mortality were unknown.

Although at the end of winter soils of the mixed conifer forest of the Southwest are wet, soil moisture deficits develop that are critical to initial seedling survival during spring and early summer drought periods of the southern part of the blue spruce range. Except on severe drought sites, these deficits usually do not kill seedlings established for two or more years. Within the blue spruce range, spring and early summer drought periods occur regularly only in the Southwest. Fall moisture deficits, which develop in most of the blue spruce range, are less detrimental to seedling establishment than spring and early summer deficits (Alexander 1974, Jones 1974b).

Blue spruce seedlings are more sensitive to day temperature between 55° and 88° F than to night temperature between 45° and 77° F (Tinus 1971). In one study, all trees died at 88° F within 20 weeks (Tinus 1974). In another study, under 24-hour light, seedlings grown at constant 54° and 64° F grew less than those at 77° F, and 88° F caused browning and death of many seedlings (Young and Hanover 1978).

The establishment of blue spruce seedlings under natural conditions is probably greatly affected by moisture availability and shading. Shading prolongs snow cover and soil moisture retention in late spring, thus providing improved conditions for seedling establishment (fig. 6).

Early growth of blue spruce seedlings is very slow. In a nursery study in Michigan, the tallest of 50 populations studied averaged 6.2 inches at 2 years (Hanover 1975). In another study in North Dakota, the tallest of seven sources was 23 inches, 5 years after outplanting at ages 3 to 5 years (Dawson and Rudolf 1966). Similarly, in a plantation in the southern part of the blue spruce range, trees were 19.1 to 23.3 inches tall after five growing seasons (Jones 1975).

Vegetative Reproduction

Natural vegetative reproduction of blue spruce has not been reported. The species does not sprout from the stump or root, but the development of epicormic branches on the trunk is common. However, grafting and air layering have been practiced successfully for many years to perpetuate desired horticultural varieties (Fröhlich 1957, Mergen 1958, Ravenstein 1957, Wells 1953). Similarly, success has also been achieved through the rooting of hardwood or greenwood stem cuttings, especially in sand-peat soil media, or hydroponically (Kirkpatrick 1940, Savella 1965, Sherwood 1968, White 1975).

Sapling and Pole Stage to Maturity

Growth and Yield

Blue spruce is a long-lived tree, living up to 600 years or more. Diameter growth is slow; trees 4 to 5 inches in diameter may be 125 to 135 years old, and trees 18 to 22 inches may be 275 to 350 years old (Sudworth 1916). The size-age relationship is dependent on site and stand density, however.

Few growth and yield data are available for blue spruce. In one study, in a mixed conifer forest in east-central Arizona, blue spruce was found to constitute a total of only 3.05 square feet per acre out of a total of 177.74 square feet. The 1,800-acre forest consisted of Douglas-fir (31.4%), quaking aspen (15.9%), white fir (14.5%), ponderosa pine (14.1%), Engelmann spruce (13.5%), southwestern white pine (5.6%), corkbark fir (*Abies lasiocarpa* var. *arizonica* (Merriam) Lemm.) (3.3%), and blue spruce (1.7%). In this study, the annual basal area growth for blue spruce was found to be 2.9% greater than that of any of the other species except corkbark fir, which was 3.7% per year (Embry and Gottfried 1971). The total basal area growth for blue spruce of 0.088 square feet per year was distributed as shown:

Size class	**Annual basal area increment**	
d.b.h.	*square feet*	*percent*
Sapling-small poles, 0.1 to 6.9 inches	0.45	48.8
Poles, 7.0 to 10.9 inches	0.63	18.3
Small sawtimber, 11.0 to 16.9 inches	1.03	18.3
Medium sawtimber, 17.0 to 22.9 inches	0.76	9.7
Large sawtimber, 23.0 inches and over	0.18	4.9
Total	3.05	100.0

Rooting Habit

Young seedlings of blue spruce are shallow-rooted, penetrating only about 2.5 inches during the first year (Jones 1973). Although blue spruce tissue is not damaged much by freezing (Pearson 1931), sequences of freezing and thawing, when the soil is wet and bare of protection from snow cover, often result in losses from frost-heaving (Alexander 1974).

Figure 6.—Blue spruce reproduction in north-central Colorado. Note coincidence of young trees and late spring snow pattern.

The root system of mature blue spruce trees is relatively shallow, compared with that of Douglas-fir and ponderosa pine, adapting it to the moist site on which it usually grows. In spite of the shallow root system, however, blue spruce is decidedly windfirm (Goor and Barney 1976, Preston 1940).

Reaction to Competition

Blue spruce is generally classed as intermediate in shade-tolerance, the middle of five tolerance categories for western conifers. It is less tolerant than subalpine fir, Engelmann spruce, and white fir; it is similar in tolerance to, or slightly more tolerant than, Douglas-fir; and it is more tolerant than southwestern white pine, ponderosa pine, lodgepole pine, Rocky Mountain juniper, quaking aspen, or its other moist-site hardwood associates (Baker 1949, Fechner 1980, Jones 1974b, Mauk and Henderson 1984).

The exact successional status of blue spruce depends upon the location within its geographic range and upon its immediate associates. For example, in the Southwest, blue spruce represents a topoedaphic climax, in which environmental factors compensate for one another (Daubenmire and Daubenmire 1968). Here blue spruce reproduces and is present in all sizes, along stream banks, in well-watered tributaries, on gentle lower slopes, and in forest borders of grassy meadows. On these sites, ponderosa pine and Douglas-fir may occur as a long-lived seral species, white fir and southwestern white pine may occur as minor seral species, and subalpine fir may be of accidental occurrence (Layser and Schubert 1979, Moir and Ludwig, 1979). Blue spruce appears to form climax stands with Engelmann spruce on slopes and in drainages at higher elevations, and with Douglas-fir and white fir on lower slopes and north aspects at lower elevations (Alexander et al. 1984, Moir and Ludwig 1979). Blue spruce occurs occasionally as a minor seral species in white fir and subalpine fir-dominated forests on cooler sites (Layser and Schubert 1979), and it is a pioneer species on some wet sites (Dixon 1935).

On cool sites, a dense or moderately dense canopy favors regeneration of subalpine fir, blue spruce, white fir, and Engelmann spruce, to the exclusion of Douglas-fir. On warm sites, an open canopy favors ponderosa pine, whereas a moderate canopy favors Douglas-fir (Westveld 1939).

Blue spruce is most common on warm sites with abundant moisture. Yet, this species can withstand drought, growing on drier sites than any other spruces (Goor and Barney 1976). It can also withstand extremely low temperatures (−40° F), and it is more resistant to high insolation and frost damage than other associated species.

Damaging Agents

Windfall.—Blue spruce, though shallow-rooted, is decidedly windfirm. Windfall is thus seldom a problem.

Insects.—Several insects are known to attack developing cones and seeds of blue spruce, but damage due to insects is not heavy. The spruce seed chalcid *Megastigmus piceae* Rohwer[4] is found throughout the range of the host (Furniss and Carolin 1977, Keen 1952, Keen 1958). Larvae of the spruce cone moth (*Laspeyresia youngana* (Kearf.)) bore food burrows through cone scales near the axis of the cones, destroying both scales and seeds. A single cone may contain one to five larvae. The growing larvae of the moth *Commophila fuscodorsama* (Kearf.) feed by boring irregular channels through cones, destroying scales and up to 10% of the seeds. Larvae of the spruce coneworm *Dioryctria reniculelloides* Mutuura and Munroe and the fir coneworm *Dioryctria abietvorella* (Groté)[5] mine young cones and feed on tender terminal growth and foliage (Hedlin et al. 1980; Keen 1952, 1958).

In addition to those attacking developing cones and seeds, other insects are occasionally damaging on blue spruce. The larvae of the western spruce budworm (*Choristoneura occidentalis* Freeman) feed on old needles in late April, and then enter the developing buds and defoliate new needles as they develop (Furniss and Carolin 1977, Leatherman 1979). Heavy, repeated attacks cause death of the tree.

The spruce needleminer (*Tanvia abolineana* Kearf.) is usually not a serious forest pest, although it may cause unsightly damage to ornamental spruce (Furniss and Carolin 1977, Hantsbarger and Brewer 1970, Keen 1952). Another needleminer (*Coleotechnites piceaella* (Kearf.)) is of less importance.

The Cooley spruce gall aphid (*Adelges cooleyi* (Gill.)) causes the formation of cone-shaped galls at the tips of the growing twigs, killing the current growth of the twigs. The attack is usually not severe enough to seriously affect large trees, but it may be of consequence on seedlings and saplings. Two other aphids, *Pineus pinifoliae* (Fitch) (pine leaf chermid) and *Pineus similis* (Gill.), also cause the formation of cone-shaped galls.

Other insects that attack blue spruce are the green spruce aphid (*Cinara fornacula* Hottes) and the related *Cinara coloradensis* (Gill.); these feed on terminal twigs, as does the white pine weevil (*Pissodes strobi* (Peck)). A twig beetle (*Pityophtorus* sp.) may attack injured trees, and the Engelmann spruce beetle (*Dendroctonus rufipennis* (Kirby)) also occurs on blue spruce. *Ips pilifrons* Swaine, which attacks recently downed trees, may deprive the Engelmann spruce beetle of favorable breeding places, thereby reducing the threat of a spruce beetle outbreak (Furniss and Carolin 1977). Secondary insects are *Dryocoetes affaber* Mannerheim and the four-eyed spruce bark beetle *Polygraphus rufipennis* (Kirby), ambrosia beetles *Gnathotrichus sulcatus* LeC. and *Trypodendron lineatum* (Olivier), and the golden buprested *Buprestis aurulenta* L., a flatheaded borer that attacks the wood (Keen 1952).

[4] *Scientific and common names of insects used in this report are in accord with Furniss and Carolin (1977).*

[5] *During a 1984 controlled pollination study on the Colorado State University campus, approximately 10% of young cones were infested with larvae of the fir coneworm. The larvae destroyed ovules in approximately the lower one-half of the infested cones.*

Diseases.—The cone rust *Chrysomyxa pirolata* Wint.[6] infects the cones of blue spruce. However, it causes only minor reduction in seed produced, though malformation of the cones may interfere with seed dispersal. Seed viability in rust-infected cones may be reduced, but only a few seeds are totally destroyed (Hepting 1971, Nelson and Krebill 1970).

A variety of diseases also attack seedlings, leaves, stems, and roots of blue spruce. Damping-off, caused by *Phytophora cinnamomi* Rands, kills new seedlings, as does the cylindrocladium root rot, caused by *Cylindrocladium scoparium* Morgan (Cordell and Skilling 1975, Hepting 1971). Nematodes of at least seven different genera may cause reduced growth of blue spruce seedlings in nurseries (Ferris and Leiser 1965); they reduce root growth (Griffin and Epstein 1964). Low seedling vigor is also caused by the root lesion nematode *Pratylenchus penetrans* Cobb (Hepting 1971). Snow molds, which grow at low temperatures, may cause nursery losses during seasons of heavy snow (Skilling 1975).

Three species of *Chrysomyxa* cause needle rusts on blue spruce in the United States; they may cause moderate amounts of shedding of new needles (Hepting 1971). Another needle cast fungus, *Rhizosphaera kalkhoffii* Bub., was first reported as occurring on eastern species of spruce and in Christmas tree plantations of blue spruce in the Middle West and the East (Nicholls et al. 1974, Waterman 1947). This disease was first reported on blue spruce in its native range in Arizona (Hawksworth and Staley 1968). In natural stands, this needle cast is not associated with the serious damage that it inflicts when the species is grown far from its native habitat, however.

Chrysomyxa arctostaphyli Diet. causes the perennial yellow witches'-broom on blue spruce branches. Abundant pycnia, produced on the needles of the broom in late spring, give off a distinctive, strong, foul odor. Spikelike tops and dead branches are commonly associated with this disease. Seldom, however, do more than 25% of the trees bear brooms. *Arctostaphylos uva-ursi* (L.) Spreng, the common bearberry or kinnikinnick, is the host of Stage III of the fungus causing yellow witches'-broom (Peterson 1969).

Armillaria mellea Vahl. ex Fr. and *Polyporus tomentosus* Fr. cause root rot in blue spruce. However, although both fungi are common, damage is slight. *Fomes pini* (Thore) Lloyd, which causes red heart, is the principal heartrot fungus on blue spruce. It is not serious, however, because the trees are usually old before the rot becomes a factor. Other heartrots, including *Fomes pinicola* (Schwartz ex Fr.) Cke., *Polyporus borealis* Fr., and *Polyporus caesius* Schrad. also attack blue spruce (Hepting 1971).

SPECIAL USES

Shortly after the species was first discovered in 1861, early writers described blue spruce as "a finely-shaped

[6] *Scientific and common names of diseases used in this report are in accord with Hepting (1971).*

tree" (Parry and Engelmann 1862) and "the most beautiful species of conifer" (André 1876), alluding to the symmetrical, pyramidal form and the glaucous, bluish or silvery-gray foliage that some trees display. The needle coloration, caused by the presence of surface waxes (Reicosky and Hanover 1976), apparently intensifies with tree age (Cram 1983b, 1984a). These traits of symmetry and blue or silver-gray cast, so common in horticultural plantings, are only occasionally found in nature. In natural stands, trees with similar color tend to occur in small, local populations, a situation that suggests genetic control of the color trait.

When young, blue spruce trees usually exhibit a pronounced layering of stiff branches, which gives it the distinct pyramidal form; when the trees become older, the branches begin to droop and the crown becomes open and irregular. Boles of blue spruce are usually highly tapered, and the epicormic shoots, which commonly develop, may give the tree a ragged appearance.

At least 38 cultivars of blue spruce have been named, based primarily on leaf coloration and crown form. Some of the more common cultivars are listed in table 2. Its leaf coloration, coupled with symmetrical crown form, makes blue spruce an exceptionally attractive Christmas tree. Christmas tree plantations of this species have been established in many eastern states (Goodno and Quink 1975, Nicholls et al. 1974).

Because of its pyramidal forms, its resistance to winter temperatures, and its relative resistance to drought stress, blue spruce is often used as a windbreak tree. It is especially popular for this use in Canada (Cram 1966), and it has been widely planted in Russia.

Blue spruce, primarily a streambottom tree, provides streambank protection. Furthermore, it enhances the esthetic value of the streambottom landscape, where it is frequently in sight of travelers on highways that follow the streamcourses. Conversely, the streambottom habitats often support a lush herbaceous vegetation and are often disturbed by grazing and fire (Alexander et al. 1984, Hoffman and Alexander 1983).

GENETICS

Population Differences

In a study of seven provenances from Arizona, Colorado, Utah, and Wyoming, grown in North Dakota, 5-year survival varied from 22% for the Targhee National Forest, Idaho, source to 96% for an Ashley National Forest, Utah, source (Dawson and Rudolph 1966). In the same study, height differed significantly among the sources; interestingly, one of the two sources from Ashley National Forest was the tallest (1.88 feet) and the other, the shortest (1.23 feet). No latitudinal nor altitudinal pattern of survival, growth, or frost resistance seemed apparent.

In an East Lansing, Mich., nursery study of progenies from 50 populations of blue spruce throughout the native range of the species, from Montana to Arizona,

Table 2.—Some cultivated varieties of blue spruce (*Picea pungens* Engelm.).

Cultivar	Characteristics	Authorities[1]
'Argentea' Rosenthal	Silvery white	B & B, dO & B, W
'Aurea' Niemitz	Golden yellow	B & B, dO & B, W
'Bakeri' Bailey	Deep bluish white, long-leaved	B & B, dO & B, W
'Caerulea' Beissner	Bluish white	B & B, W
'Compacta' Rehder	Dwarf, compact, densely flat-topped	B, dO & B, W
'Glauca' Beissner	Bluish green; collective name for all glaucous-leaved cultivars	B & B, dO & B, W
'Glauca Pendula' Koster ex Beissner	Pendulous, bluish leaves, strongly sickle-shaped	B, dO & B
'Hoopsii' Hoops ex F. J. Grootend.	Dense, pyramidal; leaves very silvery	B & B, dO & B
'Hunnewelliana' Hornibr.	Dwarf, dense, pyramidal; leaves pale green	B & B, dO & B, W
'Koster' Boom	Pyramidal, pendulous-branched, with main branches almost horizontal; leaves bluish white to silvery white	B & B, dO & B, W
'Moerheimi' Ruys	Pyramidal, slender, dense, compact; leaves deep blue	B & B, dO & B, W
'Thomsen' Thomsen	Pyramidal; leaves whitish blue to silvery blue; long	B & B, dO & B
'Viridis' Regel	Dull green	B, dO & B, W

[1]*B* = *Bailey (1929-1930).*
B & B = *Bailey and Bailey (1976).*
dO & B = *den Ouden and Boom (1965).*
W = *Wyman (1961).*

2-year-old seedlings from Colorado, New Mexico, and Arizona grew more rapidly than those from Utah, Wyoming, or Montana. The average heights of the 10 tallest populations ranged from 7.4 to 6.3 inches; all were either from Colorado, New Mexico, or Arizona (Hanover 1975).

Variation in foliage color is apparently under strong genetic control, although the mechanism of inheritance is not yet known. Because some inconsistency in blue color from any one geographic source exists, some variation in the blue color characteristic is to be expected from seed-produced trees (Heit 1968). However, 2-year-old progenies from Arizona and New Mexico seed sources showed a much higher incidence of "blueness" than those from other areas, when grown in a Michigan nursery (Hanover 1975).

Significant variation exists between populations in the terpene concentration derived from cortical tissue. Five populations, each consisting of ten selected seed trees, differed significantly in the concentration of each of eight monoterpenes in a Michigan study. Although the total percentages of the eight monoterpenes were similar among the populations, the Utah, Colorado, and Wyoming populations were distinct from the New Mexico and Arizona populations, because of similarity in percentages of specific monoterpenes. For example, the average percentage of α-pinene was 14.3 for the three northern populations and 8.5 for the two southern ones, whereas β-phellandrene averaged 0.58% for the northern populations and 0.89% for the southern populations (Hanover 1974).

These studies suggest that genetic variation in natural populations of blue spruce does not conform to a clinal pattern. Rather, the pattern appears to be ecotypic, and considerable stand-to-stand variation and individual-tree variation also exists.

Hybrids

From studies of morphological features in 21 natural populations of blue spruce, Engelmann spruce, and mixed populations of the two species, it was concluded that blue spruce and Engelmann spruce do not hybridize in nature, although no morphological character absolutely separating the two species was found (Daubenmire 1972). Considerable overlap in cone size between these two species has also been found; Engelmann spruce varied from 1.1 to 2.3 inches and blue spruce varied from 1.8 to 4.2 inches in 11 populations growing within a radius of about 15 miles in northern Colorado (Funsch 1975). In a study of cone and seed characters in 80 populations of blue spruce and Engelmann spruce, the two species were often indistinguishable (Hanover 1975).

In an earlier study of controlled crosses between blue spruce and Engelmann spruce, up to 1% to 2% sound seed set was obtained, when Engelmann spruce was the female parent (Fechner and Clark 1969). In another study, the reciprocal cross was also successful. Only occasional embryos developed following crosses between the two species, but, more frequently, reproductive failure occurred prior to embryo formation (Kossuth and Fechner 1973).

Reciprocal, controlled pollinations between blue spruce and white spruce (*Picea glauca* (Moench) Voss) have also been successful, as verified by measurement of germination rate, needle length, and concentration of 3-carene in the hybrid progeny (Hanover and Wilkinson 1969).

These research results suggest that although hybridization between blue spruce and Engelmann spruce is not common in nature, barriers between the two species are not absolute. Furthermore, in a report of the occurrence of blue spruce in northern Montana, various intergrades between blue spruce, white spruce, and Engelmann spruce were reported for that area (Strong 1978). That, in addition to the work of Hanover and Wilkinson (1969), indicates that hybridization barriers also are not absolute between blue spruce and white spruce.

Information on inheritance patterns for some characteristics of blue spruce, though somewhat inconclusive, is provided by the results of half-sib and full-sib progeny studies involving that species. For example, Cram (1983b, 1984a) studied inheritance of needle coloration, using a qualitative rating scale of one (green) to four (silvery blue) for comparison. He found that although the proportion of blue seedlings was not significantly related to the blue color ratings of their open-pollinated parents, the needle-color ratings of 10-year-old progeny were related to those of their self-pollinated parents ($r = 0.83$). One selfed tree produced 94% blue progeny.

As is true for certain other coniferous species, albinism in blue spruce is apparently controlled by a single gene. Cram (1983a) found that the proportion of normal (green) to albino seedlings derived from self-pollinated seeds of two different trees produced a good fit to a 3:1 ratio, suggesting heterozygosity for a simple lethal factor.

In Michigan studies, hybrid progeny from crosses between white spruce and blue spruce showed a slight, but nonsignificant, increase in germination rate over the parental half-sib progeny, and at 42 weeks needle length was intermediate between those of the parental progeny. Although the hybrid progeny as a group displayed intermediacy in 3-carene biosynthesis ability between the two parents, individual-tree values showed genetic segregation in the open-pollinated (half-sib) blue spruce progeny and uniformity in the open-pollinated (half-sib) white spruce progeny (Hanover and Wilkinson 1969). Yet, the range of values for 3-carene concentration in these hybrid progeny conformed to frequencies expected from a mating of a homozygous recessive white spruce parent to a heterozygous blue spruce parent, suggesting that inheritance of 3-carene biosynthesis ability is controlled by a single pair of alleles, as had been shown for western white pine (*Pinus monticola* Dougl. ex D. Don) (Hanover 1966). However, when natural populations of blue spruce were studied for this characteristic, allele frequencies for the 3-carene gene did not conform to expected values in Colorado and New

Mexico populations, although they did conform to expected single-gene frequencies in the Utah, Arizona, and Wyoming populations (Hanover 1974). These apparent discrepancies could be artifacts of sample size or other unknown factors.

Fechner and Clark (1969) found that whereas the initiation date of germination of hybrid seed was intermediate between parental (half-sib) seed of blue spruce and Engelmann spruce, cotyledon number, mean day of total germination, and hypocotyl color were similar to those of the female parent. From their studies of controlled crosses among white spruce, blue spruce, and red spruce (*Picea rubens* Sarg.), Bongarten and Hanover (1982) reported that F_2 progeny of white spruce x blue spruce crosses were much stunted in height and in needle length. Further results of their findings are summarized in table 3.

In summary, it would appear that for most needle, chemical synthesis, and germination characteristics that have been studied in blue spruce, the gene action is quantitative. Exceptions to this seem manifest in the biosynthetic ability of 3-carene and in the production of albino seedlings, which may be single-gene controlled, and cotyledon number, hypocotyl color, and mean germination date, which may be under strong maternal influence in that species.

Table 3.—Summary of inheritance of various traits from crosses among red, white, and blue spruces. Adapted from Bongarten and Hanover 1982.

Spruce combination	Character response
(White x blue) x white (backcross)	- Similar to white spruce in all measured characters.
(White x blue) x blue (backcross)	- Similar to blue in 6-month height, needle curvature, and 3-carene concentration. - Similar to white in needle serrations. - Intermediate in β-pinene concentration.
(White x blue) x red (trihybrid)	- Similar to red in needle serrations, limonene concentration, and needle curvature. - Similar to white x red in needle color. - Similar to white x blue in 3-carene and β-pinene concentrations.

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APPENDIX

Habitat types in which *Picea pungens* is a major climax, co-climax, minor climax, or major seral species

Habitat type	Location	Site	Successional status *P. pungens*	Principal tree associates	Principal understory species	Authority
			Picea pungens series			
Picea pungens/ Amelanchier alnifolia H.T.	Mountains of west-central Colorado	Warm moist	Climax	*Abies lasiocarpa* *Pseudotsuga menziesii* *Populus angustifolia*	*A. alnifolia* *Cornus stolonifera* *Carex geyeri* *Swida servicea*	Hess and Wasser[1] 1982 Komarkova 1984[2]
Picea pungens/ Arctostaphylos uva-ursi H.T. [*P. pungens-Pseudotsuga menziesii/A. uva-ursi* H.T.]	San Juan Mountains, Colorado	Warm dry	Co-climax with *P. menziesii* *A. concolor*	*Abies concolor* *P. menziesii* *Pinus ponderosa* *Populus tremuloides* *Pinus flexilis*	*A. uva-ursi* *Juniperus communis* *Festuca arizonica* *Fragaria ovalis*	DeVelice et al. 1984[3] Moir and Ludwig 1979
Picea pungens/ Berberis repens H.T.	Mountains of Utah	Cool dry	Climax	*P. menziesii* (minor climax) *P. tremuloides* *Pinus contorta* *P. ponderosa* *Juniperus scopulorum* *P. flexilis*	*B. repens* *J. communis* *Pachistima myrsinites* *Aquilegia coerulea* *Pyrola secunda* *Ribes montigenum* *Symphoricarpos oreophilus*	Mauk and Henderson 1984 Pfister 1972 Youngblood 1984[4]
Picea pungens/ Cornus stolinifera H.T.	Mountains of north-central and northwestern New Mexico	Warm moist	Co-climax with *P. menziesii*	*P. menziesii* *P. tremuloides* *Juniperus* spp.	*C. stolinifera* *B. repens* *P. myrsinites* *Carex foenea*	Alexander et al. 1984b[5]
Picea pungens/ Juniperus communis H.T.	Mountains of central Utah	Cool dry	Climax	*P. menziesii* *P. tremuloides* *P. ponderosa* *P. flexilis* *J. scopulorum*	*J. communis* *A. uva-ursi* *S. oreophilus* *B. repens* *P. myrsinites*	Youngblood 1984[4]
Picea pungens/ Linnaea borealis H.T. [*P. pungens-Pseudotsuga menziesii/L. borealis* H.T.]	Mountains of southern Colorado and northern New Mexico	Cool well-drained	Co-climax with *P. menziesii*	*P. menziesii* *A. concolor* *P. tremuloides* *P. flexilis* *A. lasiocarpa* *Picea engelmannii*	*L. borealis* *P. myrsinites* *Vaccinium myrtillus* *Rubus parviflorus* *A. uva-ursi*	DeVelice et al. 1984[3] Moir and Ludwig 1979
Picea pungens/ Agropyron spicatum H.T.	Uinta Mountains, Utah	Warm dry	Climax	*P. menziesii* (minor climax) *P. tremuloides* *P. ponderosa* *P. contorta* *P. flexilis* *J. scopulorum*	*A. spicatum* *B. repens* *J. communis* *P. myrsinites*	Mauk and Henderson 1984
Picea pungens/ Festuca arizonica H.T.	Mountains of northern New Mexico and southern and western Colorado	Warm dry	Co-climax with *P. menziesii*	*A. concolor* *P. menziesii* *P. ponderosa* *P. tremuloides*	*F. arizonica* *C. foenea* *Erigeron* spp. *Fragaria* spp.	DeVelice et al. 1984[3] Fitzhugh, et al. 1984[6] Komarkova 1984[2]
Picea pungens/ Poa pratensis H.T.	Mountains of New Mexico	Warm to cool moist	Climax	*P. menziesii* *P. ponderosa* *P. tremuloides* *A. concolor* *Pinus strobiformis*	*P. pratensis* *Erigeron superbus* *E. eximius*) *Geranium richardsonii* *Fragaria virginiana*	Fitzhugh et al. 1984[6] Moir and Ludwig 1979
Picea pungens/ Poa sp. H.T.	Streambanks and foothills of north-central Colorado	Warm moist	Climax	Usually pure stands; occasionally contains *P. menziesii* *P. tremuloides*	*Poa* spp. *A. alnifolia* *Rosa* spp. *Salix* spp.	Hoffman and Alexander 1983
Picea pungens/ Carex foenea H.T.	White Mountains and Kaibab Plateau, Arizona; mountains of northern New Mexico	Warm to cool moist	Co-climax with *P. menziesii*	*P. menziesii* *P. ponderosa* *A. concolor* *P. tremuloides* *P. strobiformis* *P. engelmannii*	*C. foenea* *F. arizonica* *Muhlenbergia montana* *Bromus ciliatus* *Fragaria* spp. *Festuca* spp. *B. repens*	Alexander et al. 1984b[5] DeVelice et al. 1984[3] Fitzhugh et al. 1984[6] Moir and Ludwig 1979

APPENDIX—Continued

Habitat type	Location	Site	Successional status *P. pungens*	Principal tree associates	Principal understory species	Authority
Picea pungens/ Arnica cordifolia H.T.	Front Range, north-central Colorado	Cool moist	Climax	*P. menziesii* *P. tremuloides*	*A. cordifolia* *Smilacina stellata* *J. communis* *Calamagrostis canadensis*	Hess 1981
Picea pungens/ Equisetum arvense H.T.	Mountains of southern Utah	Warm to cool wet	Climax	*P. engelmannii* *P. tremuloides* *P. menziesii*	*E. arvense* *G. richardsonii* *Thalictrum fendleri* *Osmorphiza chilensis*	Youngblood 1984[4]
Picea pungens/ Erigeron eximus H.T. [*P. pungens-Picea engelmannii/ E. superbus* H.T.]	Mountains of northern New Mexico and southern Colorado	Cool dry	Co-climax with *A. concolor* *P. menziesii* *P. engelmannii*	*A. concolor* *P. menziesii* *P. engelmannii* *P. flexilis* *P. tremuloides* *A. lasiocarpa* *P. ponderosa* *P. strobiformis*	*E. superbus* (*E. eximius*) *C. foenea* *G. richardsonii* *T. fendleri* *F. arizonica* *F. virginiana*	DeVelice et al. 1984[3] Fitzhugh et al. 1984[6] Moir and Ludwig 1979
Picea pungens/ Fragaria ovalis H.T. [*P. pungens-Pseudotsuga menziesii/Valeriana acutiloba* H.T.]	Mountains of New Mexico and eastern Arizona	Cool moist	Co-climax with *P. menziesii*	*P. menziesii* *A. concolor* *P. strobiformis* *P. ponderosa* *P. tremuloides* *P. engelmannii* *A. lasiocarpa*	*F. ovalis* *V. acutiloba* *C. foenea* *F. arizonica* *Erodium circutarium* *E. superbus* *Artemisia dracunculus*	Alexander et al. 1984a Fitzhugh et al. 1984[6] Moir and Ludwig 1979
Picea pungens/Senecio cardamine H.T. [*P. pungens-Picea engelmannii/S. cardamine* H.T.]	White Mountains, Arizona	Cool moist	Co-climax with *P. engelmannii* *A. lasiocarpa*	*P. engelmannii* *A. lasiocarpa* *A. concolor* *P. ponderosa* *P. menziesii* *P. tremuloides* *P. strobiformis*	*S. cardamine* *Pteridium aquilinum* *Helenium hoopesii* *Viola canadensis*	Fitzhugh et al. 1984[6] Moir and Ludwig 1979
			***Pseudotsuga menziesii* series**			
Pseudotsuga menziesii/ Muhlenbergia virescens H.T.	Mountains of southwestern New Mexico	Warm dry	Minor climax to *P. menziesii* *P. ponderosa*	*P. menziesii* *P. ponderosa* *P. strobiformis* *P. tremuloides*	*M. virescens* *Quercus gambelii*	Fitzhugh et al. 1984[6]
Pseudotsuga menziesii/ Scree H.T. [*P. menziesii/ Physocarpus monogynus* H.T.]	Mountains of New Mexico	Warm well-drained	Minor climax to *P. menziesii*	*P. menziesii* *P. tremuloides* *A. concolor*	*P. monogynus* *B. repens* *P. pratensis*	Moir and Ludwig 1979
			***Abies concolor* series**			
Abies concolor/ Acer glabrum H.T.	Mountains of northern New Mexico and southern Colorado	Warm moist to well-drained	Minor climax to *A. concolor* *P. menziesii*	*A. concolor* *P. menziesii* *P. engelmannii* *P. tremuloides*	*A. glabrum* *A. alnifolia* *B. repens* *P. myrsinites*	DeVelice et al. 1984[3]
Abies concolor/ Arctosaphylos uva-ursi H.T.	Mountains of southern Utah	Warm dry	Seral to *A. concolor*	*A. concolor* *P. menziesii* *P. flexilis* *P. ponderosa* *J. scopulorum*	*A. patula* *S. oreophilus* *J. communis* *B. repens*	Youngblood 1984[4]
Abies concolor/ Berberis repens H.T.	Mountains of central and southern Utah	Warm dry	Seral to *A. concolor*	*A. concolor* *P. menziesii* *P. ponderosa* *P. tremuloides* *P. flexilis*	*B. repens* *J. communis* *S. oreophilus* *Rosa woodsii* *P. myrsinites*	Youngblood 1984[4]
Abies concolor/ Juniperus communis H.T.	Mountains of southern Utah	Warm dry	Seral to *A. concolor*	*A. concolor* *P. menziesii* *P. tremuloides* *P. flexilis*	*J. communis* *R. woodsii* *S. oreophilus* *B. repens*	Youngblood 1984[4]
Abies concolor/ Vaccinium myrtillus H.T.	Mountains of northern New Mexico and southern Colorado	Cool dry	Minor climax to *A. concolor* *P. menziesii*	*A. concolor* *P. menziesii* *A. lasiocarpa* *P. engelmannii* *P. tremuloides*	*V. myrtillus* *A. glabrum* *A. uva-ursi* *P. myrsinites* *R. parviflorus*	DeVelice et al. 1984[3]

APPENDIX—Continued

Habitat type	Location	Site	Successional status *P. pungens*	Principal tree associates	Principal understory species	Authority
Abies concolor/ Erigeron eximius H.T.	Mountains of northern New Mexico	Cool moist	Minor climax to *A. concolor P. menziesii*	*A. concolor* *P. menziesii* *P. engelmannii* *P. tremuloides* *P. ponderosa*	*E. eximius* (*E. superbus*) *C. foenea* *Lathyrus* sp. *Fragaria* sp.	DeVelice et al. 1984[3]
Abies concolor/ Sparse H.T.	Mountains of northern New Mexico and southern Colorado	Warm dry	Minor climax to *A. concolor P. menziesii*	*A. concolor* *P. menziesii* *P. tremuloides* *P. ponderosa* *P. strobiformis*	*S. oreophilus* *Q. gambelii* *B. repens* *Robinia neomexicana*	DeVelice et al. 1984[3] Moir and Ludwig 1979
			***Picea engelmannii* series**			
Picea engelmannii/ Carex disperma H.T.	Mountains of northwestern Wyoming and east-central Idaho	Cool moist	Occasional co-climax with *P. engelmannii*	*P. engelmannii* *P. contorta* *A. lasiocarpa*	*C. disperma*	Steele et al. 1983
Picea engelmannii/ Equisetum arvense H.T.	Mountains of northwestern Wyoming and east-central Idaho	Warm wet	Occasional co-climax with *P. engelmannll*	*P. engelmannii* *P. contorta* *A. lasiocarpa*	*E. arvense* *Streptopus amplexifolius* *Senecio triangularis* *Luzula parviflora*	Steele et al. 1983
Picea engelmannii/ Galium triflorum H.T.	Mountains of northwestern Wyoming	Cool moist	Occasional co-climax with *P. engelmannii*	*P. engelmannii* *P. contorta* *P. menziesii*	*G. triflorum* *Actaea rubra* *S. stellata*	Steele et al. 1983
Picea engelmannii/ Senecio cardamine H.T.	Blue Mountains, Arizona	Cool moist	Seral to *P. engelmannii*	*P. engelmannii* *P. menziesii* *A. lasiocarpa* *A. concolor* *P. ponderosa* *P. strobiformis* *P. tremuloides*	*S. cardamine* *F. ovalis* *G. richardsonii* *V. canadensis*	Fitzhugh et al. 1984[6]
			***Abies lasiocarpa* series**			
Abies lasiocarpa/ Acer glabrum H.T.	Mountains of central and southern Utah	Warm moist	Seral to *A. lasiocarpa*	*A. lasiocarpa* *A. concolor* *A. menziesii* *P. engelmannii* *P. flexilis* *P. tremuloides*	*A. glabrum* *A. alnifolia* *B. repens* *S. oreophilus* *O. chinensis* *T. fendleri*	Youngblood 1984[4]
Abies lasiocarpa/ Berberis repens H.T.	Mountains of northern Utah	Warm well-drained	Seral to *A. laslocarpa*	*A. lasiocarpa* *P. engelmannii* *P. contorta* *P. menziesii* *A. concolor* *P. flexilis* *P. tremuloides*	*B. repens* *R. montigenum* *J. communis* *C. geyeri* *S. oreophilus* *R. woodsii* *P. myrsinites*	Mauk and Henderson 1984 Youngblood 1984[4]
Abies lasiocarpa/ Juniperus communis H.T.	Mountains of southern Utah	Warm dry Cool dry	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. engelmannii* *P. tremuloides* *P. menziesii* *P. ponderosa* *A. conolor*	*J. communis* *R. woodsii* *S. oreophilus* *B. repens*	Youngblood 1984[4]
Abies lasiocarpa/ Vaccinium myrtillus H.T. [*A. lasiocarpa/V. myrtillus- Linnea borealis* H.T.] [*A. lasiocarpa/Vaccinium scoparium-L. borealis* H.T.]	Mountalns of northern New Mexico and southern Colorado	Cool moist well-drained	Seral to *A. lasiocarpa P. engelmannii*	*A. lasiocarpa* *P. engelmannii* *A. concolor* *P. tremuloides* *P. menziesii*	*V. myrtillus* *V. scoparium* *L. borealis* *E. superbus* (*E. eximius*) *F. virginiana* *P. myrsinites* *V. candensis*	DeVelice et al. 1984[3] Moir and Ludwig 1979
A. lasiocarpa/ Calamagrostis canadensis H.T.	Mountains of northern Utah	Warm wet	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. engelmannii* *P. contorta* *P. tremuloides*	*C. canadensis* *L. borealis* *E. arvense* *G. trifolium*	Mauk and Henderson 1984
Abies lasiocarpa/ Actaea rubra H.T.	Mountains of northwestern Wyoming, and southern Idaho	Warm molst	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. engelmannii* *P. menziesii* *P. contorta*	*A. rubra* *Lonicera utahensis* *Vaccinium globulare* *A. glabrum*	Steele et al. 1983

APPENDIX—Continued

Habitat type	Location	Site	Successional status *P. pungens*	Principal tree associates	Principal understory species	Authority
Abies lasiocarpa/ Erigeron eximius H.T. [*A. lasiocarpa/ E. superbus* H.T.]	Mountains of Arizona and New Mexico; southern Colorado	Cool dry	Seral to *A. lasiocarpa P. engelmannii*	*A. lasiocarpa* *P. engelmannii* *A. concolor* *P. tremuloides* *P. menziesii* *P. strobiformis*	*E. superbus* (*E. eximius*) *B. ciliatus* *F. virginiana* *Lonicera involucrata* *A. cordifolia*	DeVelice et al. 1984[3] Moir and Ludwig 1979
			Riparian series			
Alnus tenuifolia/ Equisetum arvense H.T.	Streambanks, montane zone, north-central Colorado	Warm moist to wet	Minor climax to *A. tenuifolia*	*A. tenuifolia* *Betula occidentalis* *P. ponderosa* *P. tremuloides*	*Salix* spp. *Rosa woodsii* *E. arvense* *A. glabrum*	Hess 1981
Populus angustifolia/ Salix exigua H.T.	Streambanks and foothills of north-central Colorado	Warm moist to wet	Minor climax to *P. angustifolia*	*P. tremuloides* *P. angustifolia* *P. ponderosa* *P. menziesii* *J. scopulorium*	*Salix* spp. *A. glabrum*	Hess 1981

[1]*Hess, Karl, and C. H. Wasser. 1982. Grassland, shrubland and forestland habitat types of the White River-Arapaho National Forests. USDA Forest Service Final Report, 335 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.*

[2]*Komarkova, Vera. 1984. Habitat types on selected parts of the Gunnison and Uncompahgre National Forests. USDA Forest Service Preliminary Report, 254 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.*

[3]*DeVelice, Robert L., John A. Ludwig, William H. Moir, and Frank Ronco, Jr. 1984. A classification of forest habitat in northern New Mexico and southern Colorado. USDA Forest Service. Draft of manuscript in preparation. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.*

[4]*Youngblood, Andrew P. 1984. Coniferous forest habitat types of central and southern Utah. USDA Forest Service. Draft of manuscript in preparation. Intermountain Forest and Range Experiment Station, Ogden, Utah.*

[5]*Alexander, Billy G., Jr., E. Lee Fitzhugh, Frank Ronco, Jr., and John A. Ludwig. 1984. A classification of forest habitat types on the Cibola National Forest, New Mexico. USDA Forest Service. Draft of manuscript in preparation. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.*

[6]*Fitzhugh, E. Lee, William H. Moir, John A. Ludwig, and Frank Ronco, Jr. 1984. Forest habitat types in the Apache, Gila, and part of the Cibola National Forests. USDA Forest Service. Draft of manuscript in preparation. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.*

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☆U.S. Government Printing Office 1984 - 578-760/25195 Reg. 8

U.S. Department of Agriculture
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Rocky Mountain Forest and Range Experiment Station

Rocky Mountains

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The Rocky Mountain Station is one of eight regional experiment stations, plus the Forest Products Laboratory and the Washington Office Staff, that make up the Forest Service research organization.

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Research programs at the Rocky Mountain Station are coordinated with area universities and with other institutions. Many studies are conducted on a cooperative basis to accelerate solutions to problems involving range, water, wildlife and fish habitat, human and community development, timber, recreation, protection, and multiresource evaluation.

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