Picea engelmannii Parry ex Engelm. **Engelmann spruce**

Pinaceae **Pine family**

Robert R. Alexander and Wayne D. Shepperd

Engelmann spruce is one of the seven species of spruce indigenous to the United States *(62).* Other common names are Columbian spruce, mountain spruce, white spruce, silver spruce, and pino real.

Habitat

Native Range

Engelmann spruce is widely distributed in the western United States and two provinces in Canada ***(61).*** Its range extends from British Columbia and Alberta, Canada, south through all western states to New Mexico and Arizona (fig. 1).

In the Pacific Northwest, Engelmann spruce grows along the east slope of the Coast Range from west central British Columbia, south along the crest and east slope of the Cascades through Washington and Oregon to northern California *(6,13,20).* It is a minor component of these high-elevation forests.

Engelmann spruce is a major component of the high-elevation Rocky Mountain forests, growing in the Rocky Mountains of southwestern Alberta, south through the high mountains of eastern Washington and Oregon, Idaho, and western Montana to western and central Wyoming, and in the high mountains of southern Wyoming, Colorado, Utah, eastern Nevada, New Mexico, and northern Arizona *(6,13,20).*

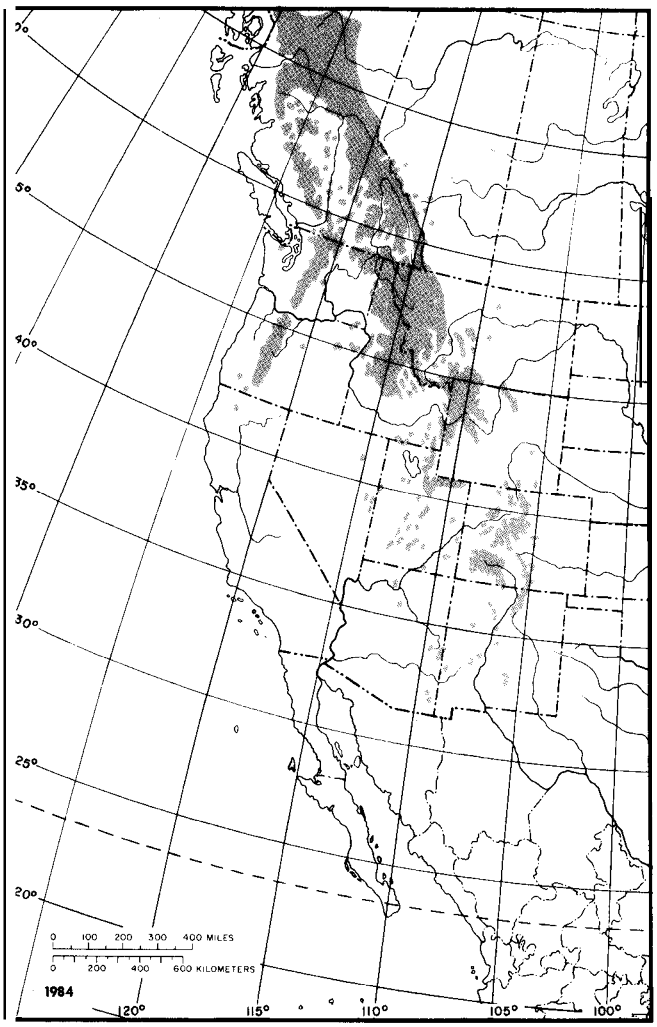

Figure 1-Natural ***range of Engelmann spruce.***

Climate

Engelmann spruce grows in a humid climate with long, cold winters and short, cool summers. It occupies one of the highest and coldest forest environments in the western United States, characterized by heavy snowfall and temperature extremes of more than -45.6” C (–50° F) to above 32.2” C (90° F). Climatic data for four subregions of the United States within the species range are given in table 1 *(23,42,65,100).*

The range of mean annual temperatures is narrow considering the wide distribution of the species. Average annual temperatures are near freezing, and frost can occur any month of the year. Average precipitation exceeds 61 cm (24 in) annually, with only moderate or no seasonal deficiency. Summer is the driest season in the Cascades and Rocky Mountains west of the Continental Divide south to southwestern Colorado. The mountains east of the divide, in southwestern Colorado, and in New Mexico and Arizona, receive considerable summer rainfall, while winter snowfall can be light *(23,48,64,100).* Winds are predominantly from the west and southwest and can be highly destructive to Engelmann spruce *(13,20).*

The authors are Chief Silviculturist (retired) and Silviculturist, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO.

Table 1.-Climatological data for four regional subdivisions within the range of Engelmann spruce

Location	Average temperature Annual		July		January		Annual precip.		Annual snowfall		Frost each period
	°C	°F	°C	°F	°C	°F	cm	in	cm	in	days
Pacific Northwest	2	35	10-13	50-55	-9 to -7	15–20	152-406	60-160	1015+	400+	45-90
U.S. Rocky Mountains											
Northern[1]	-1 to 2	30-35	4-13	45-55	-12 to -7	10-20	61-114	24–45+	635+	250+	[4]30–60
Central[2]	-1 to 2	30-35	10-13	50–55	-12 to -9	10-15	61-140	24-55	381–889+	150–350+	[4]30–60
Southern[3]	2	35	10–16	50-60	-9 to -7	15-20	61–89+	24–35+	508	200+	[4]30-75

[1]Includes the Rocky Mountains of Montana and Idaho and associated mountains of eastern Washington and Oregon.
[2]Includes the Rocky Mountains of Wyoming and Colorado and associated mountains of Utah.
[3]Includes the Rocky Mountains and associated ranges of New Mexico and Arizona and the plateaus of southern Utah.
[4]Frost may occur any month of the year

Soils and Topography

Information on soils where Engelmann spruce grows is limited. In the Pacific Coast region, soil parent materials are mixed and varied. Country bedrock is composed of a variety of sedimentary, igneous, and metamorphic rock. The most common of the great soil groups are Cryorthods (Podzolic soils), Haplumbrepts (western Brown forest soils), Haplorthods (Brown Podzolic soils), Hapludalfs (Gray-Brown Podzolic soils), and Haploxerults and Haplohumults (Reddish-Brown Lateritic soils); these great soil groups developed from deep glacial and lacustrine deposits, deep residual material weathered in place from country rock, and volcanic lava and ash. Xerochrepts (Regosolic soils), developed from shallow residual material, are also widespread. Xeropsamments (Regosolic soils) and Haplaquolls (Humic Gley soils) are the principal soils derived from alluvium. On the east side of the Cascade crest, soils are largely Haploxeralfs (Non-Calcic Brown soils) and Haploxerolls (Chestnut soils) (39,103).

In the Rocky Mountain subalpine zone, soil materials vary according to the character of the bedrock from which they originated. Crystalline granite rock predominates, but conglomerates, shales, sandstones, basalts, and andesites commonly occur. Glacial deposits and stream alluvial fans are also common along valley bottoms. Of the great soils group, Cryorthods (Podzolic Soils) and Haplorthods (Brown Podzolic Soils) occur extensively on all aspects. Cryochrepts (Thick Cold Soils) occur extensively on the drier aspects. Aquods (Ground-water Podzolic Soils) are found in the poorly drained areas. Cryoboralfs (Gray-Wooded Soils) are found where timber stands are less dense and parent material finer textured. Haploborolls (Brown Forest Soils) occur mostly in the lower subalpine zone along stream terraces and side slopes. Lithics (Lithosolic Soils) occur wherever bedrock is near the surface. Aquepts (Bog Soils) and Haplaquepts (Humic Gley Soils) occur extensively in poorly drained upper stream valleys (48,103).

Regardless of the parent materials, spruce grows best on moderately deep, well drained, loamy sands and silts, and silt and clay loam soils developed from a variety of volcanic and sedimentary rock. Good growth also is made on glacial and alluvial soils developed from a wide range of parent materials, where an accessible water table is more important than physical properties of the soil. It does not grow well on rocky glacial till, heavy clay surface soils, saturated soils, or on shallow, dry coarse-textured sands and gravels developed primarily from granitic and schistic rock or course sandstones and conglomerates *(13,23)*.

Along the east slope of the Coast Range and interior valleys of southwestern British Columbia, Engelmann spruce grows at 762 to 1067 m (2,500 to 3,500 ft). Farther south in the Cascade Mountains of Washington and Oregon, it generally grows at 1219 to 1829 m (4,000 to 6,000 ft), but it may be found at 2438 m (8,000 ft) on sheltered slopes and at 610 m (2,000 ft) in cold pockets along streams and valley bottoms. In northern California, spruce grows at 1219 to 1524 m (4,000 to 5,000 ft) (16,98).

South of the Peace River Plateau in the Canadian Mountains of British Columbia and Alberta, Engelmann spruce grows at 762 to 1829 m (2,500 to 6,000 ft); in the Rocky Mountains of Idaho and Montana and in the adjacent mountains of eastern Washington and Oregon, at 610 to 2743 m (2,000 to 9,000 ft). But above 1829 to 2286 m (6,000 to 7,500 ft), it is a minor component of the stand, and below 1524 m (5,000 ft) it is confined to moist, low slopes and cold valley bottoms *(20)*.

Engelmann spruce is found at 2743 to 3353 m (9,000 to 11,000 ft) in the Rocky Mountains of Utah, Wyoming, and Colorado, but it may extend as low as 2438 m (8,000 ft) along cold stream bottoms and to timberline at 3505 m (11,500 ft). In the Rocky Mountains of New Mexico and Arizona and on the plateaus of southern Utah, it grows at 2896 to 3353 m (9,500 to 11,000 ft), but it may grow as low as 2438 m (8,000 ft) and as high as 3658 m (12,000 ft) *(13,20).*

Associated Forest Cover

Engelmann spruce most typically grows together with subalpine fir ***(Abies** lasiocarpa)* to form the Engelmann Spruce-Subalpine Fir (Type 206) forest cover type. It may also occur in pure or nearly pure stands. Spruce grows in 15 other forest types recognized by the Society of American Foresters, usually as a minor component or in frost pockets *(95):*

201 White Spruce
205 Mountain Hemlock
208 Whitebark Pine
209 Bristlecone Pine
210 Interior Douglas-Fir
212 Western Larch
213 Grand Fir
215 Western White Pine
216 Blue Spruce
217 Aspen
218 Lodgepole Pine
219 Limber Pine
224 Western Hemlock
226 Coastal True Fir-Hemlock
227 Western Redcedar-Western Hemlock

The composition of the forest in which Engelmann spruce grows is influenced by elevation, exposure, and latitude *(30).*[1] In the Rocky Mountains and Cascades, subalpine fir is its common associate at all elevations. In the northernmost part of its range along the Coast Range and in the Rocky Mountains of Canada, it mixes with white spruce *(Picea glauca),* black spruce ***(Piceu muriunu),*** Douglas-fir ***(Pseudotsugu menziesii),*** balsam poplar ***(Populus balsumiferu),*** and paper birch *(Betula **pupyriferu).*** In the Rocky Mountains of Montana and Idaho, in the Cascades, and in the mountains of eastern Washington and Oregon, associates at lower and middle elevations are western white pine *(Pinus **monticolu),*** Douglas-fir, western larch ***(Lurix occident&s),*** grand fir ***(Abies grandis),*** and lodgepole pine *(Pinus contorta);* associates at higher elevations are Pacific silver fir ***(Abies** amabilis),* mountain hemlock ***(Tsugu mertensiunu),*** alpine larch ***(Lurix** lyallii),* and whitebark pine *(Pinus **ulbicuulis).*** In the Rocky Mountains south of Montana and Idaho, and in the mountains of Utah, lodgepole pine, interior Douglas-fir ***(Pseudotsugu menziesii*** var. ***gluucu),*** blue spruce ***(Piceu** pungens),* white-fir ***(Abies concolor),*** aspen ***(Populus tremuloides),*** and occasionally ponderosa pine *(Pinus **ponderosu)*** and southwestern white pine *(Pinus **strobiformis),*** are common associates at lower and middle elevations, and corkbark fir ***(Abies** lasiocarpa* var. ***urizonicu),*** limber pine *(Pinus flexilis),* and bristlecone pine *(Pinus **uristutu)*** at high elevations. Engelmann spruce extends to timberline in the Rocky Mountains south of Idaho and Montana, and may form pure stands at timberline in the southernmost part of its range. In the Canadian Rockies of southwestern Alberta and adjacent British Columbia and into the Rocky Mountains north of Wyoming and Utah, and the Cascades, spruce usually occupies moist sites below timberline; its high-elevation associates form timberline forests *(6,20).*

Rocky Mountain maple *(Acer glabrum)* (warm, moist sites); twinflower ***(Linnueu borealis),*** (cool, moist sites); common creeping juniper ***(Juniperus** communis)* (warm, dry sites); and grouse whortleberry *(Vaccinium **scopurium),*** heartleaf arnica ***(Arnicu cordifoliu),*** boxleaf myrtle ***(Puchistimu myrsinites),*** elk sedge ***(Curex geyeri),*** mountain gooseberry *(Ribes* ***montigenum),*** and fireweed ***(Epilobium** angustifolium)* (cool, dry sites) occur as undergrowth throughout much of the range of Engelmann spruce. Undergrowth vegetation is more variable than tree associates, however. Undergrowth characteristically found in the Pacific Northwest Region and the Rocky Mountains and associated ranges north of Utah and Wyoming include: Labrador-tea ***(Ledum** glandulosum),* Cascades azalea ***(Rhododendron** albiflorum),* rusty skunkbrush ***(Menziesiu ferrugineu),*** woodrush *(Luzula **hitchcockii),*** dwarf huckleberry *(Vaccinium **cespitosum),*** and blue huckleberry *(Vaccinium globulare),* (cool, moist sites); false solomons-seal ***(Smilucinu** stellata),* queenscup beadlily *(Clintoniu **unifloru),*** twistedstalk ***(Streptopus umplexifolius),*** and sweetscented bedstraw *(Galium triflorum)* (warm, moist sites); pinegrass ***(Culumugrostis rubescens)*** and bear-grass *(Xerophyllum **tenux)*** (cool, dry sites); Oregongrape ***(Berberis** repens),* white spirea ***(Spirueu** betulifolia),* and big whortleberry *(Vaccinium **membrunuceum)*** (warm, dry sites); and marsh-marigold *(Caltha **leptosepulu),*** devilsclub *(Oplopanax **horridum),*** and bluejoint reedgrass ***(Culumugrostis cunudensis)*** (wet sites) *(14,39).*

Undergrowth characteristically found in the Rocky Mountains and associated ranges south of Idaho and

'Classification of forest vegetation into "habitat types" based on methodology developed by Daubenmire *(31)* and Daubenmire and Daubenmire (33) and modified by others, is available for much of the western forest land. However, the classification has not been completed for all land where Engelmann spruce grows. Moreover, because of the great number of these habitat types and the complexity of their descriptions, they have not been included in this paper.

Montana include: mountain bluebells *(Mertensia ciliata)* and heartleaf bittercress *(Cardamine cordifolia)* (cool, moist sites); thimbleberry *(Rubus parviflorus)* (warm, moist sites); red buffaloberry *(Shepherdia canadensis),* Oregongrape, mountain snowberry *(Symphoricarpos oreophilus),* and Arizona peavine *(Lathyrus arizonicus)* (warm, dry sites); and Rocky Mountain whortleberry *(Vaccinium myrtillus),* groundsel *(Senecio sanguiosboides),* polemonium *(Polemonium delicatum),* daisy fleabane *(Erigeron eximius),* prickly currant *(Ribes lacustre),* sidebells pyrola *(Pyrola secunda),* and mosses (cool, dry sites) *(14).*

Life History

Reproduction and Early Growth

Flowering and Fruiting-Engelmann spruce is monoecious; male and female strobili are formed in the axils of needles of the previous year's shoots after dormancy is broken, usually in late April to early May. Ovulate strobili (new conelets) are usually borne near ends of the shoots in the upper crown and staminate strobili on branchlets in the lower crown (38,102). Separation of male and female strobili within the crown reduces self-fertilization. The dark purple male flowers are ovoid to cylindrical and pendant. Female flowers are scarlet, erect, and cylindrical. Male flowers ripen and pollen is wind disseminated in late May and early June at low elevations, and from mid-June to early July at high elevations. The conelets grow rapidly and soon reach the size of the old cones that may have persisted from previous years. The new cones mature in one season and are 2.5 to 6.3 cm (1 to 2.5 in) long. They ripen in August to early September, open, and shed their seed. The cones may fall during the following winter or may remain attached to the tree for some time (20, 89,102).

Seed Production and Dissemination-Although open-grown Engelmann spruces begin bearing cones when they are 1.2 to 1.5 m (4 to 5 ft) tall and 15 to 40 years old, seed production does not become significant until trees are larger and older. The most abundant crops in natural stands are produced on healthy, vigorous, dominant trees 3.8 dm (15 in) or more in diameter at breast height and 150 to 250 years old. Engelmann spruce is a moderate to good seed producer *(11,19,21).* Good to bumper seed crops, based on the following criteria, are generally borne every 2 to 5 years, with some seed produced almost every year *(19):*

Number of sound seeds/hectare		Seed crop rating
0–24,700	(0–10,000/acre)	Failure
24,700–123,500	(10,000–50,000/acre)	Poor
123,500–247,000	(50,000–100,000/acre)	Fair
247,000–617,500	(100,000–250,000/acre)	Good
617,500–1,235,000	(250,000–500,000/acre)	Heavy
>1,235,000	(>500,000/acre)	Bumper

There is great variation in seed production from year to year and from area to area. In one study on the Fraser Experimental Forest in Colorado, annual seed production averaged only 32,100 sound seeds per acre during the period 1956-65 (4). Only one good and two moderate crops were recorded. In more recent studies, spruce seed production has been greater, possibly because the studies were better designed to sample seed production. One such study of seed production on five National Forests, covering 42 area-seed crop years from 1962 to 1971, rated seed crops as 5 bumper, 1 heavy, 6 good, and the remaining 30 fair to failure (74). In the one year, 1967, that a bumper seed crop was produced on all areas, seed production was the highest ever recorded in Colorado (84). In another study on the Fraser Experimental Forest covering 15 years (1970–84) and 13 locations, seed production was rated 2 bumper, 3 heavy, 2 good and 8 fair to failure *(21).*

In the northern Rocky Mountains, Boe (26) analyzed cone crops in Montana between the years 1908 and 1953. Twenty-two crops observed west of the Continental Divide during the 45-year period were rated: 5 good, 8 fair, and 9 poor. East of the Divide, seed production was poorer: only 2 good, 4 fair, and 15 poor crops were reported for a 21-year period. In other studies in the Northern and Intermountain Regions, seed production was rated as good to bumper in 1 year out of 5, with the other 4 years rated as failures *(78,96).*

Observations in spruce forests before seedfall have indicated that part of each seed crop is lost to cone and seed insects *(13).* In a recently completed study in Colorado, insect-caused loss of Engelmann spruce seed averaged 28 percent of the total seed produced during a 4-year period (1974-1977) (88). The percentage of infested cones was highest during years of poor seed production. The primary seed-eating insects were a spruce seedworm *(Cydia youngana = (Laspeyresia youngana)* and an unidentified species of fly, possibly a *Hylemya,* found only in the larval stage.

Some seed is lost from cutting and storing of cones by pine squirrels *(Tamiasciurus hudsonicus fremonti),* but the actual amount is unknown. After seed is shed, small mammals such as deer mice *(Peromyscus maniculatus),* red-backed mice *(Clethrionomys gapperi),* mountain voles *(Microtus montanus),* and chipmunks *(Eutamias minimus)* are the principal source of seed loss. Undoubtedly, mammals consume much seed, but the amount is not known and results of studies on protecting seed are conflicting. For example, in western Montana, spruce seedling success was little better on protected than unprotected seed spots *(90),* but in British Columbia, protection of spruce seed from rodents was essential to spruce regeneration success *(94).*

Cones begin to open in September. Most seed is shed by the end of October, but some falls throughout the winter. The small, winged seeds are light, averaging about 297,000/kg (135,000/lb) (102). Nearly all of the seed is disseminated by the wind, squirrels, other mammals, and birds are not important in seed dispersal.

Seed is dispersed long distances only in years of bumper seed crops. For example, studies in the Rocky Mountains show that 237,200 to 617,800 sound seeds/ha (96,000 to 250,000/acre) were dispersed 122 to 183 m (400 to 600 ft) from the source into clearcut blocks 183 m to 244 m (600 to 800 ft) wide (74). Seedfall in cut stands ranged from 1,236,000 to 12,355,000 seeds/ha (500,000 to 5,000,000/acre). In years of good to heavy seed crops, seedfall into cleared openings diminished rapidly as distance from seed source increased. Prevailing winds influence the pattern of seedfall in openings 61 to 244 m (200 to 800 ft) across, with about 40 percent of the seeds falling within 31 m (100 ft) of the windward timber edge *(4,16,74).* Seedfall then diminishes but at a less rapid rate of decline as distance increases to about two-thirds of the way-46 to 183 m (150 to 600 ft)—across the openings. At that distance, the average number of seeds falling is about 25 percent (at 46 m [150 ft]) to less than 5 percent (at 183 m [600 ft]) of the number of released in the uncut stand *(4,74,78,80).* Beyond this point, seedfall gradually increases toward the leeward timber edge, but is only about 30 percent of the seedfall along the windward edge *(13,16).* In the openings observed, a U-shaped pattern of seedfall was poorly defined. The "tailing-off' suggests that significant quantities of seed were released during periods of high winds *(36).*

Seedling Development-Viability of Engelmann spruce seed is rated good and the vitality persistent. The average germinative capacity of spruce is higher than for many associated species *(102):*

Species	Average germinative capacity
Engelmann spruce	69
Subalpine fir	31–34
Lodgepole pine	65–80
Western white pine	44
Interior Douglas-fir	60–93
Western larch	57
Grand fir	46–57
Western hemlock	53-56
Pacific silver fir	20-26
White fir	30-37

Viable seeds of spruce that survive over winter normally germinate following snowmelt when seedbeds are moist and air temperature is at least 7" C (45" F). Field germination of spruce over long periods in Colorado have ranged from 0 to 28 percent of the sound seeds dispersed, depending upon the seedbed and environmental factors *(9,73).*

In the undisturbed forest, spruce seeds germinate and seedlings become established on duff, litter, partially decomposed humus, decaying wood, and mounds of mineral soil upturned by windthrown trees. Any disturbance that removes the overstory produces new microhabitats (80). Under these circumstances, germination and initial establishment are generally better on prepared mineral soil, and disturbed mineral soil and humus seedbeds because moisture conditions are more stable *(27,35,41,73,94).* However, initial survival of spruce on severe sites at high elevations in the Intermountain Region was higher on duff seedbeds than on mineral soil seedbeds (37). Spruce seedling establishment on burned seedbeds has been variable. Success is related to severity of burn, depth of ash, and amount of exposed mineral soil *(29,80,91).* Regardless of the seedbed, high initial mortality usually slows establishment of seedlings. Once established (at least 5 years old), the ability to survive is not increased by a mineral soil seedbed, but is favored by adequate soil moisture, cool temperature, and shade.

Engelmann spruce will germinate in all light intensities found in nature, but 40 to 60 percent of full shade is most favorable for seedling establishment at high elevations. Light intensity and solar radiation are high at elevations and latitudes where spruce grows in the central and southern Rocky Mountains, and seedlings do not establish readily in the open. Planted seedlings often develop a chlorotic appearance that has been attributed to solarization-a phenomenon by which light intensity inhibits photosynthesis and which ultimately results in death *(82).* Mortality can be reduced by shading seedlings. At low elevations and high latitudes in the northern Rocky Mountains, spruce can become established and survive in the open *(17).* Spruce can establish and survive better in low light intensities than its common, intolerant associates such as lodgepole pine, Rocky Mountain Douglas-fir, and aspen, but at extremely low light intensities it cannot compete favorably with such shade-enduring associates as the true firs and hemlocks *(20).*

Engelmann spruce is restricted to cold, humid habitats because of its low tolerance to high temperature and drought *(25,45).* However, solar radiation at high elevations heats soil surfaces [up to 66" C (150" F or more)] and increases water losses from both seedlings and soil by transpiration and evaporation *(9,73,80)*.

Because of its slow initial root penetration and extreme sensitivity to heat in the succulent stage, drought and heat girdling kill many first-year spruce seedlings. Drought losses can continue to be significant during the first 5 years of seedling development, especially during prolonged summer dry periods *(9,34,73)*.

Tree seedlings in the succulent stage are particularly susceptible to stem-girdling. The cortex is killed by a temperature of 54" C (130" F), but prolonged exposures to somewhat lower temperatures may also be lethal. On the Fraser Experimental Forest, heat-girdling caused much early seedling mortality on unshaded seedbeds *(9,73)*. Soil-surface temperature exceeded 65" C (150" F) in the open on a north aspect and 71" C (160" F) on a south aspect at 3200 m (10,500 ft) elevation in June. Maximum air temperature during this period did not exceed 26" C (78° F). In western Montana, at low elevations, soil surface temperatures exceeded 71" C (160" F) on gentle north slopes several times during one summer (80). Early shade protection increased survival of newly germinated spruce seedlings; 30 to 50 percent of the seedlings were lost to heat-girdling on unshaded plots, compared to 10 percent on shaded plots. In southwestern Alberta, when newly germinated spruce seedlings were deprived of water, nearly three-fourths of the mortality on four different unshaded seedbed types was caused by heat-girdling *(34)*. Surface temperatures as low as 45" C (113" F) caused heat girdling, but losses were not high until soil surface temperatures were above 50" C (122" F). Shading reduced heat-girdling on all seedbed types. Soil surface temperatures in excess of lethal levels for spruce seedlings, especially on burned seedbeds, have been reported in British Columbia (94).

Air and soil temperatures (below the surface) are not usually directly responsible for seedling mortality, but they affect growth. In a growth chamber study of Engelmann spruce seedlings under 30 different combinations of day and night temperatures, the greatest height and root growth, and top and root dry matter production was with a diurnal variation of 19" C (66" F) (air and soil) day temperatures and 23" C (73" F) (air and soil) night temperatures (45). Shepperd *(92)*, using the same night temperature regime, raised the day soil temperature to 23" C (72° F) and significantly increased root growth.

Frost can occur any month of the growing season where spruce grows. It is most likely to occur in depressions and cleared openings because of cold air drainage and radiation cooling. Newly germinated spruce seedlings are most susceptible to early fall frosts. In a greenhouse and laboratory study, new seedlings did not survive temperatures as low as -9.5" C (15° F) until about 10 weeks old *(71)*. Terminal bud formation began at 8 weeks; buds were set and needles were mature at 10 to 12 weeks after germination.

After the first year, seedlings are most susceptible to frost early in the growing season when tissues are succulent. Shoots are killed or injured by mechanical damage resulting from tissue freezing and thawing. Frost damage has been recorded in most years in Colorado *(81)*. In light frost years, damage was minor, but heavy frosts either damaged or killed all new shoots of open-grown seedlings.

In early fall, the combination of warm daytime temperatures, nighttime temperatures below freezing, and saturated soil unprotected by snow are conducive to frost-heaving. On the Fraser Experimental Forest, Colorado, these conditions generally occurred about 1 out of 2 years *(9,73)*. Frost-heaving has been one of the principal causes of first-year seedling mortality on scarified seedbeds on north aspects *(9)*. Furthermore, seedlings continue to frost-heave after four growing seasons. Shading has reduced losses by reducing radiation cooling.

The moisture condition of the seedbed during the growing season largely determines first-year seedling survival. On some sites in the central Rocky Mountains, summer drought causes great first-year mortality, especially in years when precipitation is low or irregular. On the Fraser Experimental Forest in the central Rocky Mountains, drought and desiccation caused more than half the first-year seedling mortality on south aspects, and nearly two-thirds of the total after 5 years. On north aspects during the same period, drought accounted for about 40 percent of first-year seedling mortality, and more than half the mortality at the end of 5 years (9).

In the northern Rocky Mountains, late spring and early summer drought is a serious threat most years to first-year seedlings. In western Montana, all seedlings on one area were killed by drought in a 2-week period in late summer when their rate of root penetration could not keep pace with soil drying during a prolonged dry period (80). Late spring and early summer drought is also a serious cause of first-year seedling mortality in the southern Rockies. Drought losses can continue to be significant throughout the Rocky Mountains during the first 5 years of seedling development, especially during prolonged summer dry periods *(9,73)*.

The moisture provided by precipitation during the growing season is particularly critical to seedling survival during the first year. A greenhouse study of the effects of amount and distribution of moisture on seedling survival (simulating common summer precipitation patterns in north-central Colorado) showed that under favorable seedbed and environmental conditions: (1) at least 2.5 cm (1 inch) of well distributed precipitation is needed monthly before seedlings will survive drought; (2) with this precipitation pattern, more than 3.75 cm (1.5 in) of monthly rainfall is not likely to increase seedling survival; but (3) few seedlings will survive drought with less than 5 cm (2 in) of rainfall monthly when precipitation comes in only one or two storms *(18).*

Summer precipitation may not always benefit seedling survival and establishment. Summer storms in the Rocky Mountains may be so intense that much of the moisture runs off, especially from bare soil. Moreover, soil movement on unprotected seedbeds buries some seedlings and uncovers others *(80).*

Understory vegetation can be either a benefit or serious constraint to spruce seedling establishment *(2,35,83).* Spruce seedlings become established more readily on sites protected by willows *(Salix* spp.), shrubby cinquefoil *(Potentilla fruiticosa),* fireweed, and dwarf whortleberry than in the open. Because these plants compete less aggressively for available soil moisture than those listed below, the net effect of their shade is beneficial to seedling survival. In contrast, mortality occurs when spruce seedlings start near clumps of grass or sedges or scattered herbaceous plants such as mountain bluebells, currants *(Ribes* spp.), and Oregongrape that compete severely for moisture and smother seedlings with cured vegetation when compacted by snow cover (83).

The only significant biotic factor affecting spruce regeneration on a long-term study on the Fraser Experimental Forest was birds. About 15 percent to 20 percent of the total mortality resulted from the clipping of cotyledons on newly germinated seedlings by grey-headed juncos *(Junco caniceps) (9,73,75).*

Damping-off, needlecast, snowmold, insects, rodents, and trampling and browsing by large animals also kill spruce seedlings, but losses are no greater than for any other species *(20).*

The number of seeds required to produce a first-year seedling and an established seedling (5 years old) and the number of first-year seedlings that produce an established seedling vary greatly, depending upon seed production, distance from source, seedbed, and other environmental conditions. In one study in clearcut openings in Colorado during the period 1961-1975, covering a wide variety of conditions, on the average 665 sound seeds (range 60-2,066) were required to produce one first-year seedling, and 6,800 (range 92620,809) to produce a seedling 4 or more years old. An average of 21 first-year seedlings was necessary to produce a single seedling 4 or more years old, although as few as 4 and as many as 24 first-year seedlings survived under different conditions (74).

Aspect and cultural treatments can also affect establishment of Engelmann spruce. In another Colorado study (covering the period 1969–1982), an average of 18 sound seeds was required to produce a single first-year seedling on shaded, mineral soil seedbeds on a north aspect; and 32 sound seeds were needed to produce a 5-year-old seedling. In contrast, 156 seeds were required to produce a first-year seedling on shaded, mineral soil seedbeds on a south aspect, and 341 seeds to produce a 5-year-old seedling *(8,9).* Shearer *(91),* studying the effects of prescribed burning and wildfire after clearcutting on regeneration in the western larch type in Montana, also found that natural and planted spruce survived better on the north aspect than on the south aspect.

Environmental conditions favorable and unfavorable to the establishment of Engelmann spruce natural regeneration are summarized in Figure 2.

The early growth of Engelmann spruce at high elevations is slow *(60).* First-year spruce seedlings field-grown on mineral soil seedbeds under partial shade in Colorado have a rooting depth of 7.6 to 10.2 cm (3 to 4 in), with a total root length of 12.7 cm (5 in) (72). In the Rocky Mountains of Arizona and New Mexico, root depths of vigorous l-year-old seedlings averaged about 7.1 cm (2.8 in) on both shaded mineral soil seedbeds and on seedbeds where humus depth was about 2.5 cm (1 in) (49). Observations in the Rocky Mountains of Idaho and Montana and British Columbia indicate that first-year penetration of spruce seedlings averages only about 3.8 cm (1.5 in) *(80,94).*

Initial shoot growth of natural seedlings is equally slow in Colorado. First-year spruce seedlings are seldom taller than 2.5 cm (1 in). After 5 years, seedlings average 2.5 to 7.6 cm (1 to 3 in) in height under natural conditions, and 5.1 to 10.2 cm (2 to 4 in) in height on both partially shaded and unshaded, prepared, mineral-soil seedbeds, Seedlings 10 years old may be only 15.2 to 20.3 cm (6 to 8 in) tall under natural conditions, and 25.7 to 30.5 cm (10 to 12 in) tall on both partially shaded and unshaded, prepared, mineral-soil seedbeds *(7),* (fig. 3). After 10 years, trees grow faster, averaging about 1.2 to 1.5 m (4 to 5 ft) in height in about 20 years in full sun or light overstory shade and in about 40 years under moderate overstory shade. Severe suppression of seedlings does occur at low light levels. It is not uncommon to find trees 80 to 120 years old only 1.0 to 1.5 m (3 to 5 ft) tall under the heavy shade of a closed forest canopy (76) (fig. 4).

	Favorable	*Unfavorable*
Seed crop	More than 600,000 seeds per hectare (242,800/acre)	Less than 60,000 seeds per hectare (24,300/acre)
Aspect	North	South
Temperatures	Ambient air more than 0° C (32° F) night and less than 25" C (77" F) day; maximum surface less than 30" C (86° F)	Ambient air less than 0° C (32° F) night and more than 25" C (77° F) day; maximum surface greater than 30" C (86" F)
Precipitation	More than 10 mm (0.4 in)/week	Less than 10 mm (0.4 in)/week
Soil	Light-textured, sandy-loam	Heavy-textured, clay-loam
Seedbed	50 percent exposed mineral soil 40 to 60 percent dead shade Duff and litter less than 5 cm (2 in) Light vegetative cover	10 percent or less exposed mineral soil 10 percent or less dead shade Duff and litter more than 5 cm (2 in) Heavy vegetative cover
Survival	Seedlings more than 12 weeks old by mid-September Low population of birds and rodents that eat seeds and seedlings Protection from trampling Snow cover when frost-heaving conditions exist	Seedlings less than 12 weeks old by mid-September High population of birds and rodents that eat seeds and seedlings No protection from trampling No snow cover when frost-heaving conditions exist

Figure 2—*Environmental conditions favorable and unfavorable to Engelmann spruce regeneration* (9).

Seedling growth has been somewhat better elsewhere in the Rocky Mountains, especially at low elevations and high latitudes. For example, in one study in the intermountain West, annual shoot growth of natural lo-year-old seedlings averaged 11.4 cm (4.5 in) on clearcut areas, and 8.3 cm (3.2 in) on areas with a partial overstory (67). Planted spruces, 5- to 8-years old, averaged 51 to 61 cm (20 to 24 in) in height in Utah. In Montana, planted spruces have been reported to reach breast height 11.4 m (4.5 ft)] in about 10 years *(21).*

Early diameter growth of Engelmann spruce is less affected by competition for growing space than that of its more intolerant associates. In a study of seed spot density in northern Idaho, diameter growth of spruce seedlings after 17 years was only slightly greater on thinned seed spots, and height growth was unaffected by the thinning. In contrast, diameter and height growth of western white pine increased significantly as the number of seedlings per seed spot decreased (79).

Figure *3-Engelmann spruce seedlings on mineral soil seedbeds average only 20.3 cm to 30.5 cm (8 to 12 in) in height after 10 years.*

Vegetative Reproduction-Engelmann spruce can reproduce by layering *(47).* It most often layers near timberline, where the species assumes a dwarfed or prostrate form. Layering can also occur when only a few trees survive fires or other catastrophes. Once these survivors have increased to the point where their numbers alter the microenvironment enough to improve germination and establishment, layering diminishes. In general, this form of reproduction is insignificant in the establishment and maintenance of closed forest stands *(21,76).*

Figure 4—*Engelmann spruce advanced reproduction released by removal of the overstory. Trees average 1.0 m to 1.5 m (3 to 5 ft) in height and are 80 to 120 years old*

Sapling and Pole Stage to Maturity

Growth and Yield-Engelmann spruce is one of the largest of the high-mountain species. Under favorable conditions, average stand diameter will vary from 38.1 to 76.2 cm (15 to 30 in), and average dominant height from 14 to 40 m (45 to 130 ft), depending upon site quality and density *(20)* (fig. 5). Individual trees may exceed 101.6 cm (40 in) in diameter and 49 m (160 ft) in height *(60)*. Engelmann spruce is a long-lived tree, maturing in about 300 years. Dominant spruces are often 250 to 450 years old, and trees 500 to 600 years old are not uncommon *(13)*.

Engelmann spruce has the capacity to grow well at advanced ages. If given sufficient growing space, it will continue to grow steadily in diameter for 300 years, long after the growth of most associated tree species slows down *(20,60)*.

Yields are usually expressed for the total stand. Engelmann spruce does not normally grow in pure stands but in various mixtures with associated species. Average volume per hectare in old-growth (normally 250 to 350 years old) spruce-fir may be practically nothing at timberline, 12,350 to 37,070 fbm/ha (5,000 to 15,000 fbm/acre) on poor sites, and 61,780 to 98,840 fbm/ha (25,000 to 40,000 fbm/acre) on better sites. Volumes as high as 197,680 to 247,100 fbm/ha (80,000 to 100,000 fbm/acre) have been reported for very old stands on exceptional sites *(77,99)*. Average annual growth in virgin spruce-fir forests will vary from a net loss due to mortality to as much as 494 fbm/ha (200 fbm/acre), depending upon age, density, and vigor of the stand (69). Engelmann spruce usually makes up at least 70 percent and often more than 90 percent of the basal area in trees 12.7 cm (5.0 in) and larger at breast height in these stands *(76)*.

With prompt restocking after timber harvest and periodic thinning to control stand density and maintain growth rates, growth of individual spruce trees and yields of spruce-fir stands can be greatly increased and the time required to produce the above volumes and sizes reduced. For example, in stands managed at the growing stock levels (GSL) considered optimum for timber production (GSL 140 to 180) on 140- to 160-year rotations with a 20-year thinning interval, average volumes per hectare will range from 74,100 to 98,800 fbm/ha (30,000 to 40,000 fbm/acre) on poor sites to 222,400 to 259,500 fbm 1 ha (90,000 to 105,000 fbm/acre) on good sites. Volume production declines on all sites when growing stock level is reduced below the optimum for timber production, and the decline is greater with each successive reduction in GSL. Average annual growth will vary from 445 to 1,606 fbm/ha (180 to 650 fbm/acre) ***(15)***. Moreover, since most subalpine fir will be removed in early thinnings, these yields will be largely from Engelmann spruce.

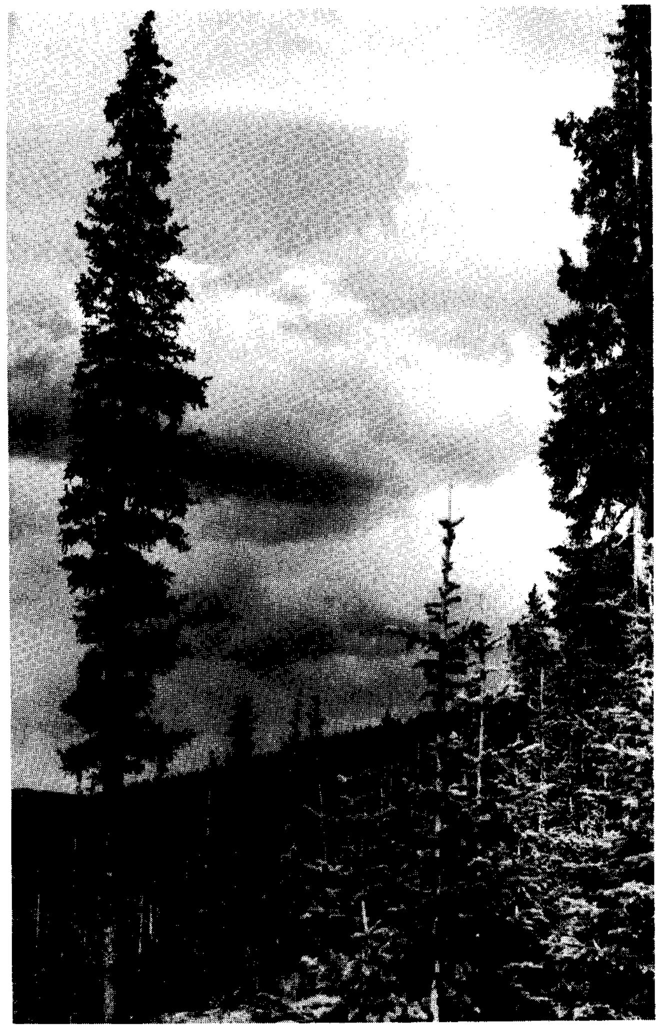

Figure 5—Dominant Engelmann spruce on the Fraser Experimental Forest, Colorado. Tree at the left is 4.6 dm (18 in) in diameter, more than 27 m (90 ft) tall, and 250 years old at breast height.

Rooting Habit--Engelmann spruce has a shallow root system. The weak taproot of seedlings does not persist beyond the juvenile stage, and when trees grow where the water table is near the surface or on soils underlain by impervious rock or clay hardpans, the weak, superficial lateral root system common to the seedling stage may persist to old age. Under these conditions, most roots are in the first 30 to 46 cm (12 to 18 in) of soil. But, where spruce grows on deep, porous, well drained soils, the lateral root systern may penetrate to a depth of 2.4 m (8 ft) or more *(20).*

Reaction to Competition-Engelmann spruce is rated tolerant in its ability to endure shade (24). It is definitely more shade-enduring than interior Douglas-fir, western white pine, lodgepole pine, aspen, western larch, or ponderosa pine but less so than subalpine fir (the most common associate throughout much of its range), grand fir, white fir, and mountain hemlock. The Engelmann spruce—subalpine fir type is either a co-climax type or long-lived seral forest vegetation throughout much of its range. In the Rocky Mountains of British Columbia and Alberta, and south of Montana and Idaho, Engelmann spruce and subalpine fir occur as either codominants or in nearly pure stands of one or the other. In the Rocky Mountains of Montana and Idaho, and in the mountains of Utah, eastern Oregon and Washington, subalpine fir is the major climax species. Engelmann spruce may also occur as a major climax species, but more often it is a persistent long-lived seral species. Pure stands of either species can be found, however (6).

Although spruce-fir forests form climax or near climax vegetation associations, they differ from most climax forests in that many stands are not truly all-aged *(60).* Some stands are clearly single-storied, indicating that desirable spruce forests can be grown under even-aged management. Other stands are two- or three-storied, and multi-storied stands are not uncommon *(13,68).* These may be the result of either past disturbances, such as fire, insect epidemics, or cutting, or the gradual deterioration of old-growth stands due to normal mortality from wind, insects, and disease. The latter is especially evident in the formation of some multi-storied stands. On the other hand, some multi-storied stands appear to have originated as uneven-aged stands and are successfully perpetuating this age-class structure *(10,43,104).*

Although climax forests are not easily displaced by other vegetation, fire, logging, and insects have played an important part in the succession and composition of spruce-fir forests. Complete removal of the stand by fire or logging results in such drastic environmental changes that spruce and fir are usually replaced by lodgepole pine, aspen, or shrub and grass communities *(80,97).* The kind of vegetation initially occupying the site usually determines the length of time it takes to return to a spruce-fir forest. It may vary from a few years, if the site is initially occupied by lodgepole pine or aspen, to as many as 300 years, if grass is the replacement community

What is known about the utilization of water by Engelmann spruce in Colorado can be summarized as follows: (1) leaf water potential decreases in proportion to the transpiration rate but is influenced by soil temperature and water supply; (2) needle water vapor conductance (directly proportional to stomata1 opening) is controlled primarily by visible irradiance and absolute humidity difference from needle to air (evaporative demand), with secondary effects from temperature and water stress; (3) nighttime minimum temperatures below 3.9" C (39" F) retard stomata1 opening the next day, but stomata function well from early spring to late fall, and high transpiration rates occur even with snowpack on the ground; (4) leaf water vapor conductance is higher in Engelmann spruce than in subalpine fir, but lower than in lodgepole pine and aspen; (5) Engelmann spruce trees have less total needle area per unit area of sapwood water conducting tissue than subalpine fir but more than lodgepole pine and aspen; and (6) Engelmann spruce trees have a greater needle area per unit of bole or stand basal area than subalpine fir, lodgepole pine, and aspen. At equal basal area, annual canopy transpiration of spruce is about 80 percent greater than lodgepole pine, 50 percent greater than subalpine fir, and 220 percent greater than aspen. These high rates of transpiration cause Engelmann spruce to occur primarily on moist sites *(50,51,52,53,54,55,56,57,58).*

Both even- and uneven-aged silvicultural systems are appropriate for use in Engelmann spruce forests, but not all cutting methods meet specific management objectives *(5,12,17).* The even-aged cutting methods include clearcutting, which removes all trees in strips, patches, blocks, or stands with a single cut; and shelterwood cutting, which removes trees in one, two, or three cuts and its modifications. Because of susceptibility to windthrow, the seed-tree method is not a suitable way to regenerate spruce. The seedbed is prepared for regeneration after clear-cutting, or after the seed cut with shelterwood cutting, by various methods ranging from burning and mechanical scarification to only that associated with logging activity *(5,12,17).*

The uneven-aged cutting methods appropriate to spruce are individual tree and group selection cuttings and their modifications, which remove selected trees in all size classes at periodic intervals over the entire area or in groups up to 0.8 hectares (2 acres) in size. Reproduction occurs continuously, but methods of site preparation are limited *(12,131.*

Shelter-wood and individual tree selection cutting methods will favor associated species such as true firs and hemlocks over spruce. Clearcutting, group shelterwood, and group selection cutting methods will favor Engelmann spruce over these more tolerant associates, but will increase the proportion of intolerant associates such as lodgepole pine and Douglas-fir *(13).*

Damaging Agents-Engelmann spruce is susceptible to windthrow, especially after any initial cutting in old-growth forests (fig. 6).

Partial cutting increases the risk because the entire stand is opened up and therefore vulnerable. Windfall is usually less around clearcuts because only the boundaries between cut and leave areas are vulnerable, but losses can be great if no special effort is made to locate windfirm cutting-unit boundaries *(1,3).* While the tendency of spruce to windthrow is usually attributed to a shallow root system, the development of the root system varies with soil and stand conditions. Trees that have developed together in dense stands over long periods of time mutually protect each other and do not have the roots, boles, or crowns to withstand sudden exposure to wind if opened up too drastically, If the roots and boles are defective, the risk of windthrow is increased. Furthermore, regardless of kind or intensity of cutting, or soil and stand conditions, windthrow is greater on some exposures than others. Alexander *(13)* has identified spruce windfall risk in relation to exposures in Colorado as follows:

Below Average:
1. Valley bottoms, except where parallel to the direction of prevailing winds, and flat areas.
2. All lower, and gentle, middle north-east-facing slopes.
3. All lower, and gentle, middle south- and west-facing slopes that are protected from the wind by higher ground not far to windward.

Figure 6—*Windthrown Engelmann spruce, Fraser Experimental Forest, Colorado.*

Above Average:
1. Valley bottoms parallel to the direction of prevailing winds.
2. Gentle middle south and west slopes not protected to the windward.
3. Moderate to steep middle, and all upper north- and east-facing slopes.
4. Moderate to steep middle south- and west-facing slopes protected by higher ground not far to windward.

Very High:
1. Ridgetops.
2. Saddles in ridges.
3. Moderate to steep middle south- and west-facing slopes not protected to the windward.
4. All upper south- and west-facing slopes.

The risk of windfall in these situations is increased at least one category by such factors as poor drainage, shallow soils, defective roots and boles, and overly dense stands. Conversely, the risk of windfall is reduced if the stand is open-grown or composed of young, vigorous, sound trees. All situations become very high risk if exposed to special topographic situations, such as gaps or saddles in ridges at high elevations to the windward that can funnel winds into the area *(1,3,13).*

The spruce beetle *(Dendroctonus rufipennis)* is the most serious insect pest of Engelmann spruce (86). It is restricted largely to mature and overmature spruce, and epidemics have occurred throughout recorded history. One of the most damaging outbreaks was in Colorado from 1939 to 1951, when beetles killed nearly 6 billion board feet of standing spruce (64) (fig. 7). Damaging attacks have been largely associated with extensive windthrow, where downed trees have provided an ample food supply for a rapid buildup of beetle populations. Cull material left after logging has also caused outbreaks, and there are examples of large spruce beetle populations developing in scattered trees windthrown after heavy partial cutting. The beetle progeny then emerge to attack living trees, sometimes seriously damaging the residual stand. Occasionally, serious spruce beetle outbreaks have developed in overmature stands with no recent history of cutting or windfall, but losses in uncut stands that have not been subjected to catastrophic wind storms have usually been no greater than normal mortality in old growth *(13).*

Spruce beetles prefer downed material to standing trees, but if downed material is not available, then standing trees may be attacked. Large, overmature trees are attacked first, but if an infestation persists, beetles will attack and kill smaller trees after the large trees in the stand are killed. In the central

Figure 7—*Engelmann spruce killed by spruce beetles, White River Plateau, Colorado.*

Rocky Mountains susceptibility to beetle attack can vary by location; the following sites are arranged from most to least susceptible: (1) trees in creek bottoms, (2) good stands on benches and high ridges, (3) poor stands on benches and high ridges, (4) mixed stands, and (5) immature stands *(59,85).* Analysis of past infestations suggests the following kinds of stands are susceptible to outbreaks: (1) single- or two-storied stands, (2) high proportions of spruce in the overstory, (3) basal area of 34 m/ha (150 sq ft^2/acre) or more in older and larger trees, and (4) an average lo-year periodic diameter growth of 1.0 cm (0.4 in) or less (87).

The western spruce budworm *(Choristoneura occident&s)* is another potentially dangerous insect attacking Engelmann spruce and subalpine fir *(40).* Although spruce and fir are among the preferred hosts, budworm populations have been held in check by combinations of several natural control factors—parasites, predators, diseases, and adverse climatic conditions. The potential for future outbreaks is always present, however. An excellent summary of the ecology, past insecticidal treatments, and silvicultural practices associated with western spruce budworm in northern Rocky Mountain forests is given by Carlson *et al. (28).*

The most common diseases of Engelmann spruce are caused by wood-rotting fungi that result in loss of volume and predispose trees to windthrow and windbreak (46). In a recent study of cull indicators and associated decay in Colorado, the major root and butt fungi in mature to overmature Engelmann spruce were identified as ***Phellinus nigrolimitatus, Flammula alnicola, Polyporus tomentosus*** var. ***curnatua, Gloeocystidiellum radiosum,*** and ***Coniophora puteana.*** Trunk rots, which caused 88 percent of the decay, were associated with ***Phellinus pini, Haematosterceum sanguinolentum, Echinodontium sulcatum,*** and ***Amylosterceum chailletii.*** Spruce broom rust ***(Chrysomyxa arctostaphyli)*** is also common in spruce-fir forests. It causes bole deformation, loss of volume, and spiketops; increases susceptibility to windbreak; and provides infection courts for decay fungi in spruce (20,461.

Dwarfmistletoe ***(Arceuthobium microcarpum)*** causes heavy mortality in spruce in Arizona and New Mexico, but it has a limited range in the Southwest and is not found elsewhere *(44).*

Engelmann spruce does not prune well naturally. Thin bark and the persistence of dead lower limbs make it susceptible to destruction or severe injury by fire (fig. 8). Many root and trunk rots in old growth appear to be associated with fire injury. Because of the climate where spruce grows, the risk of fire is less than in warmer and drier climates *(20).*

Special Uses

Engelmann spruce-subalpine fir forests occupy the greatest water yielding areas in the Rocky Mountains. They also provide timber, habitats for a wide variety of game and nongame wildlife, forage for livestock, and recreational opportunities and scenic beauty (5). However, these properties are indigenous to where spruce grows rather than to any special properties associated with the species.

The lumber of spruce is likely to contain many small knots. Consequently, it yields only small amounts of select grades of lumber, but a high proportion of the common grades (70). In the past, spruce was used principally for mine timbers, railroad ties, and poles. Today, much of the lumber is used in home construction where great strength is not required, and for prefabricated wood products. In recent years, rotary-cut spruce veneer has been used in plywood manufacture. Other uses of spruce include specialty items such as violins, pianos and aircraft parts *(22,63).*

The pulping properties of Engelmann spruce are excellent. Long fibers, light color, and absence of resins permit trees to be pulped readily by the sulfite, sulfate, or groundwood processes ***(22,101).*** The species has been used for pulp in the northern Rocky

Figure 8—*Engelmann spruce does not prune well naturally. This old-growth stand still retains many dead lower branches.*

Mountains but not in the central or southern Rocky Mountains.

Genetics

Population Differences

Available information on population differences of Engelmann spruce is limited to a few studies. For example, spruce trees from high-elevation seed sources and northern latitudes break dormancy first in the spring, and, when grown in low-elevation nurseries with low- and middle-elevation seed sources, are the first to become dormant in the fall. Conversely, low-elevation and southern latitude seed sources frequently are more resistant to spring frosts, but are less winterhardy than middle- and high-elevation seed sources (38). In one study that compared seedlings from 20 seed sources, ranging from British Columbia to New Mexico, planted at an elevation of 9,600 feet in Colorado, seedlings from northern latitudes and lower elevations made the best height growth (93). Overall survival from all sources was 73 percent with no significant differences among sources.

Races and Hybrids

There are no recognized races or geographical varieties of Engelmann spruce. There is abundant evidence that natural introgressive hybridization between Engelmann and white spruce occurs in sympatric areas, especially around Glacier Park in Montana (32). It has been suggested that Engelmann and Sitka spruces cross in British Columbia, but it seems more likely that the crosses are between Sitka and white spruce. Engelmann spruce has been artificially crossed with several other spruces, but with only limited success (38).

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