Picea rubens Sarg. Red Spruce

Pinaceae Pine family

Barton M. Blum

Red spruce *(Picea rubens)*, also known as yellow spruce, West Virginia spruce, eastern spruce, and he-balsam, is one of the more important conifers in the northeastern United States and adjacent Canada. It

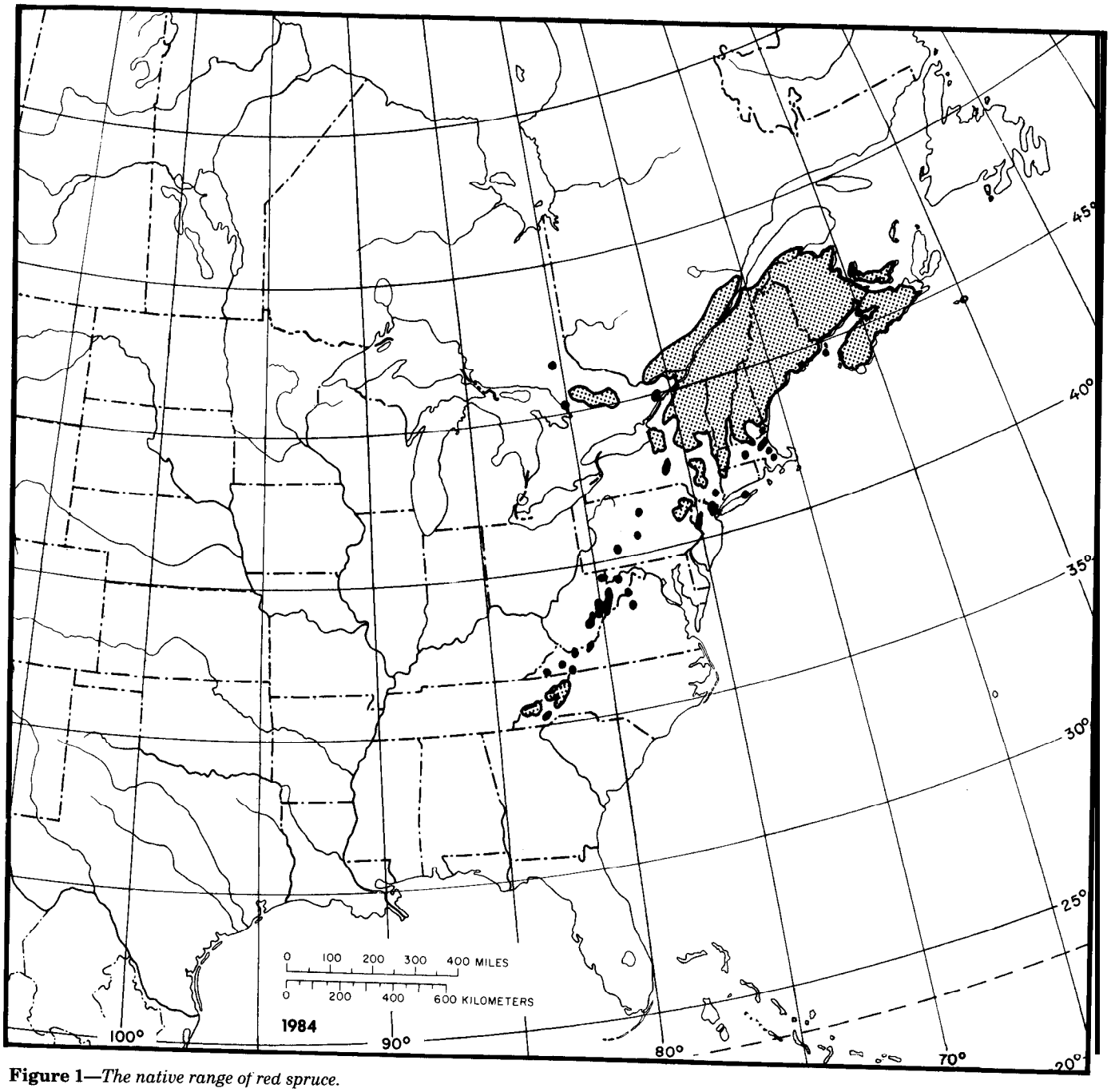

Figure 1—*The native range of red spruce.*

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is a medium-size tree that may grow to be more than 400 years old. The wood of red spruce is light in color and weight, straight grained, and resilient. It is used for making paper, for construction lumber, and for musical stringed instruments. Its many uses rival those of eastern white pine *(Pinus strobus) (21)*.

Habitat

Native Range

The range of red spruce (fig. 1) extends from the Maritime Provinces of Canada west to Maine, southern Quebec, and southeastern Ontario, and south into central New York, eastern Pennsylvania, northern New Jersey, and Massachusetts. It also grows south along the Appalachian Mountains in extreme western Maryland, and eastern West Virginia, and north and west in Virginia, western North Carolina, and eastern Tennessee. Discontinuous stands may also be found in Haliburton Township, in Algonquin Provincial Park, and near Sturgeon Falls in Nippising Township, and in the southwestern Parry Sound District in Ontario, Canada.

Climate

Red spruce grows best in a cool, moist climate. The climate of the northeastern part of its range can be summarized as follows: annual precipitation (total), 910 to 1320 mm (36 to 52 in); annual snowfall, 203 to 406 cm (80 to 160 in); days with snow cover, 100 to 140; January temperature, -7" to –1° C (20" to 30" F) maximum and -18" to -13" C (0° to 8" F) minimum; July temperature, 21" to 27" C (70" to 80" F) maximum, and 11" to 14" C (52° to 58" F) minimum; frost-free days, 90 to 150 *(28)*. Red spruce attains maximum development in the higher parts of the southern Appalachian Mountains where the atmosphere is more humid and the rainfall heavier during the growing season than in other parts of its range (47). Local extension of the range of red spruce, as along the southern Maine coast, is related to marine exposure, which provides a cool growing season and ample moisture supply *(8)*.

Soils and Topography

The soils where red spruce and its associates grow are mostly acid Spodosols, Inceptisols, and sometimes Histosols with a thick mor humus and a well-defined A_2 horizon-characteristics commonly associated with abundant rainfall, cool climates, and softwood cover *(11)*. Commonly, the pH of these soils ranges from 4.0 to 5.5. In northern New England, red spruce is found predominantly on shallow till soils that average about 46 cm (18 in) to a compact layer. It will grow on many sites unfavorable for other species, such as organic soils overlying rocks in mountainous locations, steep rocky slopes, thin soils, and wet bottomland (26). On poorly drained soils, lack of aeration limits growth (22).

In the northern part of its range, red spruce (fig. 2) grows at elevations from near sea level to about 1370 m (4,500 ft) (22). In the southern Appalachian Mountains it comes in at elevations as low as 1370 m (4,500 ft) and from there to about 1520 m (5,000 ft) it is mixed with hardwoods and eastern hemlock *(Tsuga canadensis)*. At 1520 m (5,000 ft) balsam fir *(Abies balsamea)* joins with red spruce to form the dominant spruce-fir climax type. In West Virginia, spruce-fir stands are found as low as 980 m (3,200

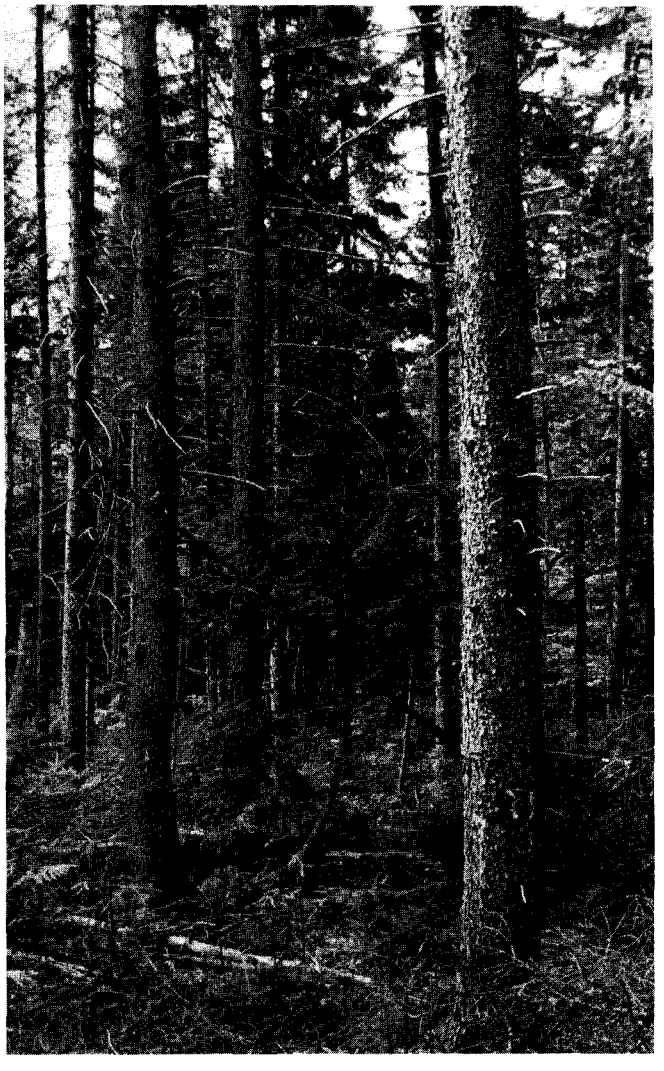

Figure *Z-A red spruce stand.*

ft). Above 1890 m (6,200 ft) in the southern Appalachians, red spruce appears less frequently than Fraser fir ***(Abies fraseri)*** (47). In the White Mountains of New Hampshire, balsam fir is the predominant species above 1220 m (4,000 ft) but red spruce is well represented from about 790 to 1010 m ***(2,600*** to 3,300 ft) (27).

Associated Forest Cover

Pure stands of red spruce comprise the forest cover type Red Spruce (Society of American Foresters Type 32). Red spruce is also a major component in 5 and a minor component in 13 other forest cover types *(10)*:

5 Balsam Fir
12 Black Spruce
16 Aspen
17 Pin Cherry
18 Paper Birch
21 Eastern White Pine
22 White Pine-Hemlock
23 Eastern Hemlock
25 Sugar Maple-Beech-Yellow Birch
30 Red Spruce-Yellow Birch
31 Red Spruce–Sugar Maple-Beech
33 Red Spruce-Balsam Fir
34 Red Spruce-Fraser Fir
35 Paper Birch-Red Spruce-Balsam Fir
37 Northern White-Cedar
60 Beech-Sugar Maple
107 White Spruce
108 Red Maple

Some of the shrubs associated with red spruce are: blueberry *(Vaccinium* spp.), hobblebush ***(Viburnum*** *lantanoides)*, witherod *(V.* ***cassinoides),*** rhodora ***(Rhododendron*** *canadense)*, lambkill *(Kalmia angustifolia)*, mountain-holly *(Nemopanthus* ***mucronata),*** speckled alder *(Alnus rugosa)*, red raspberry *(Rubus* ***idaeus*** var. ***strigosus),*** creeping snowberry *(Gaultheria* ***hispidula),*** wintergreen ***(G.*** *procumbens)*, ***fly*** honeysuckle ***(Lonicera canadensis),*** gooseberry ***(Ribes*** spp.), witch-hazel *(Hamamelis* ***virginiana),*** downey serviceberry ***(Amelanchier arborea),*** beaked hazel *(Corylus* ***cornuta),*** and Canada ***yew*** *(Taxus canadensis).*

A number of mosses and herbs are also found growing in red spruce forest types. Certain mosses, herbs, and shrubs, however, have been shown to be related to site quality of red spruce (22). The three main associations, ***Hylocomium / Oxalis, Oxalis / Cornus,*** and *Viburnum / Oxalis*, in that order, indicate increasing site productivity and increasing hardwood competition. Similar site types in the higher elevations of the Appalachian Mountains of North Carolina include ***Hylocomium / Oxalis*** on north-facing slopes above 1520 m (5,000 ***fit),*** *Oxalis / Dryopteris* at high elevations and all exposures, and the best site type for red spruce and Fraser fir, ***Viburnum*** */ Vaccinium / Dryopteris* ***(47).***

The ***Oxalis*** */ Cornus* association is considered the best for growing conditions in the northern part of the range. On these sites the soil is rich enough for red spruce but not fertile enough for the tolerant hardwoods to offer serious competition (22).

Life History

Reproduction and Early Growth

Flowering and Fruiting-Red spruce is monoecious; male and female flower buds open in May in axils of the previous year's shoots on different branches of the same tree. The pendant male flowers are bright red; female flowers are erect and bright green tinged with purple ***(21).*** Although cone buds differentiate as early as July preceding flowering in the following spring, they are difficult to distinguish until September. For experienced workers they provide a possible means of identifying seed years at that time. The cones mature from about mid-September to early October, the autumn following flowering ***(41).*** Cones are 3 to 4 cm (1.3 to 1.5 in) long, light reddish brown, with rigid, rounded scales often slightly toothed on the edges. Cones are receptive to pollen when fully open, a condition which lasts for only a few days.

Seed Production and Dissemination-Good seed crops occur every 3 to 8 years, with light crops during intervening years (22). Red spruce cones number about 140/liter (5,000/bu), which yields 454 to 680 g (1.0 to 1.5 lb) of seeds. The number of cleaned seeds per kilogram ranges between 220,000 and 637,000 (100,000 and 289,000/lb), with an average of about 306,000 (139,000/lb) ***(41).***

Red spruce seeds fall about 1.2 m (4 ft) per second in still air; the following formula determines distance of travel for wind-disseminated spruce seeds at various heights (47):

$$D = S^h (1.47v)$$

Where D = distance in feet which seed will travel, S = number of seconds required for seed to fall from a height of h (ft) on a tree, and v = velocity of the prevailing wind in miles per hour.

Randall *(37)*, in a study of seed dispersal into clearcut areas, stated that at a distance of 100 m (5 chains or 330 ft) from the timber edge, the number of spruce seeds trapped were more than adequate for regenera-

tion in a good seed year and adequate in an average year. Most of the spruce in the surrounding stands was red spruce.

Seedling Development-Most red spruce seeds germinate the spring following dispersal; some, however, may germinate in the fall soon after dropping from the tree. Germination is epigeal. On favorable seedbeds the usual spring germination period is from late May to early July. On duff, which is more subject to surface drying than most other seedbed materials, some seeds may lose viability by midsummer, and some may show delayed germination well into August (22). Little if any viable seeds remain in the forest floor beyond 1 year ***(13).***

Adequate moisture is the chief factor controlling germination of red spruce. Germination takes place on almost any medium (mineral soil, rotten wood, or shallow duff) except sod. Mineral soil is an excellent seedbed for germination. Generally ample moisture is available and soil temperatures are moderate. Litter and humus are poorer seedbeds because they are likely to be hotter and drier than mineral soil *(11)*. On thicker duff, germination may be poor also because moisture conditions are less favorable. Temperatures of 20" to 30" C (68" to 86" F) are generally favorable for germination. Seeds will not germinate satisfactorily at temperatures below 20" C (68" F) and are permanently injured by long exposure to temperatures higher than 33" C (92" F) *(22)*.

Germination and initial establishment proceed best under cover. Seedlings can become established under light intensities as low as 10 percent of full sunlight; however, as they develop, they require light intensities of 50 percent or more for optimum growth. Seedlings starting in the open undergo heavy mortality when soil surface temperatures reach 46" to 54" C (115" to 130" F) even for a short time *(11)*. Drought and frost heaving are major causes of mortality the first year. Crushing by hardwood litter and snow are also causes of seedling mortality. Winter drying in some years and locations can cause severe leader damage and dieback.

Natural reproduction depends more on seedling survival than on requirements for germination. Spruce seedlings have an exceptionally slow-growing, fibrous, shallow root system. Consequently, a critical factor in their survival and establishment is the depth of the 01 organic layers of the soil profile. When the combined thickness of these layers exceeds 5 cm (2 in), spruce seedlings may not reach mineral soil and the moisture necessary to carry them through dry periods. Red spruce seedlings and the commonly associated balsam fir seedlings are similar in many ways and are controlled by the same factors, but as a rule spruce is the weaker, slower growing species during the establishment period *(22)*.

Seedlings that have attained a height of about 15 cm (6 in) can be considered established. Once established, their early growth is determined largely by the amount and character of overhead competition. Dense growth of bracken ***(Pteridium aquilinum),*** raspberry, and hardwood sprouts are the chief competition for seedlings on heavily cutover lands; but red spruce survives as much as 145 years of suppression and still responds to release *(11,39)*.

Compared to its associates, red spruce is one of the last species to start height growth in the spring, usually beginning the first week in June and ending 9 to 11 weeks later. Radial growth usually begins about the second week of June and continues through August *(22)*.

Vegetative Reproduction-Red spruce rarely, if ever, layers *(15,22,45)*. Recently developed techniques facilitate propagation from stem cuttings under controlled conditions, particularly juvenile cuttings *(7,9,38,45)*.

Sapling and Pole Stages to Maturity

Growth and Yield-Red spruce (fig. 3) is a medium-size tree at maturity, reaching 30 to 61 cm (12 to 24 in) in d.b.h. and 18 to 23 m (60 to 75 ft) in height in the Northeast, and up to 35 m (115 ft) in the Appalachian Mountains. Its maximum age is about 400 years (22). The American Forestry Association lists a tree 133 cm (52.5 in) in d.b.h. and 33.5 m (110 ft) tall in Great Smoky National Park in North Carolina as the largest living red spruce.

The rate of red spruce's growth is strongly influenced by light conditions. Although trees can live in dense shade for many years, once they reach sapling to pole stage nearly full sunlight is beneficial. Understory trees no more than 1.2 or 1.5 m (4 to 5 ft) tall may be more than 50 years old, whereas trees of the same age in the open may be approaching small sawtimber size *(22)*.

Under favorable conditions, red spruce may reach an average d.b.h. of 10 cm (4 in) and height of 7 m (23 ft) in 20 years, and be over 23 cm (9 in) in d.b.h. and 19 m (62 ft) tall in 60 years (22).

Diameter growth of red spruce has been related to vigor, live crown ratio (ratio of live crown to total height), live crown length, and initial diameter at breast height *(6,32)*. High vigor red spruce with a live crown ratio of 0.5 or better averaged 4.3 cm (1.7 in) of diameter growth in 10 years. Growth rates of trees with smaller crown ratios and less vigorous trees

Figure *3-Red spruce seeding into grassland on the mountains of West Virginia.*

Table l-Classification of red spruce trees *(11)*

Tree class (rating as growing stock)	Vigor	Crown class	Live crown ratio[1]	Average 10-year growth in d.b.h.	
				cm	*in*
A, superior	I	Dominant and Intermediate	0.6+	4.6	1.8
B, good	I	Dominant and Intermediate	0.3 to 0.5	3.3	1.3
C, acceptable	II	Overtopped	0.6+		
		Intermediate	0.6+		
		Dominant	0.6+	2.3	0.9
D, inferior		Intermediate	0.3 to 0.5	1.5	0.6
E, undesirable	III	Intermediate	0.3+	0.5	0.2
		All others	0.3 or less		

[1]Ratio of live crown to total height.

decreased progressively to an average of 0.8 cm (0.3 in) in 10 years for trees of low vigor or with crown ratios smaller than 0.4 (22). A tree classification for red spruce is shown in table 1 *(11)*.

In one study *(40)*, average net annual growth in softwood stands (66 to 100 percent softwood species) that can be expected from stands receiving minimal silvicultural input was found to be about 3.5 m^3/ha (50 ft^3/acre). In mixed-wood stands (21 to 65 percent softwood species) this dropped to about 2.8 m^3/ha (40 ft^3/acre), although the majority of the growth was contributed by softwoods. A further breakdown of the data shows the contributions of spruce, most of which was assumed to be red spruce, to be 51 percent in softwood stands and 39 percent in mixed-wood stands.

Yields per acre, in total volumes of all trees larger than 1.5 cm (0.6 in) in d.b.h. (inside bark and including stump and top but not butt swell), are given in table 2 (33).

Table 2-Yield of red spruce by age class and site index (adapted from 33)

Age	Site index[1] 12.2 m or 40 ft	15.2 m or 50 ft	18.3 m or 80 ft	21.3 m or 70 ft
yr		*m³/ha*		
20	6	8	11	14
40	94	132	164	200
60	244	335	422	507
80	308	424	533	640
100	332	456	575	691
yr		*ft³/acre*		
20	80	120	160	200
40	1,350	1,890	2,350	2,850
60	3,490	4,780	6,030	7,240
80	4,400	6,060	7,610	9,150
100	4,740	6,520	8,210	9,870

[1]Base age 50 years when age is measured at d.b.h.-total tree age is estimated to be 65 years at that time.

Table 3-Merchantable yield of red spruce (adapted from 48)

Years since cut	Density index (regional average 100) 50	100	150
		d/ha	
10	17.1	24.4	29.5
20	29.8	37.7	43.3
30	43.5	52.0	58.0
40	58.1	67.3	73.4
50	73.8	83.1	89.7
		ft³/acre	
10	245	349	422
20	425	539	618
30	622	743	828
40	830	961	1,049
50	1,054	1,187	1,281

These yields are normal yields from even-aged stands growing primarily on old fields. Therefore, they are higher than yields that might be expected from more irregular stands such as those developing after cutting *(22)*.

Site index has not been of great utility in rating the potential productivity of spruce-fir sites because of the tolerance of the species and its ability to survive in a suppressed state. Site index at base age 50 years is as good a measure of productivity as any of several growth functions, however *(39)*. Recently, polymorphic site index curves were developed for even-aged spruce and fir stands in northern Maine; they should be valuable for estimating site productivity (20).

Table 4—Aboveground biomass and annual production of all tree components and foliage for red spruce at latitude 45" 30' N. (adapted from *17)*

Moisture regime	Biomass		Annual production	
	t/ha	*tons/acre*	*t/ha*	*tons/acre*
Dry	121.3	54.1	4.5	2.0
Fresh	263.2	117.4	8.7	3.9
Moist	461.3	205.8	9.9	4.4
Wet	164.1	73.2	3.8	1.7

Other yield tables for the Northeast *(48)* take into consideration stand density, composition, and time since cutting. These tables give merchantable volume of spruce and fir combined in trees 15.2 cm (6 in) in d.b.h. and larger from a 0.3 m (1 ft) stump to a 7.6 cm (3 in) top, diameter inside bark, and are somewhat conservative. Yields of merchantable volume for different stand densities from 10 to 50 years after cutting, where 90 percent of the trees are spruce and fir growing on predominantly softwood sites, are given in table 3.

The development of stand projection growth models that permit computer simulation of red spruce tree growth for various management practices and silvicultural treatments over a range of stand conditions has flourished in recent years. For ex-

Figure *4-A dense red spruce stand in Maine.*

ample, the model FIBER was developed in the Northeast (43) for spruce-fir, northern hardwood and a range of Mixedwood forest types between the two. Such models have proved very useful for forest management planning.

In recent years, interest in total biomass yield and productivity has increased, and in the future is likely to become more important in management considerations. As an example, above-ground biomass and productivity values of typical red spruce stands in Canada are given in table 4 for stands in a steady state, across a moisture regime catena (17).

Rooting Habit-Spruce and fir are shallow-rooted, with most of the feeding roots in the duff and the top few centimeters of mineral soil (11). The average rooting depth for all sites in Maine was found to be 33 cm (13 in), with a maximum of 56 cm *(22* in) (22).

Reaction to Competition-Red spruce is classified as shade tolerant in the United States and tolerant or very tolerant in Canada. Opinions differ as to whether red spruce is more tolerant than balsam fir, but the relative tolerance may vary with soil fertility and climate (22).

The species' chief competition comes from balsam fir and hardwoods that produce heavy shade, like beech and maple. Competition from aspen, birch, and other thin-crowned species is not so severe. Red spruce prunes itself about as well as most softwoods in dense stands (fig. 4). As much as one-third of the live crown may be pruned artificially without seriously affecting radial growth (5).

A number of studies have demonstrated the ability of red spruce to respond to release after many years of suppression, The vigor of this response does decline somewhat with age, however, and older trees may require about 5 years to recover before showing accelerated growth (7). Reduction of growth to about 2.5 cm (1 in) of diameter in 25 years, for a duration of 100 years, represents about the limit of suppression for red spruce. Many of its associated tree species such as balsam fir and hemlock may outgrow red spruce after release (22).

Red spruce may be grown successfully using even-age silvicultural prescriptions *(11,12)*. Red spruce is very shallow-rooted, however, making it subject to windthrow, a major silvicultural constraint in the management of the species. As a general rule, it is recommended that no more than one-fourth to one-half of the basal area be removed in the partial harvest of a spruce-fir stand, depending on site, to avoid excessive windthrow damage.

Most of the major forest cover types previously listed in which red spruce is a component are considered either climax or subclimax.

Damaging Agents-The shallow root system, thin bark, and flammable needles of red spruce make trees of all ages very susceptible to fire damage (11). The acreage of red spruce originally present in the southern Appalachians has been reduced to a fraction of what it once was by fire and clearcutting (22). Many former spruce sites are occupied by inferior tree species, blackberries, and ferns after 20 years *(47)*.

The most important insect enemy of red spruce is the spruce budworm, *Choristoneura fumiferana*. Although red spruce is much less vulnerable to damage than balsam fir or white spruce, largely due to later bud flushing in the spring *(3),* much damage and mortality occur in stands containing large quantities of mature balsam fir. Blum and McLean (4) suggest that factors such as stand age, species composition, density, and vigor contribute to the vulnerability of spruce-fir stands to budworm damage and suggest steps to alleviate damage. Additional, detailed information may also be found in Sanders, *et al. (42)* for spruce-fir stands in the Northeast, the Lake States, and Canada.

The eastern spruce beetle, *Dendroctonus rufipennis,* damages mature trees of red spruce. Two species of sawflies, the European spruce sawfly, *Diprion hercyniae,* and the native yellowheaded spruce sawfly, *Pikonema alaskensis,* have severely defoliated red spruce in localized areas (22). The eastern spruce gall adelgid, *Adelges abietis,* can be a serious pest on spruce when abundant. The pine leaf adelgid, *Pineus pinifoliae*, forms unsightly but relatively harmless conelike galls on red and black spruce *(Picea mariana),* which are alternate hosts (46).

Red spruce has few diseases. Needle cast caused by *Lirulu mucrosporu* may result in severe defoliation of the lower crown and a subsequent reduction of growth. *Phellinus pini* and *Phaeolus schweinitzii,* the most destructive of red spruce wood-rotting fungi, are usually confined to overmature or damaged trees. *Climucocystis borealis* causes butt rot in overmature trees (22). Trees are occasionally attacked by *Armillaria mellea* and *Znonotus tomentosa.*

All along the eastern Appalachian mountain chain, from the New England states to Georgia, growth has declined in high-elevation red spruce since the 1960's (25). In recent years, this decline has been accompanied by increased mortality and crown damge in high-elevation red spruce. Apparently, no significant natural biotic or abiotic causal agents have been identified, although it has been hypothesized that

interaction among naturally occurring insect and disease factors and anthropogenic air pollutants, or air pollutants acting alone, are at the root of the problem. Sulphur dioxide (SO_2), nitrogen oxides (NO,), and volatile organic compounds are the pollutants of primary concern; secondary pollutants such as ozone and nitric and sulfuric acids are also believed to be important factors (29).

Growth decline and mortality in low-elevation red spruce in northern New England, while increasing in some areas, appear to be within the normal ranges for trees and forests of various ages, compositions, and density. However, some foliar symptoms have been detected in both red spruce and white pine, particularly from ozone exposure.

Red spruce is occasionally infected with eastern dwarf mistletoe, ***Arceuthobium pusillum,*** a parasite causing growth reduction, tree mortality, and degradation of wood quality (24).

Mice and voles have been found to consume and store significant amounts of spruce seeds in preference to those of balsam fir, suggesting one reason for the low ratio of spruce to fir seedlings commonly found in naturally regenerated stands *(1,23)*. Wildlife damage to the terminal buds of young spruce, presumably by birds, also has been noted (2). Some injury and mortality are also caused occasionally by porcupines, bears, deer, and yellow-bellied sapsuckers (11). Red squirrels clip twigs and terminals and eat reproductive and vegetative buds (41).

Special Uses

The wood of red spruce, white spruce ***(Picea glauca),*** and black spruce cannot be distinguished with certainty by either gross characteristics or minute anatomy, and all three are usually marketed simply as eastern spruce. Chief uses are for lumber and pulpwood, with limited amounts going into poles, piling, boatbuilding stock, and cooperage stock (36). Flakeboard and plywood have been made from spruce in recent years. It is also the preferred wood for piano sounding boards, guitars, mandolins, organ pipes, and violin bellies ***(21).***

Forest cover types that include red spruce support a wide variety of wildlife. They are particularly important as winter cover for deer and, to a certain extent, moose. Small game includes ruffed grouse, snowshoe hare, and woodcock. Many song birds and fur bearers also frequent these forest types (44).

A unique use of red spruce was spruce gum, an exudate that accumulates on trunk wounds. This was the raw material for a flourishing chewing-gum industry in Maine during the last half of the 19th century and early years of this century ***(21).***

Genetics

Successful interspecific crosses with ***Picea rubens*** as male or female parents have been reported or confirmed for ***P. mariana, F! omorika,*** *P.* ***glehnii, P. orientalis,*** and *P.* ***koyamai (15); P. sitchensis (14);*** *P.* ***glauca,*** ***F!*** *mexicana* ***(16); l? x lutzii*** Little *(P.* ***sitchensis x l? glauca), P. maximowiczii,*** and ***l? likiangensis*** *(19)*.

Crossability of *P. rubens* with ***l? omorika*** is good with ***P.*** *mexicana* and ***P. likiangensis*** moderate; with ***l? mariana, I? orientalis, l? maximowiczii,*** and F! ***glehnii*** fair to poor; and with *P.* ***koyamai, l? sitchensis, P. x lutzii,*** and ***P. glauca*** very poor. Several species fail to cross with ***l?*** *rubens (15,16,18,19)*.

Hybrids between ***l?*** *rubens* and ***P. mariana*** occur to some extent in nature, but parental species remain phenotypically pure in their characteristic habitats *(15,30,31,34,35)*.

Literature Cited

1. Abbott, Herschel G., and Arthur C. Hart. 1960. Mice and voles prefer spruce seeds. USDA Forest Service, Station Paper 153. Northeastern Forest Experiment Station, Upper Darby, PA. 12 p.
2. Blum, Barton M. 1977. Animal damage to young spruce and fir in Maine. USDA Forest Service, Research Note NE-231. Northeastern Forest Experiment Station, Broomall, PA. 4 p.
3. Blum, Barton M. 1988. Variation in the phenology of bud flushing in white and red spruce. Canadian Journal of Forest Research 18:315–319.
4. Blum, Barton M., David A. McLean. 1984. Chapter 6: Silviculture, forest management, and the spruce budworm. p. 83-101. *In* Schmitt, Daniel M.; David G. Grimble, and Janet L. Searcy, tech. coords. Managing the spruce budworm in eastern North America. U.S. Department of Agriculture, Agriculture Handbook 620. Washington, DC.
5. Blum, Barton M., and Dale S. Solomon. 1980. Growth trends in pruned red spruce trees. USDA Forest Service, Research Note NE-294. Northeastern Forest Experiment Station, Broomall, PA. 6 p.
6. Bowen, A. Temple, Jr. 1964. The relation of tree and stand characteristics to basal area growth of red spruce trees in partially cut stands in eastern Maine. Maine Agricultural Experiment Station, Bulletin 627. Orono. 34 p.
7. Brix, H. R., and R. van den Driessche. 1977. Use of rooted cuttings in reforestation: a review of opportunities, problems, and activities. British Columbia Forest Service/Canadian Forestry Service, Joint Report 6. Ottawa, ON. 16 p.
8. Davis, Ronald B. 1966. Spruce-fir forests of the coast of Maine. Ecological Monographs 36(2):94.
9. Dancik, B. P. 1980. Forest genetics studies at the University of Alberta. *In* Proceedings, Seventeenth Meeting, Canadian Tree Improvement Association. Pt. 1. p. 201–205.

10. Eyre, F. H., ed. 1980. Forest cover types of the United States and Canada. Society of American Foresters, Washington, DC. 148 p.
11. Frank, Robert M., and John S. Bjorkbom. 1973. A silvicultural guide for spruce-fir in the Northeast. USDA Forest Service, General Technical Report NE-6. Northeastern Forest Experiment Station, Broomall, PA. 29 p.
12. Frank, Robert M., and Barton M. Blum. 1978. The selection system of silviculture in spruce-fir stands-procedures, early results, and comparisons with unmanaged stands. USDA Forest Service, Research Paper NE-425 Northeastern Forest Experiment Station, Broomall, PA. 15 p.
13. Frank, Robert M., and Lawrence 0. Safford. 1970. Lack of viable seed in the forest floor after clearcutting. Journal of Forestry 68(12):776–788.
14. Girouard, R. M. 1970. Propagating four species of spruce by stem cuttings. Canadian Forestry Service, Bi-monthly Research Notes 26(4):29–31.
15. Gordon, Alan G. 1976. The taxonomy and genetics of Picea *rubens* and its relationship to ***Picea mariana.*** Canadian Journal of Botany 54(9):781–813.
16. Gordon, Alan G. 1978. Genecology and the contribution of genetic variation to productivity systems in spruce forest ecosystems. *In* Proceedings Sixteenth Meeting, Canadian Tree Improvement Association, Pt. 1. p. 89-91.
17. Gordon, Alan G. 1979. Productivity and nutrient cycling in natural forests. *In* Canada/MAB Report 12, Biomass Strategy Consultation. p. 34-49. Co-sponsored by the Canadian Committee for the UNESCO Program on Man and the Biosphere (MAB) and the Science Council of Canada.
18. Gordon, Alan G. 1980. Spruce genetics, Sault Ste. Marie in 1977 and 1978. *In* Proceedings, Seventeenth Meeting Canadian Tree Improvement Association, Pt. 1. p. 117-121.
19. Gordon, Alan G. 1980. Genetics and genecology of spruce, Sault Ste. Marie, Ontario, 1979 and 1980. *In* Proceedings, Eighteenth Meeting, Canadian Tree Improvement Association, Pt. 1. p. 89-91.
20. Griffen, Ralph H., and James E. Johnson. 1970. Polymorphic site index curves for spruce and balsam fir growing in even-aged stands in northern Maine. University of Maine Life Sciences and Agriculture Experiment Station, Bulletin 765. Orono. 22 p.
21. Hart, Arthur C. 1959. Silvical characteristics of red spruce ***(Picea rubens).*** USDA Forest Service, Station Paper 124. Northeastern Forest Experiment Station, Upper Darby, PA. 18 p.
22. Hart, Arthur C. 1965. Red spruce ***(Picea rubens*** Sarg.) *In* Silvics of forest trees of the United States. p. 305-310. H. A. Fowells, comp. U.S. Department of Agriculture, Agriculture Handbook 271. Washington, DC.
23. Hart, Arthur C., Hershel G. Abbott, and Edward R. Ladd. 1968. Do small mammals and birds affect reproduction of spruce and fir? USDA Forest Service, Research Paper NE-110. Northeastern Forest Experiment Station, Broomall, PA. 8 p.
24. Hawksworth, F. G., and A. L. Shigo. 1980. Dwarf mistletoe on red spruce in New Hampshire. Plant Disease Reporter 64:880– ***882.***
25. Hertel, Gerard D. 1987. Spruce-fir research cooperative: a program description. Spruce-fir research cooperative, USDA Forest Service, Broomall, PA. 22 p.
26. Leak, W. B. 1976. Relation of tolerant species to habitat in the White Mountains of New Hampshire. USDA Forest Service, Research Paper NE-351. Northeastern Forest Experiment Station, Broomall, PA. 10 p.
27. Leak, William B., and Raymond E. Graber. 1974. Forest vegetation related to elevation in the White Mountains of New Hampshire. USDA Forest Service, Research Paper NE-299. Northeastern Forest Experiment Station, Broomall, PA. 7 p.
28. Lull, Howard W. 1968. A forest atlas of the Northeast. USDA Forest Service, Northeastern Forest Experiment Station, Upper Darby, PA. 46 p.
29. MacKenzie, James J., and Mohammed T. El-Ashry. 1988. Ill winds: airborne pollution's toll on trees and crops. World Resources Institute. 74 p.
30. Manley, S. A. M. 1972. The occurrence of hybrid swarms of red and black spruces in central New Brunswick. Canadian Journal of Forest Research 2(4):381–391.
31. Manley, S. A. M., and F. Thomas Ledig. 1979. Photosynthesis in black and red spruce and their hybrid derivatives: ecological isolation and hybrid adaptive inferiority. Canadian Journal of Botany 57(4):305–314.
32. McLintock, Thomas F. 1948. Evaluation of tree risk in the spruce-fir region of the Northeast. USDA Forest Service, Station Paper NE-16. Northeastern Forest Experiment Station, Upper Darby, PA. 7 p.
33. Meyer, Walter H. 1929. Yields of second-growth spruce and fir in the northeast. U.S. Department of Agriculture, Technical Bulletin 142. Washington, DC. 52 p.
34. Morgenstern, E. K. 1969. Survival and growth of red spruce provenances in three experiments in Ontario. *In* Proceedings, Eleventh Commonwealth Forest Tree Breeding Meeting. p. 206–211.
35. Morgenstern, E. K., A. G. Corriveau, and D. P. Fowler. 1981. A provenance test of red spruce in nine environments in eastern Canada. Canadian Journal of Forest Research 11(1):124–131.
36. Ostrander, M. D. 1974. Eastern spruce...an American wood. USDA Forest Service, FS-263. Washington, DC. 10 p.
37. Randall, Arthur G. 1974. Seed dispersal into two spruce-fir clearcuts in eastern Maine. University of Maine Life Sciences and Agriculture Experiment Station, Research in the Life Sciences 21(8):15.
38. Rauter, R. M. 1980. Genetic improvement of spruce and larch for Ontario, 1977-78. *In* Proceedings, Seventeenth Meeting, Canadian Tree Improvement Association, Pt. 1. p. 123-128.
39. Safford, Lawrence 0. 1968. Evaluation of growth characteristics of individual free-growing red spruce trees as a means of estimating forest productivity. Thesis (Ph.D.), University of Maine, Orono. 148 p.
40. Safford, Lawrence 0. 1968. Ten year average growth rates in the spruce-fir region of northern New England. USDA Forest Service, Research Paper NE-93. Northeastern Forest Experiment Station, Upper Darby, PA. 20 p.
41. Safford, L. 0. 1974. ***Picea*** A. Dietr. Spruce. *In* Seeds of woody plants in the United States. p. 587-597. C. S. Schopmeyer, tech. coord. U.S. Department of Agriculture, Agriculture Handbook 450. Washington, DC.

42. Sanders, C. J., R. W. Stark, E. J. Mullins, J. Murphy, eds. 1985. Recent advances in spruce budworm research: Proceedings, CANUSA Spruce Budworms Research Symposium, September 16-20, 1985, Bangor, ME. Canadian Forestry Service, Ottawa, ON. 527 p.
43. Solomon, Dale S., Richard A. Hosmer, and Homer T. Hayslett, Jr. 1987. FIBER handbook: a growth model for spruce-fir and northern hardwood types. USDA Forest Service, Research Paper NE-602. Northeastern Forest Experiment Station, Broomall, PA. 19 p.
44. Society of American Foresters (Maine Chapter). 1977. Improvement, maintenance, and protection of fish and wildlife habitat. The Maine Forest Review 11:2-8.
45. Stanek, W. 1967. Natural layering of red spruce in Quebec. Canadian Forestry Service, Bi-monthly Research Notes 23(6):42.
46. U.S. Department of Agriculture, Forest Service. 1979. A guide to common insects and diseases of forest trees in the northeastern United States. USDA Forest Service, NA-FR4. Northeastern Area State and Private Forestry, Broomall, PA. 123 p.
47. Walter, Lawrence C. 1967. Silviculture of the minor southern conifers. p. 56-62. Stephen F. Austin State College School of Forestry, Bulletin 15. Nacogdoches, TX.
48. Westveld, M. 1953. Empirical yield tables for spruce-fir cutover-lands in the Northeast. USDA Forest Service, Station Paper 55. Northeastern Forest Experiment Station, Upper Darby, PA. 64 p.