

The red spruce-balsam fir forest of Maine: Evolution of silvicultural practice in response to stand development patterns and disturbances

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ROBERT S. SEYMOUR

Silvical properties

Red spruce (*Picea rubens*) and balsam fir (*Abies balsamea*) are so similar that "spruce-fir" is often used as if it were a single species. The early monographs of Zon (1914) and Murphy (1917) accurately characterize both species as occupying a similar ecological niche: late-successional, very tolerant of shade, shallow rooted, and widely adapted to a variety of site and stand conditions. These species differ in important ways that influence silvicultural treatment (Fowells 1965). Fir produces abundant seeds, but is so susceptible to various heart-rot fungi that its potential life span is limited by the high risk of wind breakage or uprooting. Balsam fir is often cited as the classic example of a species ruled by a pathological rotation, effectively limited to ages 40-70, depending on site quality. Fir is also the preferred host and suffers extensive mortality from defoliation by the spruce budworm (*Choristoneura fumiferana*). The introduced balsam woolly adelgid (*Adelges piceae*) also is a serious pest of fir in coastal regions but does not cause serious damage inland.

In contrast, red spruce produces seeds infrequently, but is quite resistant to decay and tends to survive budworm defoliation. As a result, red spruce is inherently long-lived, and 300+ year-old trees were not uncommon in virgin forests (Cary 1894a; Oosting and Billings 1951; Leak 1975). Perhaps its most important silvical properties are the abilities to persist as advance regeneration and to respond well to release after many decades of suppression in very low-light conditions in the understory. Cary (1896) was the first to document the capability of red spruce to respond to release at advanced ages, but this remarkable quality was also highlighted by other early foresters (Graves 1899; Hosmer 1902). Subsequent studies (Westveld 1931; Davis 1989) have found that the ability of spruce to develop slowly in the understory gives this species an initial height advantage that allows it to compete successfully with faster growing fir and hardwoods after release from overstory cover.

Forest types and abundance

The natural range of both red spruce and balsam fir encompasses virtually all of Maine; however, stands where spruce and fir dominate occur primarily in the northern and eastern parts of the state. Within this zone, red spruce is ubiquitous on soils developed from glacial till, but stand species composition varies greatly with soil drainage and topography. In the most recent compilation of forest types for North America (Eyre 1980), red spruce is named as a major component of six associations and occurs in nine others. Spruce and fir dominate Maine's forests in terms of area and volume; 46% of the State's forest area falls into the spruce-fir forest type. Red spruce and balsam fir also rank first and second, respectively, in growing

stock volume. Together they comprise 60% of the softwood volume and 39% of all volume in the State (Powell and Dickson 1984). Interestingly, this dominance of Maine's forests by spruce may be relatively recent. Although spruce-fir forests were once regarded as stable features of the Maine landscape since deglaciation (Westveld 1953), recent analysis of pollen records suggests that today's red spruce-fir forest emerged only ca. 1000 years ago, corresponding to a decline in hemlock and beech abundance (Jacobson et al. 1987).

Large pulp and paper companies have long dominated ownership of the Maine's spruce-fir forest, and Maine currently has much more industrially owned timberland (over 3 million ha) than any other state. Logging has been so widespread (potentially altering natural species composition extensively) that the best ecological descriptions come from observations of virgin forests by early foresters (e.g., Graves 1899; Hosmer 1902). Based on relationships of vegetation with soils and landforms along with observed successional patterns, Westveld (1931, 1951, 1953) described what would now be called a series of habitat types similar to those formulated by Leak (1982) for the White Mountains of New Hampshire. "Dominant softwood" sites are those where a combination of soil drainage, nutrient status, and topographic position tends to exclude the more demanding northern hardwood species (e.g., sugar maple, *Acer saccharum*). These can be further subdivided into four sub-types. "Spruce swamps" support nearly pure stands of black spruce (*P. mariana*) in mixture with tamarack (*Larix laricina*) and northern white-cedar (*Thuja occidentalis*) on organic or very poorly drained mineral soils. "Spruce flats" occur on shallow glacial tills with impeded drainage at low elevations; red spruce and balsam fir, in various mixtures, dominate these sites with minor components of paper birch (*Betula papyrifera*) and red maple (*Acer rubrum*). "Spruce slopes" occur on mountainsides above an elevation of ca. 800m on shallow, very rocky soils. Fir and paper birch represented a minor component of the spruce slope type prior to human disturbance. A fourth variant of the dominant softwood type occurs along the Maine coast as a result of maritime influences (Davis 1966).

So-called "secondary softwood" sites occur on mid-slopes supporting well drained soils. Deeper rooting zones and improved nutrient status allow various hardwood species to form an important stand component. Yellow birch (*Betula alleghaniensis*), red maple, American beech (*Fagus grandifolia*) and sugar maple are the principal associates of red spruce and fir in what is commonly called the "mixedwood" type. Pure spruce stands of old-field origin also fall naturally into this type, since these agricultural soils originally had a strong hardwood component and revert to hardwoods after disturbances. In Maine, old-field spruce stands tend to be dominated by the more aggressive white spruce (*P. glauca*); old-field red spruce stands were more common in Vermont (Westveld 1931).

The natural ranges of red spruce and eastern hemlock (*Tsuga canadensis*) overlap in eastern and central Maine, where significant areas of mixed-conifer stands occur. Eastern white pine (*Pinus strobus*) frequently forms an important component of these spruce-hemlock stands, and also occurs as a scattered, valuable trees on spruce-flat sites. The boreal white and black spruces are uncommon associates of red spruce-dominated stands in Maine. In 1982 white and black spruce comprised only 10% and 8%, respectively, of all spruce volume statewide (Powell and Dickson 1984). White spruce often forms a minor component of pure spruce-fir stands, especially those dominated by fir. Black spruce is limited to very poorly drained swamps, and is rarely found on upland sites. It has recently been recognized that

red and black spruce hybridize extensively (Manley 1972). Spruce hybrids tend to dominate poorly drained sites with a frequent history of disturbance (Manley and Fowler 1969; Osawa 1989). Rigorous procedures for determining the degree of hybridization (Manley 1971) are rarely applied. Trees with characteristics of both species are usually called "red" spruce, perhaps causing the abundance of genetically pure red spruce to be overestimated.

Disturbance history

Spruce budworm

During the 20th century, the most profound natural influence on growth and development of red spruce forests in Maine has been the eastern spruce budworm, a native insect. Documented outbreaks resulting in extensive tree mortality have occurred on two occasions: ca. 1913-19 and recently from 1972-86. A third outbreak that reached epidemic status in the boreal forest during the late 1940s caused only non-fatal defoliation in northern Maine (Irland et al. 1988). This insect arguably has been studied more than any other forest pest in North America, and a voluminous literature has accumulated from comprehensive investigations of these outbreaks (Swaine and Craighead 1924; Morris 1963; Sanders et al. 1985). Most research on budworm dynamics has been carried out in boreal forests where fir occurs in mixture with white and black spruce. The red spruce-fir forests in Maine and the southern Maritimes are more diverse in composition and structure, and have more complex and less well understood response patterns to uncontrolled budworm attack.

Controversy remains about the causes and periodicity of budworm outbreaks. Intensive studies of budworm population dynamics and observations of forest age structures suggest a natural cycle of 30-40 years, controlled by climate, availability of extensive areas of mature host foliage (balsam fir), and other natural limiting factors (Morris 1963; Royama 1984). Blais (1985), on the other hand, has argued that outbreaks were less common and less extensive in virgin forests than during the current century, based on studies of radial growth suppression of old white spruce in trees mostly in eastern Canada. Blais attributed the more frequent outbreaks to an increased abundance of balsam fir (the favored budworm host) resulting from extensive cutting of spruce, insecticidal protection of mature fir stands, and fire protection that has gradually reduced the area of non-host hardwood forests. The argument that forest exploitation has rendered spruce-fir forests more vulnerable to budworm attack is not new or unique; Swaine and Craighead (1924), Mott (1980), and many other writers have advanced similar arguments in support of silvicultural control strategies aimed at reducing fir abundance (Blum and MacLean 1985).

No definitive studies have examined the presettlement history of budworm outbreaks in the red spruce-dominated forests of Maine, so what follows is somewhat speculative. Mott's (1980) review of historical evidence reveals the possibility of two outbreaks during the 1800s: one in coastal Maine during the 1870s which did not reach tree-killing status inland, and a speculative one during the early 1800s. Evidence for an early 1800s outbreak comes from eyewitness accounts of extensive spruce mortality by early explorers and a distinct pattern of growth suppression during 1810-14 described by Austin Cary (1894a) as "reduced in some cases to almost microscopic." Although Cary attributed this growth suppression to

a period of unusually cold weather, it does coincide with an outbreak postulated by Blais (1968) nearby in Quebec. The extent of this outbreak throughout northern Maine is unclear. Cary stated that "this zone of rings has been found in spruce trees in all parts of the State", whereas Lorimer (1977) found little evidence of extensive budworm-caused tree mortality in surveyors' notes dating from the 1820s, when such evidence would have been quite apparent. One can conclude that Maine's red spruce region escaped a tree-killing budworm outbreak for a minimum of ca. 100 years (i.e., from the early 1800s to 1913), a much longer frequency than the nine outbreaks reconstructed by Blais (1985) throughout the boreal fir region during the same period. Further evidence that budworm was not an important influence during the late 1800s comes from Hopkins (1901) monograph on "insect enemies of spruce in the Northeast"; and Cary's (1900) accounts, which concentrate on bark beetles and do not even mention any budworm-like defoliators.

Uncontrolled budworm outbreaks exert a controlling influence on stand development in forests dominated by balsam fir. After several years of complete defoliation, mature stands invariably are completely killed, while immature stands suffer partial mortality analogous to a heavy crown thinning. The outbreak then collapses as a result of foliage depletion, and surviving trees develop without further defoliation until the next outbreak ca. 40 years later. Between outbreaks, advance seedlings that originated beneath mature stands prior to defoliation develop into vigorous immature stands, while surviving 40-year-old trees develop into large-crowned, highly vulnerable 80-year-old individuals. In this manner, the budworm effectively perpetuates a two-aged forest structure by periodically thinning the 40-year age class and killing the 80-year age class (Baskerville 1975a; MacLean 1984).

The budworm's effect on stand development in forests with a strong red spruce component is more complex. Studies of uncontrolled outbreaks during the 20th century demonstrate that some spruce can be killed, but that this species is much less vulnerable to mortality than fir (Craighead 1924; MacLean 1985; Osawa et al 1986). Post-outbreak stand structures thus depend on the relative abundance of red spruce and fir, as well as associated non-host species. One common pattern involved immature mixedwood or spruce-dominated stands that originated during the late 1800s after a heavy sawlog cuttings. Many such stands also had a residual overstory of fir left after the sawlog harvests, and were thus two-storied when the budworm outbreak developed ca. 1910. In these mixed-species stands, budworm tended to kill only the fir in both the residual and regenerating strata, thereby creating even-aged stands dominated by spruce or hardwoods (Seymour 1980). Sixty years later, these stands at age 90-100 were less vulnerable to the 1970s outbreak than were younger, 50-60-year-old pure-fir stands that originated after the 1913-19 attack. The logging-origin, spruce-dominated and mixedwood stands experienced only partial mortality and patchy regeneration, whereas the budworm-origin, fir-dominated stands were again completely killed and regenerated. Over time, in the absence of logging or catastrophic disturbances, the lower vulnerability of red spruce to budworm attack, coupled with its greater inherent longevity than fir, would eventually tend to promote multi-aged structures. Stands would become increasingly dominated by red spruce, as the more vulnerable fir was repeatedly purged from mixed stands.

Other natural disturbances

The preoccupation with spruce budworm as a dominant natural influence on stand development is relatively recent. When professional and scientific attention was first directed at the red spruce forest in late 1800s, the dominant concern was damage by the spruce bark beetle (originally *Dendroctonus piceaperda* Hopk., now *D. rufipennis* Kirby). Hopkins' (1901) investigations showed that, like other *Dendroctonus* species, this insect caused serious damage primarily to old, large-diameter trees. The scale of mortality apparently varied widely, from scattered mortality of individual stems to up to heavy losses over several adjoining townships. Peak mortality evidently occurred during the 1880s, coincident with large-scale spruce sawlog cutting operations on all major river systems of the State (Cary 1900). Severe bark-beetle mortality evidently regenerated "dense thickets of fir and other young growth" (Cary 1900); photographs in Hopkins (1901) show radial growth response of suppressed balsam fir that had formerly occupied understory status but was released by complete mortality of overstory spruce.

Wind damage is also an important disturbance agent, because of the shallow-rooted habit of spruce and susceptibility of fir to heart rots. Unlike insect epidemics, however, wind damage is usually a chronic phenomenon. Early surveyors noted large-scale windfalls (over 0.5 km in length) along only 2.6% of township lines, virtually all of which was spruce and fir on stony flats and swamps (Lorimer 1977). Assuming that surveyors would dependably record windfall for ca. 30 years, Lorimer calculated a recurrence interval for major windthrow (>25 ha) of 1150 years.

Fire was a concern of early foresters in Maine as it was elsewhere, but it is virtually impossible to separate a few, very large and probably man-caused fires from purely natural events. Extensive spruce logging, especially of pure stands on upper slopes and near railroads, appeared to increase both fire frequency and severity during the late 1800s in comparison to the presettlement era (Cary 1894b; Weiss and Millers 1988). Estimates of the natural recurrence interval of fire in northeastern Maine vary from a minimum of 800 to over 1900 years, depending on whether the 1803 fire (which covered 80,000 ha in the survey area alone) is included (Lorimer 1977).

Lethal disturbances affecting hardwood species also have greatly influenced stand development of mixed spruce-hardwood stands. Reams and Huso (1990) documented radial growth increases during 1935-55 in 54% of stands sampled ca. 1980 throughout northern Maine. They noted that this period coincides with extensive mortality and top-kill of *Betula* spp. resulting from the birch dieback epidemic, and the "killing front" of the introduced beech bark disease that eliminated *Fagus grandifolia* from the overstory of many stands in eastern and central Maine (Millers et al. 1989). Lethal disturbances affecting other conifer species that potentially have affected spruce-fir stand development include the larch sawfly (*Pristiphora erichsonii*) outbreak of the late 1800s that virtually eliminated tamarack from poorly drained sites throughout the spruce-fir region, and the pine leaf adelgid (*Pineus pinifoliae*) which can kill eastern white pine without damaging the alternative host red spruce (USDA Forest Service 1985).

Effect of natural disturbances on stand structures

The largely historical evidence reviewed above suggests that, unlike the boreal spruce-fir forest, large-scale stand-creating disturbances were much less common in the red spruce region prior to extensive logging of spruce. Rather, the evidence appears to support a regime of disturbances that were perhaps quite frequent relative to the life span of red spruce, but which rarely resulted in complete overstory mortality. The typical origin of virgin spruce appears to be a gradual response to a series of releasing disturbances, until reaching the overstory at relatively advanced ages. Evidence of this pattern comes from comparing the age-size relationships of virgin spruce from Cary (1894a) and Graves (1899) with those of both managed (Seymour and Lemin 1988) and unmanaged (Meyer 1929) even-aged stands (Fig. 1). Cary aged 1050 spruce logs from all major river systems of Maine during the early 1890s and found that 72% of all trees fell into the 100-year age class between 150-250, and less than 5% were under 125 years old. On the average, a spruce required nearly 200 years to reach a stump diameter of 36 cm (14 inches). Graves' age-size data from the Adirondacks follow a very similar pattern. In contrast, Meyer's normal yield tables show that spruces will reach 25 cm (10 inches) dbh at ca. age 100 on average site land; with early spacing, this time can be shorted to ca. 70 years -- 40-60% of the ages of comparably sized trees from virgin stands.

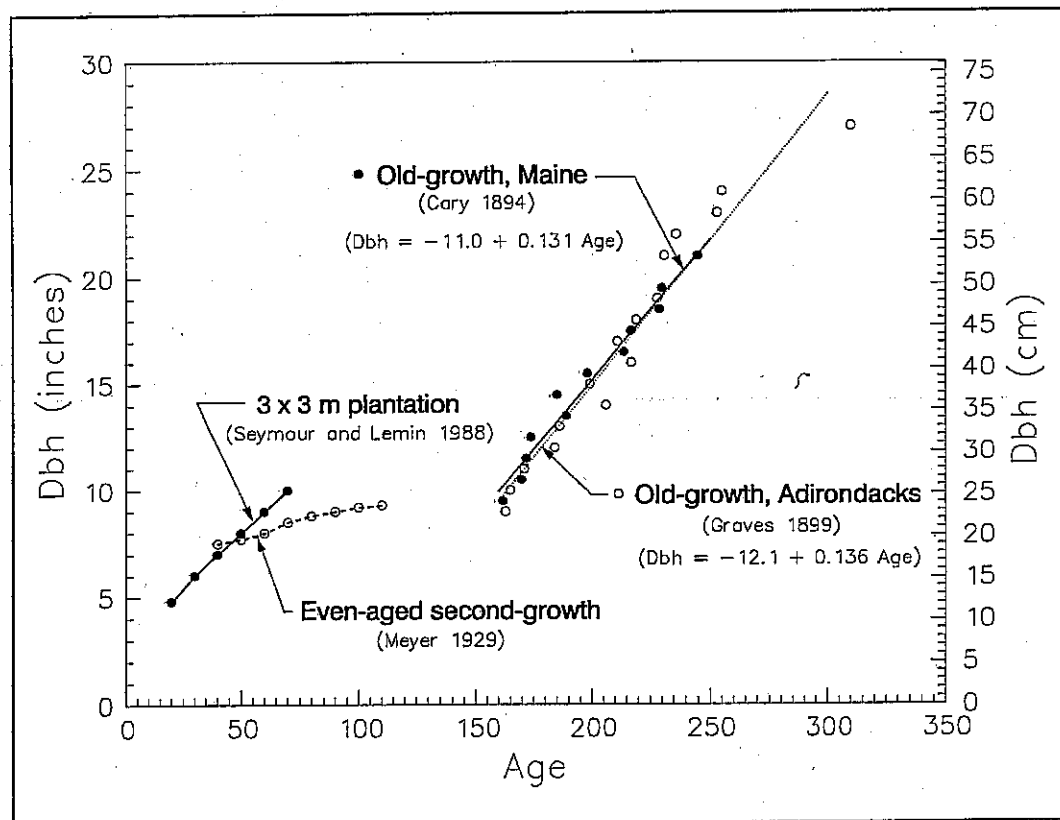


Fig. 1. Comparison of diameter-age relationships of virgin old-growth red spruce with managed and unmanaged even-aged stands.

Graves (1899) also measured recent periodic growth, and found that trees averaged 0.25-0.30 cm (0.10-0.12 inches) of diameter per year, with little pattern by diameter class other than a slight increase in the 28-36 cm (11-14 inch) classes. These growth rates are slightly less than the diameter-growth rate implied by the least-squares regression slope of 0.33 cm (0.13 inches) per year, but are significantly greater than the *average* dbh growth of 0.15-0.23 cm (0.06-0.09 inches) for all dbh classes over their entire lives. The fact that mean annual growth was still increasing, even for spruce over 50 cm (20 inches) dbh, is further evidence that such trees initially developed through a period of suppression where they grew at a below-average rate. More recent studies of age structure of intact, old growth stands also document the presence of several age classes, and an overall relationship between age and size such that the largest diameter, dominant red spruces were usually the oldest trees in the stand (Oosting and Billings 1951; Leak 1975).

The relative proportions of even- and uneven-aged stands in the presettlement forest are uncertain. Cary (1896) described height-growth patterns of free-growing spruces on two different soils, but noted that "but a small proportion of the trees that make up our spruce lumber have grown in any such way. Most have grown under a shade, often a dense and overpowering one." Cary (1896) further described a common forest type of "small and thick spruce timber" growing on "rocky knolls or ridges alternating with swampy ground" as "very old second growth which started up after some primeval fire or blowdown." He also encountered a 110-year-old fire-origin stand in which spruce was still in a subordinate stratum relative to the dominant white pine and declining paper birch and aspen, and commented "plainly, the prehistoric forest was by no means free from fire", but the clear implication was that such an origin was quite uncommon. Graves (1899) observed that pure spruce-fir stands, which occurred mainly on poorly drained flats or shallow, organic soils on upper slopes, tended to exhibit even-aged structures, as a result of their shallow-rooted habit and high risk of complete blowdown there. When Meyer (1929) sought even-aged stands for the first red spruce normal yield tables, he relied heavily on old-field stands; natural even-aged red spruce stands in Meyer's data base throughout northern New England occurred mostly on poorly drained sites.

It is possible that even-aged stands were common, but overlooked by early foresters simply because they were either immature, small-diameter, or dominated by balsam fir and hence of little value. Most even-aged stands probably originated after pure spruce-fir stands on poorly drained soils were subjected to severe windstorms; outbreaks of bark beetles or spruce budworm would usually not kill entire stands of spruce unless all trees were very old. Another probable origin is a heavy partial disturbance followed by windthrow of isolated surviving trees with unstable height:diameter ratios resulting from having grown in dense, undifferentiated stands (Oliver and Larson 1990). Post-disturbance blowdown was a common pattern of development after early partial cuttings, which led Cary (1899, 1902) to recommend clearcutting such stands. Fires were uncommon, and usually created stands of intolerant hardwoods which can require over a century to develop a composition of pure spruce-fir. The apparent lack of truly even-aged stands does not necessarily imply the existence of more than two age classes. Nevertheless, if extended suppression were the characteristic origin of dominant, mature spruce trees, then small-scale releasing disturbances must have been the dominant influences on stand development and structure.

Historical logging practices

While study and analysis of structure and development of virgin spruce stands offers many interesting and provocative ideas, over a century of logging in Maine's spruce-fir region has greatly reduced the possibility of further research. Nearly a century ago, Cary (1896) estimated that only 14% of the entire Kennebec River drainage had never been cut for spruce. Hosmer (1902) also commented that the virgin stands he studied "represents a class of forest of which very little is now left in Maine." Oosting and Billings (1951) found abundant examples of virgin old-growth in the southern Appalachians, but were able to locate only four northern examples in the late 1940s, all in the White Mountain National Forest. Nearly all the present commercial forest in Maine has developed in response to some kind of harvesting, and likely exhibits structures and compositions that may be quite different than those of virgin stands. The following chronological narrative, patterned after Seymour (1985), is offered on the premise that an understanding of how forest structures influenced logging practices, and vice-versa, is valuable background for discussing more intensive silvicultural systems for today's forests.

Although Maine is probably most famous for its logging of old-growth white pine, there is little doubt that red spruce, not pine, has been the staple of both early and present industries in Maine. Logging in the early 1800s initially concentrated solely on pine, and the easily accessible pine resource was depleted within a few decades. By ca. 1870, spruce supplanted pine as the dominant species in the annual river drives (Cary 1896). The first spruce harvests during this period tended to cut only spruce over 30-40 cm (12-16 inches) dbh in a highly selective fashion, probably from mixed stands on deep well-drained soils where the largest trees grew. As markets improved and large-diameter stands became scarce, many stands were cut repeatedly for sawlogs, each time to lower diameter limits, until all timber over 25 cm (10 inches) stump diameter was removed. In the 1890s, the rapidly developing pulp and paper industry built several mills on major rivers and began large-scale acquisitions of timberland formerly cut over for pine and spruce sawlogs. Unlike other regions such as the Lake States and parts of the Appalachians that were liquidated during the same period, Maine's spruce-fir forest remained well stocked with merchantable trees after the initial wave of exploitation for sawlogs. As a result, many stands were again harvested to even smaller diameter limits. Continued lowering of merchantability standards allowed not only stands cut previously to be re-entered, but also rendered operable "bunches" of small-diameter stands that had been skipped over during earlier entries into the same area (Cary 1896).

The increased severity of cutting in response to pulpwood demands was perceived with concern. Cary (1896) described an early pulpwood operation near Berlin, N.H. as follows:

"It is the hardest cutting ever seen by the writer...the surface of the ground was an almost unbroken brush-heap...Plenty of ground that started with fifty hadn't more than two or three cords¹ of wood of any kind standing on it... A hundred years will not suffice to grow another crop of spruce logs ... and at two hundred it could not fail...to be much smaller than the original stand."

¹One cord of spruce equals approximately 85 cubic feet or 2.4 cubic meters of solid wood, excluding bark.

In the first report of his extensive regeneration research, Westveld (1928) also described the transition in cutting practices:

"Increased demands for spruce pulpwood, making possible utilization of small-sized trees, have resulted in a gradual increase in the severity of cuttings, until in recent years the practice is generally being followed of clearcutting lands of all pulpwood species. Prior to the adoption of this cutting method a rough selection system was being practiced in which only trees of large size were removed. Under this method of cutting little difficulty was experienced in keeping the forest in a productive condition."

These early foresters recognized that repeated cuttings had been made possible only by the incompleteness of earlier entries. During this era, stand productivity was measured in terms of how much residual growing stock was left for future cuttings and did not consider future yields from regeneration.

By 1910, fifty years of preferential cutting of old-growth spruce had left extensive areas stocked with old balsam fir of all sizes to respond to release. The epidemics of spruce bark beetle, while probably less extensive, also had essentially the same effect. By early in the 20th century, Maine probably had far more mature balsam fir than had ever existed in the virgin forest (Zon 1914), and the state's spruce-fir resource was subjected to an extensive spruce budworm outbreak that killed an estimated 27 million cords by the early 1920s. While the timing could have been coincidental, early entomologists attributed the unprecedented severity of this outbreak to the unnaturally high fir component of the forest during the early 1900s (Swaine and Craighead 1924). By all accounts, the 1913-19 budworm outbreak left the spruce-fir forest seriously depleted of merchantable trees, and pulpwood shortages apparently were regarded as inevitable. In an assessment of Maine's future pulpwood supply, Clapp and Boyce (1924) wrote:

"The outlook...is probably an enforced curtailment of pulp and paper production...which will hit first and hardest the pulp mills without available timber supplies of their own. The cut of many other mills will probably be shifted in much greater degree than at present to their own inadequate holdings, with still more serious overcutting. It is very doubtful if immediate application of the most intensive forestry measures over the entire spruce-fir type of the State can produce results soon enough to prevent such a curtailment."

Historical evidence reviewed by Seymour (1985) shows volumes per acre standing and harvested during the 1930s as low as 18-30 cubic meters per ha (3-5 cords per acre). Harvesting operations covered larger areas than formerly, removing scattered remnants of the virgin forest that survived the outbreak in very understocked stands.

Beginning ca. 1950, stands regenerated after early pulpwood cuttings and the 1913-19 budworm outbreak began to reach merchantable size over large areas. Growth rates and stocking levels increased dramatically, and the first official assessment of the Maine forest (Ferguson and Longwood 1960) showed a large surplus of periodic growth over harvest. Cutting practices from the late 1940s through the 1960s were dominated by diameter limit cuttings that varied by species (Hart 1963). These cuttings tended to remove the larger spruces from two-storied stands, most of which had survived and responded to release as saplings or small poletimber from the earlier sawlog cuts and budworm attack. Periodic growth continued to exceed harvest during the 1960s (Ferguson and Kingsley 1972) as the early-1900s-origin age class began to mature into high-volume, single-canopy

stands. Diameter-limit cuttings in this age class became increasingly unsatisfactory. As removal rates rose, windthrow of residual stands became more severe, just as they had after similar cuttings in old-growth stands several decades earlier. Then in the mid-1970s, a massive budworm outbreak infested the entire resource, necessitating large-scale annual insecticidal protection programs. Within a short time during the late-1970s, clearcutting became an important (although not necessarily dominant) harvesting practice to pre-salvage dying stands dominated by fir. Pre-salvage clearcutting continued through the early 1980s until the outbreak subsided, and some landowners continue to rely primarily on clearcutting.

Evolution of stand and forest structure, 1860-1990

While the primary purpose of harvesting in Maine's industrial spruce-fir forest has always been pulpwood production, not silvicultural treatment, there are nevertheless important lessons for silviculturists in the patterns of stand response. For example, merchantability limits for spruce pulpwood have not changed greatly since the turn of the century, yet "clearcuts" designed to harvest all merchantable pulpwood have produced very different results depending upon the particular stand structure(s) that were common during each era. The original, scattered sawlog cuttings removed only modest volumes from irregular, old-growth stands; their main silvicultural effect was probably to encourage establishment, and partial release, of large advance regeneration in the understory or in small gaps (Fig. 2). Subsequent re-entries, first for smaller logs and then for pulpwood, probably tended to release this regeneration more or less completely, as well as any residual, older balsam firs that were usually not merchantable. Such heavy cutting was often followed on poor sites by extensive windthrow, and virtually all stands were then subjected to the 1913-19 spruce budworm outbreak, further reducing the representation of the older age classes and giving complete occupancy to the already well established regeneration. Cutting in the decades following the outbreak probably continued this pattern. Over time regeneration established during or prior to the outbreak continued to develop, but merchantable volumes remaining in unharvested stands continued to decline as higher-volume stands were harvested. The budworm's effect was so pervasive that virtually all spruce-fir stands that had not already been released by early cuttings were at least partially regenerated by 1925. Indeed, most spruce-fir harvesting from before 1900 until the 1960s could be characterized as a staged liquidation of original members of the old growth forest that had survived the early partial sawlog cuts and the budworm attack and had not blown down, gradually releasing somewhat irregular, but essentially even-aged stands. This history has created a forest with a seriously unbalanced age structure, dominated by even- or two-aged stands that originated in the decades surrounding the peak budworm mortality ca. 1920 (Fig. 3).

When the more uniform, even-aged stands regenerated during the early part of the century became merchantable during the late 1960s, new and different regeneration patterns began to emerge when excessive losses to windthrow and budworm risk led some landowners to substitute clearcutting for the previous diameter-limit prescriptions. Stand structures were quite uniform and had matured to the point where small-diameter, unmerchantable stems had mainly died from suppression or budworm defoliation. As a consequence of their younger age, higher stand density, and total lack of previous disturbances, advance regeneration beneath these stands

was either absent or poorly established. Like earlier commercial clearcuts, these harvests left essentially no residual growing stock, but unlike previous cuts, large well established advance growth was not present to occupy the cutover sites immediately. Hence, stand development tended to revert to an earlier successional stage dominated by pioneer vegetation, with spruce and fir relegated to substrata or shaded out completely except on the poorest sites. Unlike earlier "clearcuts" which merely released well established advance growth, harvesting operations began to regenerate truly new age classes on a significant scale.

The "New Forest"

The past century has witnessed a dramatic change in the structure of Maine's spruce-fir forest. These large-scale, episodic removals of mature trees, by logging in combination with spruce bud worm, bark beetles and windstorms, have transformed Maine's spruce-fir forest from one dominated by mixed-aged, old-growth stands, to a forest dominated by younger, more uniform stands that may be more extensive in area and lack the within-stand height and age diversity of the old growth. This change in stand structures has, in turn, been accompanied by a change in silvicultural emphasis by large industrial landowners. Partial cutting systems designed to exploit the ability of residual trees and large advance regeneration have gradually given way to even-aged plantation-like silviculture that now characterizes practice in most intensively managed conifer forests worldwide. This rapidly expanding age class is known as the "New Forest", not only on account of its young age, but because it exhibits patterns of development in response to cutting and management that may well be unprecedented.

The maturation of uniform, second-growth stands and the related onset of clearcutting as a widespread harvesting practice have led to an oversimplified view of the current spruce-fir forest and its silvicultural challenges. Much silvicultural research on "intensive management" currently focuses narrowly on creating and culturing uniform, even-aged stands. Recent evidence suggests that actual harvesting and silvicultural practices encompass a much broader spectrum of activities and stand structures. For example, if clearcutting had become the dominant regeneration measure during the 1970s, then the 1-10-year old age class in 1980 (Fig. 3) should comprise well over 0.4 million ha. The actual area is less than 20% of this total (Seymour and Lemin 1989), suggesting that practices other than complete clearcutting predominated during this decade. Some of this apparent discrepancy can be explained by spruce-fir clearcuts that reverted to the early successional aspen-paper birch forest type; however, most is likely a result of continued use of various types of partial harvests which leave significant numbers of residual trees, similar to most historical practices. Such stands would fall in the "two-storied" and "uneven-aged" categories (Fig. 3), which contain all plots that do not clearly exhibit an even-aged structure including the very common two-aged stands. While few, if any of these uneven-aged stands contain any semblance of a balanced age structure, they represent an important category that cannot be ignored in any comprehensive treatment of the resource.

The apparent diversity in silvicultural practices and stand structures is further supported by 1986 mid-cycle remeasurement of Maine's spruce-fir resource (Maine Forest Service 1988). In an attempt to avoid the confusion inherent in classifying age structures of stands that contain trees with suppressed origins, stands were

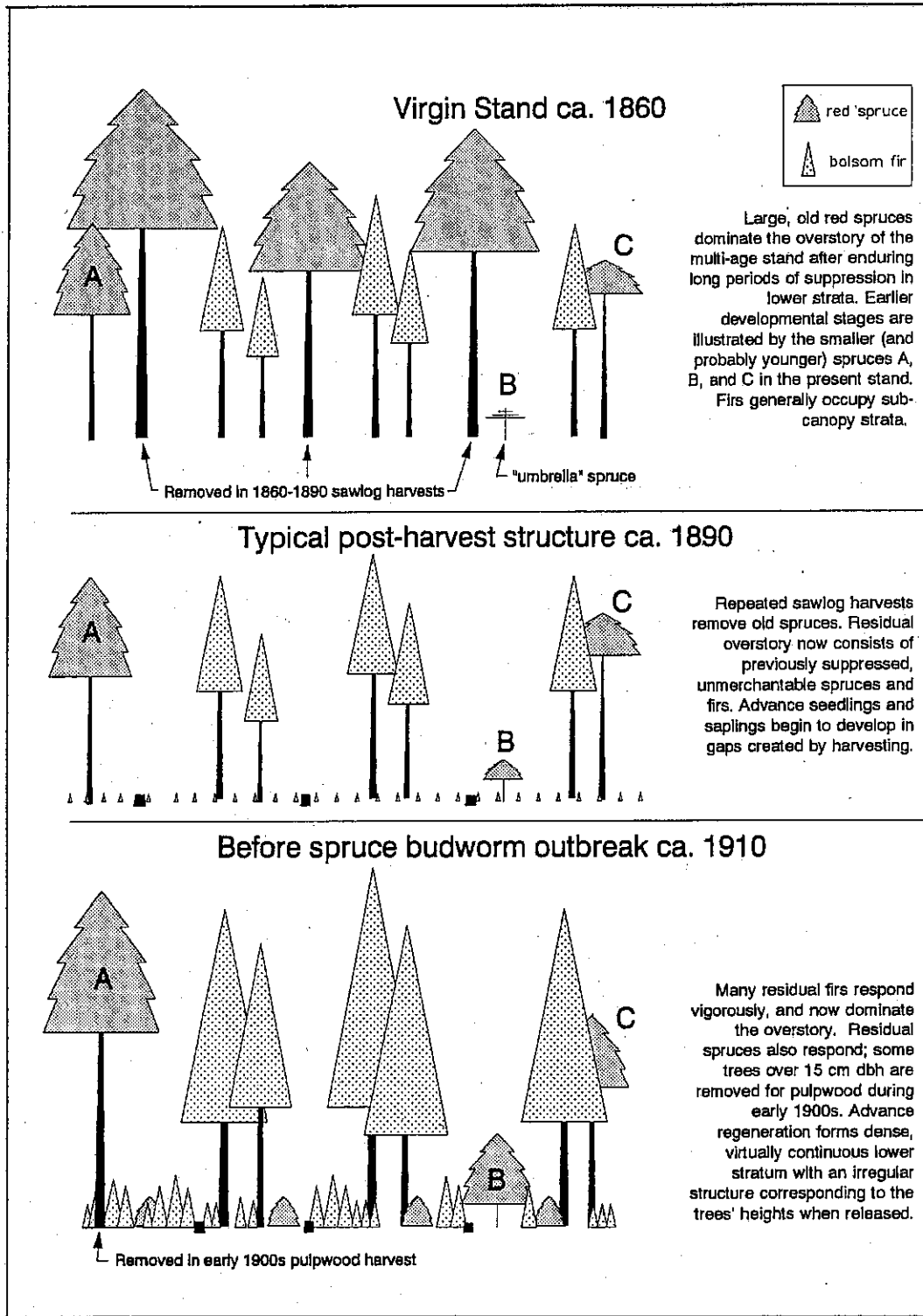
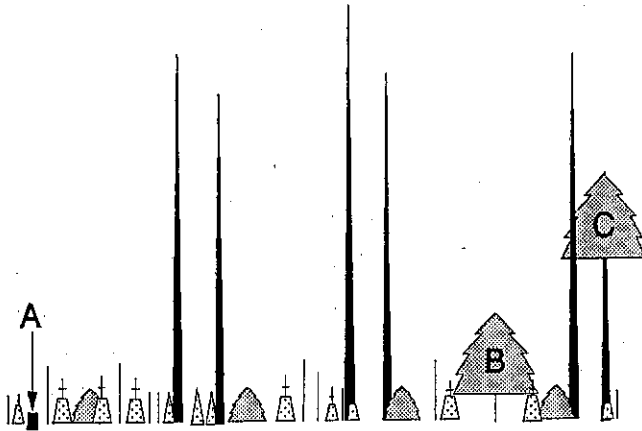


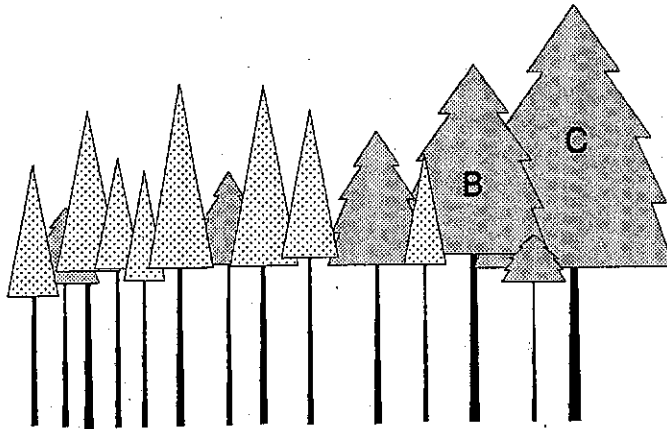
Fig. 2. Development of typical spruce-fir stand after logging and budworm attack ca. 1860-1970.

After budworm outbreak ca. 1925



All mature firs (and some spruces) killed by budworm outbreak ca. 1913-19. Many advance fir saplings also succumb; some survive but suffer severe dieback of terminal shoots.

Second-growth stand ca. 1970



After recovery, stand quickly returns to stem exclusion stage, as the sapling advance regeneration develops vigorously. Where remnant spruces B and C (from the original old-growth stand) do not blow down or succumb to bark beetles, they now dominate the overstory. Where budworm-caused mortality and logging removed the overstory completely, stand has very even-aged structure, with fir generally dominant over spruce.

classified according to height structure. After over a decade of budworm mortality and intensive salvage cutting, stands under 3 m (10 feet) tall accounted only for just over 0.2 million ha. Stands over 12 m (40 feet) tall still comprised 74% of the resource, and 59% of these exhibited a vertically stratified structure with a lower stratum of either a different species or younger age class (Fig. 4). These data are entirely consistent with 1988 summary of harvest practices (Maine Forest Service 1989) which show that complete clearcutting is less common than various forms of partial cutting throughout the entire State (Fig. 5). While most of the partial cuts undoubtedly are heavy enough to promote regeneration, the presence of some residual growing stock distinguishes them from truly uniform even-aged stands.

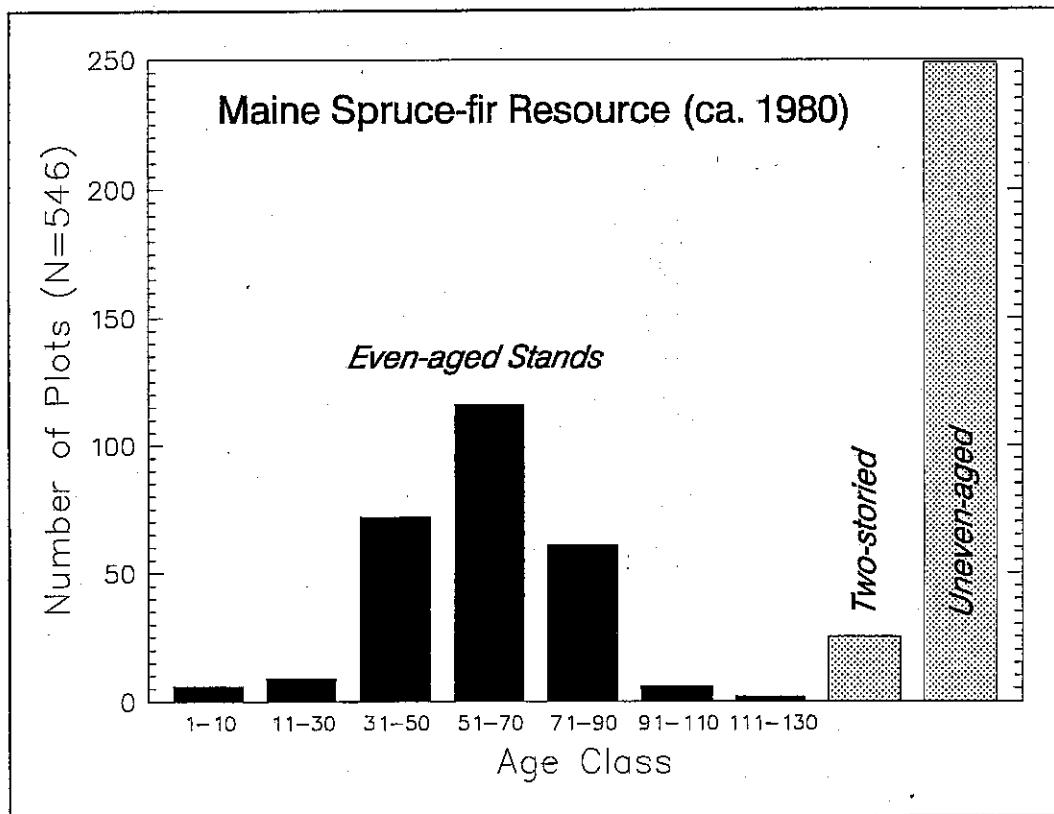


Fig. 3. Approximate age structure of Maine's spruce-fir resource as classified by the USDA Forest Service ca. 1980. [Source: unpublished data used by Powell and Dickson (1984)]

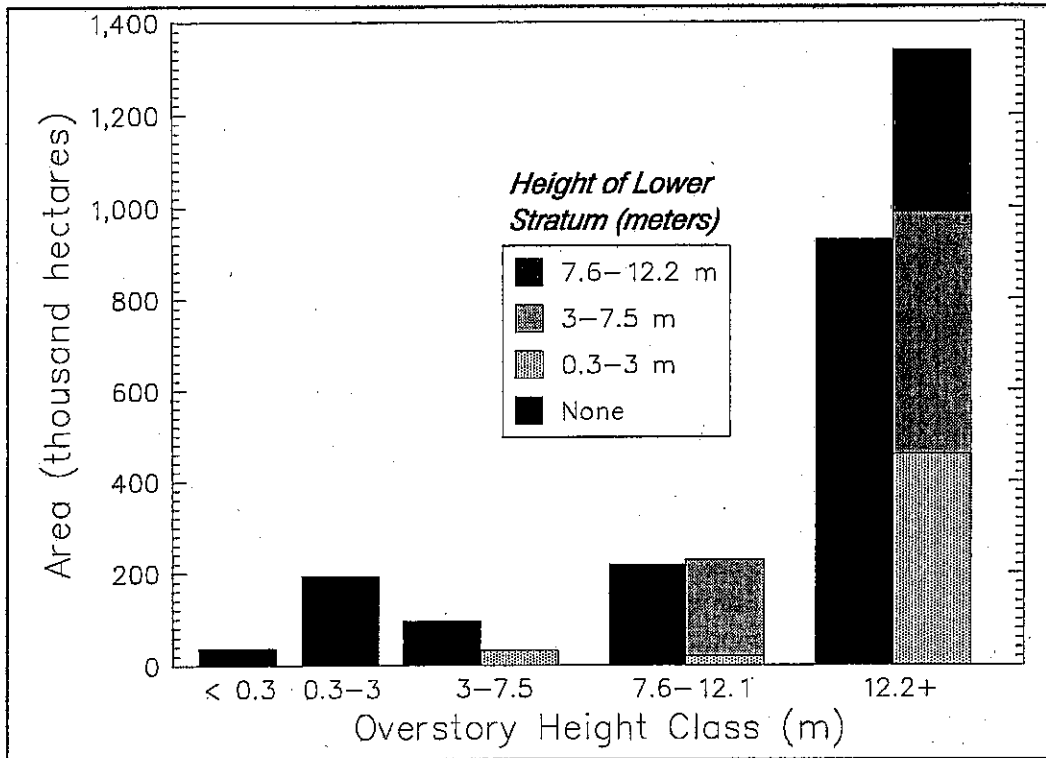


Fig. 4. Height structure of Maine's spruce-fir resource, 1986. [Source: Maine Forest Service (1988)]

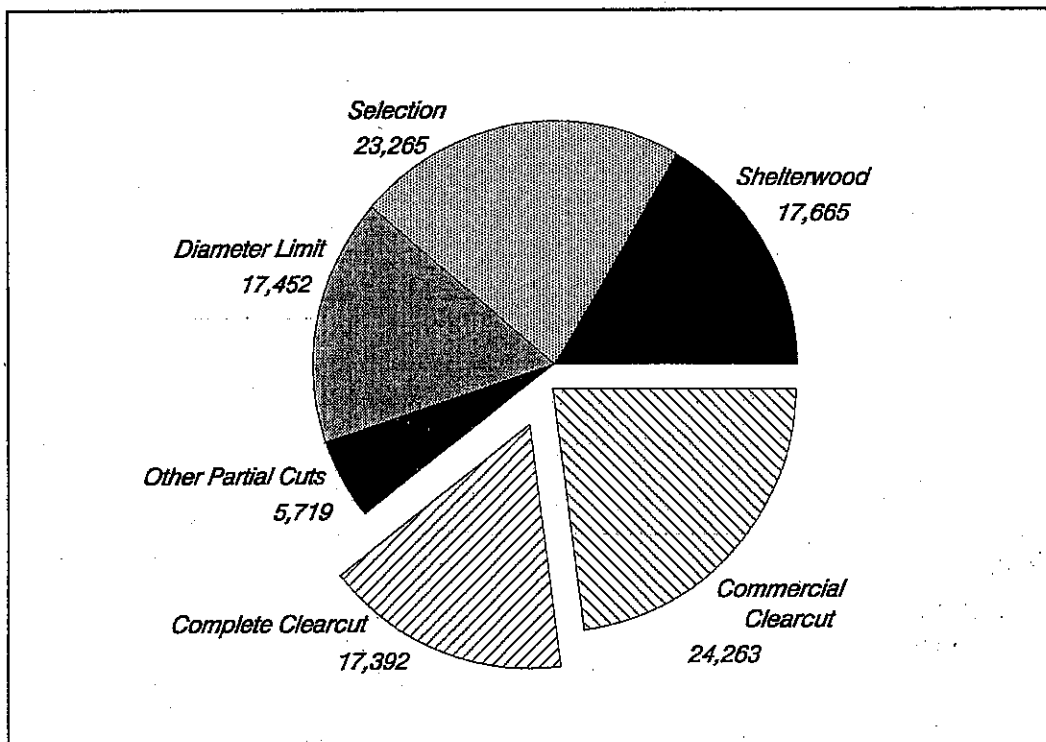


Fig. 5. Areas (hectares) treated by various harvesting practices in Maine, 1988. [Includes entire state; data for spruce-fir type only not available. Source: Maine Forest Service (1989)]

A stand development model

The following section attempts to assemble the historical and scientific information reviewed above into a working hypothesis of stand development for both natural and logging-origin red spruce-fir stands, using the model of Oliver (1981). Oliver postulated that disturbance-origin forests develop through four stages: stand initiation, stem exclusion, understory reinitiation, and old-growth. During the first three stages, stands exhibit a more or less even-aged structure, although their size structure may be quite stratified if species composition is mixed. Prior to exploitation, natural stand structures were probably dominated by the "old growth" developmental stage, in which new age classes may be continually released but which never completely dominate the overstory (Lorimer 1977). Many-aged, old-growth stands were probably most common on well drained soils supporting mixedwood stands, or pure spruce-fir stands in sheltered topographical positions which rarely experienced complete mortality from windstorms or other agents.

Pure spruce-fir stands on shallow soils are more susceptible to large-scale overstory mortality from "releasing disturbances" that release any younger age classes that may be present. When the overstory begins to break up gradually (for example, by senescence of shorter-lived intolerant hardwoods or fir, or budworm defoliation) during the understory reinitiation stage, abundant spruce and fir advance regeneration can occupy the understory completely prior to complete destruction of the overstory by windthrow or insect attack. In this case, the stand initiation stage is bypassed completely, and stem exclusion (defined as the time after which no new trees are recruited into the stand) begins immediately. Stem exclusion may prevail for 50 years or more, depending on the specific fir-spruce composition. As fir begins to drop out, either from episodic budworm outbreaks or rot-induced wind breakage, the stand again enters understory reinitiation, during which small advance seedlings, mainly of fir, begin to develop in the understory. Another 50-100 years of stem exclusion may elapse during which a two-aged structure prevails, with 50-150-year-old spruce dominating younger fir except in large gaps where a pure-fir composition may develop. As fir again begins to drop out of the stand, spruce seedlings and saplings that may have originated at the same time as the declining fir (Davis 1989), respond and become a more important stand component. After 150 years, stands may eventually develop a true, multi-aged structure indicative of Oliver's "old growth" stage, with spruce of several classes and younger fir opportunistically developing in gaps of varying scale. Once this structure is attained, it could conceivably be maintained indefinitely by small-scale disturbances or senescence that affect only the oldest spruces.

If this successional pattern is interrupted by logging or major disturbance, the resulting outcome depends on the status and fate of the advance regeneration and formerly suppressed residual trees from the older age classes, if any survive. Response is also influenced by site quality; the proportion of hardwood species; and where advance growth is sparse, the amount of disturbance to the forest floor. Extremes would be an understocked old-growth spruce stand with a completely regenerated understory of large spruce saplings that is killed by bark beetles, and an immature (age 40) even-aged stand still in stem exclusion killed by wildfire. The former would almost certainly respond promptly and maintain more or less the same pure-conifer composition, while the second would likely revert completely to intolerant hardwoods. An important lesson from recent experience is that superficially

similar harvesting operations, which differ only slightly in their timing of overstory removal relative to the status of advance regeneration, can have a major effect on subsequent stand composition and resulting development.

Historically, stands reached understory reinitiation prior to (or at least coincidental with) their becoming merchantable for pulpwood. The type of commercial clearcutting practiced from the early 1900s to the 1960s rarely resulted in inadequate regeneration if logging damage was controlled; the main issue was an increased proportion of fir in the second-growth stands (Zon 1914; Westveld 1931). More recently, however, predicted wood scarcities throughout the spruce-fir region (Seymour and Lemin 1989) have led to cutting smaller-diameter, younger stands that may not have reached, or have only begun, understory reinitiation. Such complete clearcuts midway during the stem-exclusion stage have virtually no natural analogue. Spruce-fir stands rarely collapsed completely at this relatively young age, except perhaps when subjected to very uncommon hurricane-force windstorms which may completely blow down immature stands.

Unlike historical cuttings where the stand initiation stage occurred in the understory, complete "clearcuts" in such immature stands cause stand initiation to occur after harvest where much growing space is left vacant. Although small advance seedlings of spruce and fir may be present, they become rapidly overtopped by a vigorous growth of pioneer species (*Rubus* spp., *Betula papyrifera*, *Prunus pensylvanica*, *Populus* spp.) that do not develop nearly as vigorously if advance spruce and fir seedlings and saplings fully occupy the growing space prior to overstory removal. Site quality also strongly influences competing vegetation; on poorly drained soils, the main problem is overtopping by low-vigor intolerant hardwoods which may suppress growth but usually does not reduce stocking. On better soils, however, vigorous development of tolerant hardwoods and *Rubus* may suppress and eventually kill overtopped seedlings, causing a major forest type change. Small red spruces appear to be even more vulnerable than firs. Harvesting disturbance can further exacerbate regeneration problems by stimulating germination of buried seeds of weeds, by destroying advance seedlings, or by removing residues that provide "dead shade" for fragile advance seedlings (McCormack 1984; Seymour 1986).

Even in cases where casual observation suggests that conifer advance regeneration is well established, different patterns may emerge in the relative development of red spruce and balsam fir. Fir begins frequent seed production at a younger age than spruce, and seedlings are more robust because of their more vigorous root development (Place 1955). In dense even-aged stands early during the understory-reinitiation stage, advance growth will consist of nearly pure fir, even if the overstory is predominantly spruce. Even after both species are present as advance growth, fir usually continues to outnumber spruce and tends to respond more aggressively to release; in general, firs less than a half-meter tall will outgrow spruces of equal size during the decade immediately after release (Westveld 1931; Davis 1989). Later in development, rates of height growth become similar, but the initial superiority of fir conveys a lasting competitive advantage. Spruce saplings with a flat-topped "umbrella" morphology respond similarly to shorter spruces with full crowns, but may retain an advantage over fir because of their initially taller stature. Westveld (1931) found an optimum height growth response in spruces 1.0-1.5 meters tall that averaged 30-48 years old when released. Thus, spruce must attain a height advantage of 1-2 meters over fir in the understory prior to release in order

to assure its continued presence in the overstory of the developing stand. Since light, partial disturbances favor small firs as much or more than small spruces, it is only after several decades that spruce eventually gains an advantage because of its greater ability to withstand extended suppression (Davis 1989).

Partial cutting can alter natural development patterns by selectively removing spruce from mixed stands, resulting in potentially long-lasting changes in stand composition. Although there is no definitive evidence, it is commonly believed that much of Maine's northern hardwood type, and even some mixedwood stands, have been converted to essentially pure hardwood stands via preferential high-grading of spruce (Weiss and Millers 1989). Concentrated partial cutting of spruce from pure spruce-fir stands over large areas has also likely changed spruce:fir proportions in favor of fir. This change may be even more dramatic and long-lasting after stand regeneration. Complete overstory removal cuttings in biologically immature spruce-dominated stands may cause a radical change in subsequent composition to fir, because of the greater initial abundance and establishment ability of advance seedlings of this species. The dominance of red spruce in virgin forests was because of its great longevity relative to fir. Over a century of harvesting concentrated until recently on spruce has effectively removed this critical natural advantage, and has led to increasing dominance of fir in young stands.

The above model of spruce-fir development does not attempt to describe subtle variations in development caused by regional differences in site quality, interactions with other species, responses of competing vegetation, effects of insects and disease, and many other ecological and socio-economic factors. For example, the mixtures of spruce and fir with hemlock and eastern white pine typical of northern Washington County respond quite differently to disturbance than the fir-dominated stands of the St. John Valley. The model is offered as a point of departure to structure further studies designed to clarify these important regional patterns.

Silvicultural systems

This section attempts to outline how silviculturists have applied knowledge of stand development gleaned from over a century of experience and research. Before considering specific systems, it is helpful to summarize some general principles of spruce-fir silviculture that apply to any system. The main even-aged regeneration methods currently in use are outlined in Fig. 6; variants of these general procedures and specific treatment options are detailed below.

Stand establishment

Avoiding regeneration failures requires that adequate stocking of advance seedlings be achieved prior to the final removal of the mature overstory. This simple but effective principle was advocated by Westveld (1931) and has been stressed repeatedly, most recently at a regionwide symposium (Needham and Murray 1991). Prior to 1950 when logging was confined mostly to winter with snow cover using relatively benign technology, in stands that were well-regenerated with large saplings as a result of prior partial entries, there was little need for concern about understocking. Indeed, Smith (1981) characterized this ease of regeneration as a "magic" property of the eastern spruce-fir forest in comparison to many other spruce forests worldwide where lower rainfall and vagaries of seed production make

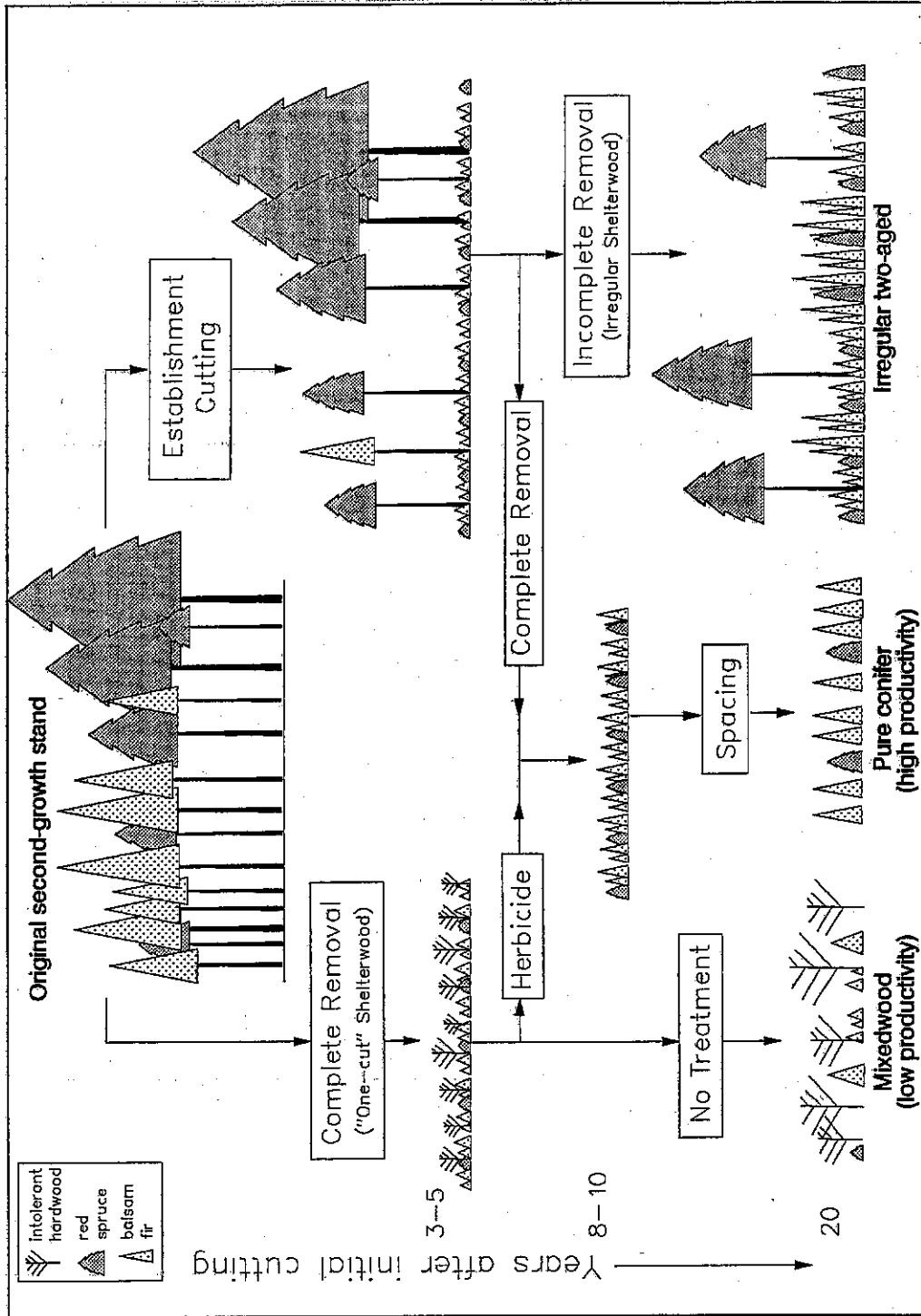


Fig. 6. Even-aged regeneration options for typical second-growth spruce-fir stands.

natural reproduction much less dependable. Since then, development of mechanized logging, year-round operations, and dense, even-aged stands with no history of disturbance and sparse advance regeneration, force close attention to the regeneration process.

Mature second-growth stands of today typically have adequate stocking of small (under 30 cm) advance growth that developed naturally in the understory. The

first consideration is whether seedlings can withstand abrupt exposure. The traditional rule that trees must be 15-30 cm tall (Frank and Bjorkbom 1973) has been found to be conservative; smaller seedlings can survive in great numbers if they are rooted in mineral soil or if they are protected by dead shade of logging residues. Excessive site disturbance during logging risks loss of advance growth and exacerbates subsequent problems from competing vegetation. Winter cutting on frozen ground with snow cover using controlled-layout tree-length or shortwood systems with on-site delimiting is vastly preferable to haphazard whole-tree skidding during the growing season.

When the mature stand is completely removed and advance growth released in a single "clearcut" harvest without prior entries to promote regeneration establishment, silviculturists have adopted the terms "one-cut shelterwood" and "overstory removal" to stress the crucial role of advance seedlings in successful regeneration (Seymour et al. 1986; Smith 1986). True silvicultural clearcutting, where new seedlings develop in exposed microsites after the final harvest, is a very undependable method for regenerating spruce-fir stands. Like most non-serotinous conifers, little red spruce or fir seed remains viable beyond the year of dissemination (Frank and Safford 1970). If there is no seed crop in the year of cutting, or if a "catch" is not obtained within two years or less, clearcut sites invariably are completely dominated by pioneer vegetation.

Whether subsequent treatments are necessary to release regeneration from competition depends on the height and density of the advance seedlings when released, as well as the site quality which governs composition and development of competing vegetation. Seedlings under ca. 30 cm tall generally will become overtopped by pioneer vegetation except on the poorest sites, and early release using a selective herbicide is required to ensure continued dominance by the conifers. Larger advance growth (1-2 meters tall) will usually outgrow all but sprouting hardwoods without treatment.

Often advance growth is so abundant that severe overstocking can result. While stands usually do not stagnate and may eventually produce high volumes of small-diameter trees, rotations can be seriously delayed if early thinnings are not conducted. Concerns about species conversion, from spruce to fir and from conifers to hardwoods, are difficult to address with regeneration cuttings alone, since virtually all practices (such as conventional shelterwood cutting) that favor red spruce also favor fir or tolerant hardwoods. Thus, species composition is best controlled by recruiting adequate densities of the favored species and eliminating competitors with subsequent cultural treatments.

Growing stock manipulation

Most recommendations and experimental attempts at spruce-fir management have involved marginal changes in the common logging rules of the time, usually in the form of leaving more residual spruce growing stock. These partial cuttings tended to be a combination of thinning and release cutting, applied to the common, irregular stand structures of the time that defied generalization. Conventional density management regimes involving repeated commercial thinnings in uniform, even-aged stands, have been applied only experimentally. Virtually none of the large age class of second-growth even-aged stands was ever treated this way, even though stocking guides and suggested thinning schedules (Frank and Bjorkbom 1973) have existed for nearly 20 years. Poor windfirmness has been the major

constraint to applying any sort of thinning or partial cutting system to middle-aged or older stands, and most attempts have found that blowdown losses nearly offset accretion of residual trees. Unlike most hardwoods, pine, and hemlock, spruce and fir are not windfirm as individual trees. The challenge is to make partial entries as light and uniform as possible, while taking care to leave fully stocked residual stands that resist wind as an integral unit. Lack of windfirmness is strictly an economic problem; chronic losses of individual trees or small patches are ideally adapted to perpetuating these species.

Precommercial thinning of densely stocked natural regeneration, to create uniformly spaced crop trees similar to a plantation, has received increasing interest during the last two decades (Murray and Cameron 1987). Studies of pure fir stands on good sites in northern New Brunswick established by G. L. Baskerville in the late 1950s show impressive growth responses, and suggest an optimum spacing of 2 meters to maximize volume production of pulpwood-sized (10 cm dbh) trees (Ker 1987). Ten-year results from the only study in mixed red spruce-fir stands (Frank 1987) show that fir responds more than red spruce, but that all species benefit from reduced competition. Commercial thinnings removing 10-20 cm trees are also contemplated as the "New Forest" reaches merchantable size, using single-grip harvesters developed to thin similar small-diameter spruce stands in Scandinavia. Such thinnings are still experimental, and no consensus has been reached about issues such as timing, thinning method, removal rates, residual stocking levels, or whether such treatment is even desirable.

Manipulating stand composition via partial cuttings that remove vulnerable fir to increase stocking of resistant red spruce and non-host species has long been recommended to reduce vulnerability to spruce budworm damage (Blum and MacLean 1985). Repeated trials show that such a strategy may be viable only when begun early in stand development, and where it is possible to create pure spruce stands (Dimond et al. 1984). Even pure spruce stands, while demonstrably less vulnerable than fir, will likely suffer economically significant growth reduction and tree mortality without insecticidal protection (MacLean 1985; Osawa et al. 1986) so this lower vulnerability may not be an exploitable advantage in today's forest economy with projected shortages. A further problem is that multi-storied stands, recommended by some authors (e.g., Westveld 1946) to reduce budworm vulnerability, may suffer nearly complete loss of the lower regenerating strata, since they are subjected to heavy feeding from dispersing large larvae and cannot be protected with conventional insecticide treatments that do not penetrate the overstory canopy. Hence, virtually any stand structure that can be used to grow significant volumes of spruce and fir also risks large losses from an uncontrolled outbreak (Baskerville 1975b). Currently, the best hope is to grow vigorous stands that will respond to protection when future outbreaks develop.

Selection cutting

Foresters who carried out pioneering studies of spruce-fir growth and management originally focused their attention on devising various diameter-limit prescriptions (generally, 36 cm or 14 inches dbh) that would increase future growth in comparison to the heavier cutting rules of the time that removed most trees over 23-25 cm (9-10 inches) dbh. Since the large-diameter spruces were very old (Fig. 1), cutting them could easily be justified on the basis of financial maturity, as well as to release the ostensibly younger, smaller-diameter poletimber and saplings. Using

stand-table projection techniques, they estimated future growth and speculated about volumes removed in future cutting cycles of 20-40 years. A crude sort of selection management emerged as a paradigm, designed to take advantage of low logging costs of large trees and the usual abundance of small-diameter growing stock with a potential to respond to release. Westveld (1953) and Hart (1963) continued to recommend a slightly more refined type of selection cutting, implemented through differential diameter limits and careful individual tree marking based on risk and vigor classes. There is little evidence, however, that marking to a particular diameter-class structure was applied during this period; such attempts are more recent, and limited to the Penobscot Experimental Forest (Frank and Blum 1978).

As described earlier, actual harvesting practices from the beginning of spruce cutting ca. 1860 until the budworm outbreak 50 years later involved relatively frequent re-entries into the same stands. This may have created a false perception that stands would indeed yield periodic volumes indefinitely. Close examination of these studies reveals that repeated cutting was made possible largely by continued reduction in merchantability standards, not by accretion of residual trees. Both Graves (1899) and Hosmer (1902) found that a small proportion (18-20%) of merchantable residual trees actually increased in growth in response to earlier sawlog cuttings. Dramatic growth responses were more typical of saplings (Westveld 1931). Such frequently repeated cutting actually had the effect of narrowing within-stand age diversity in comparison to the virgin structures, not enhancing it. Initially, cuttings removed the oldest age classes without creating truly new ones; later entries then were forced to cut much of the remaining growing stock, regenerating far *more* area than a sustained yield calculation would dictate. At best, cuttings tended to create and maintain a two-aged stand structure, by periodically removing much of the merchantable growing stock while leaving some undersized, old residuals to respond along with abundant advance regeneration.

Even-aged systems

The transition to even-aged silvicultural practice in spruce-fir parallels that in other forest types in the Northeast (Seymour et al. 1986) and United States (Smith 1972), as large areas of even-aged stands regenerated early in the century began to mature in the 1960s. Recent summaries of spruce-fir silviculture (Frank and Bjorkbom 1973; Blum et al. 1983) tend to emphasize conventional treatment of uniform, even-aged stands, but as noted above, such practices apply to less than half the resource. The most common practice appears to be heavy partial cuttings which regenerate much of the stand, but which leave significant numbers of residual trees that often respond to release and that materially influence development of the reproduction. These stands usually have an irregular, two-aged structure, falling between the extremes of plantations and balanced selection stands. In general, stand development probably follows a pattern similar to that described by Marquis (1991) for Allegheny hardwood stands with residual sugar maple poles over black cherry (*Prunus serotina*) advance seedlings. In this case, red spruce, white pine or hemlock represent the "two-rotation" trees analogous to sugar maple; balsam fir would be the main short-rotation species (analogous to black cherry), along with an occasional, minor component of paper birch and aspen (Smith 1986; Davis 1989). Superficially, such cuttings resemble the seed-tree method. However, since most of the new age

class originates as advance growth, they are best thought of as incomplete removal cuttings in an irregular shelterwood system.

Irregular shelterwood. Most two-aged management described above has been quite extensive in application; often, two-aged stands result merely because merchantability differences dictated different diameter limits by species, or because high logging costs of small trees have made them difficult to remove economically. Intensive application of two-aged irregular shelterwood management is more recent, and no consensus has emerged. Attention is focused on early selection of the two-rotation trees that will be retained after the final, incomplete removal cutting of the main age class, and that will be allowed to grow at least part way through the next rotation of the regenerating age class. For example, many even-aged spruce-fir stands contain a few white pines which develop high-quality, knot-free boles as a result of competing with densely stocked spruce-fir. At the end of a 50-70-year spruce-fir pulpwood rotation, such pines reach 20-30 cm (8-12 inches) dbh as codominants, but unlike similar spruces, have the ability to remain windfirm and grow as emergents until 60-76 cm (24-30 inches) dbh or larger, thereby earning very high rates of return. Leaving such pines as residuals involves little sacrifice in harvest value (since often they are only pulpwood or small-sawlog size) and does not interfere with the developing reproduction for at least several decades. Ideally, the final incomplete removal cutting would be preceded by at least one uniform shelterwood establishment cutting entry during a pine seed year, to establish pine advance reproduction along with the normally abundant spruce and fir seedlings.

Another common application of irregular shelterwood cutting involves retention of spruces or hemlocks from the lower crown classes. To respond well and not blow down, such trees must be much shorter than the maximum upper height for the site, so that they can expand their crowns upward after release and develop windfirmness as individual trees (Oliver and Larson 1990). Future commercial thinning schedules must consider developing such holdover trees. Unlike stand structures of the past, it will not suffice to expect a population of small-diameter residuals to "be there" at the final removal cutting. For example, early, heavy dominant or crown thinnings would tend to release partially spruces that had lapsed into lower strata, while at the same time favoring development of large-crowned dominant and codominant spruces or firs. Such treatments may be especially appropriate in stands on good sites where the upper stratum is pure fir, but where the lower stratum contains some intermediate or overtopped spruces of the same age. This practice could help to reverse the prevailing trend towards higher fir composition by maintaining or increasing the spruce component of fir-dominated stands. In contrast, heavy low thinnings in such stands would be inappropriate, since they would probably eradicate spruce from the stand.

Many foresters avoid creating two-storied stands under the belief that irregularity implies a less productive stand structure that also complicates management. Irregular stands may actually be preferable under many circumstances, however. First, several-stage removal of the overstory, culminating with retention of well distributed residual trees, promotes an uneven height structure in the sapling regeneration. This structure accelerates natural expression of dominance and may obviate precommercial thinning. Several decades after the final removal, residuals should develop into large-diameter stems that can be removed along with smaller stems in the first commercial thinning, perhaps making the thinning more profitable or allowing it to be conducted sooner. The naturally pruned, branch-free residuals

provide a low-cost way to grow high value, knot-free sawlogs. Carefully chosen residuals also can greatly improve the appearance of harvested sites, and offer a simple alternative to the selection system where aesthetics are important. Finally, and perhaps most importantly, two-storied stands provide a way to use simple, even-aged practices to maintain and favor species with slow juvenile growth patterns such as red spruce and hemlock, which are at a great competitive disadvantage relative to more aggressive species such as fir or most hardwoods when grown in mixed-species, even-aged stands.

Intensive management of the New Forest. Since clearcutting has become a dominant harvesting technology on many industrial timberlands and markets have developed for very small stems of all species, very uniform, even-aged stands have become the focus for high-yield silvicultural systems. Typically, stands are regenerated by one-cut shelterwood removal cuttings, followed at ages 3-5 by an aerial herbicide release treatment to control pioneer vegetation and sprouting hardwoods. Stands also respond to release at older ages, but the current recommendation is to apply herbicide before any overtopping or suppression is evident (Newton et al. 1987). After some initial complacency during the 1970s, herbicide release is now regarded as virtually essential to prevent understocking of conifers or even complete type conversion to hardwoods after clearcutting. If density is high and stocking uniform, motormanual precommercial thinning is sometimes done by contract workers using Scandinavian spacing saws. When this technology was first applied in the early 1980s, efforts were made to favor spruces over firs, even where spruces were quite subordinate. More recently, crop-tree selection rules emphasize the most dominant stems regardless of species. This practice can create nearly pure fir stands in the typical case where spruce lapses somewhat behind fir early in development. Carefully targeted herbicide strip treatments, carried out early in the growing season by helicopters equipped with special booms and precise guidance systems, has also been tested experimentally (McCormack and Lautenschlager 1988), but has not become operational. Since herbicide release yields substantial benefits at modest costs (under \$125/ha), it accounts for a much greater area treated annually in comparison to the more expensive motormanual spacing that can cost over \$500/ha (Seymour and Gadzik 1985). Herbicide release has become by far the dominant silvicultural investment, and is expanding annually (Fig. 7).

A small amount of the area regenerated annually is planted (Fig. 7), mainly to convert productive soils dominated by previously high-graded, low-quality hardwood stands to monocultures of black or white spruce, red pine, or exotic larches. Site conversion planting has been greatly facilitated by development of wood energy markets and biomass harvesting technology which permits very effective site preparation to be done at no cost. Neither balsam fir nor red spruce are planted operationally for timber production. Some planting is done to remedy understocking resulting from failed attempts at natural regeneration, but the current tendency is to accept marginal stocking, and virtually no fill planting (i.e., in voids) is done.

Future yields and treatments of these intensively managed stands remain uncertain. As the old second-growth stands diminish and the new forest reaches merchantability, scarce wood supplies will likely encourage widespread commercial thinning in 25-40-year-old stands. Future options for natural regeneration will range from a repetition of the one-cut shelterwood in extensive practice, to intensive application of the uniform or irregular shelterwood methods involving several

partial entries prior to the final removal. Unquestionably, the spruce budworm will return, and unless new population control intervention techniques are developed, insecticide spraying will be required on all managed, infested stands to prevent large-scale mortality.

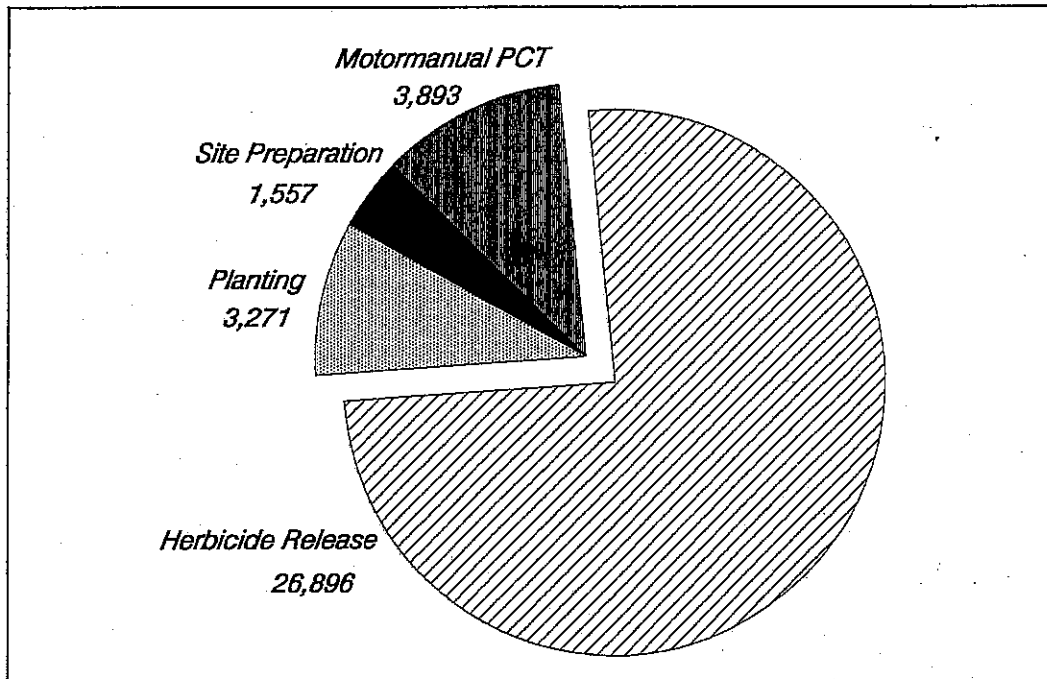


Fig. 7. Areas (hectares) treated by various intensive silvicultural practices in Maine, 1988. [Includes entire state, but virtually all are applied to spruce-fir stands. Source: Maine Forest Service (1988)]

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Literature cited

- Baskerville, G. L. 1975a. Spruce budworm: super silviculturist. *Forestry Chronicle* 51:138-140.
 Baskerville, G. L. 1975b. Spruce budworm: The answer is forest management: Or is it? *For. Chron.* 51:157-160.
 Blais, J. R. 1985. The ecology of the eastern spruce budworm: a review and discussion. p. 49-59. In: Sanders, C. J., et al. (1985).

- Blum, B.M., J. W. Benzie, and E. Merski. 1983. Eastern spruce-fir. p. 128-130. In: Burns, R.M., compiler. *Silvicultural systems for the major forest types of the United States*. USDA Agr. Handb. 445. 191 p.
- Blum, B.M., and D.A. MacLean. 1985. Potential silviculture, harvesting and salvage practices in eastern North America. p. 264-280 In: Sanders, C. J., et al. (1985).
- Cary, A. 1894a. On the growth of spruce. p. 20-36. In: *Second annual report, Maine Forest Commissioner, Augusta, ME.*
- Cary, A. 1894b. Early forest fires in Maine. p. 37-59. In: *Second annual report, Maine Forest Commissioner, Augusta, ME.*
- Cary, A. 1896. Report of Austin Cary. p. 15-203 + Appx. In: *Third annual report, Maine Forest Commissioner, Augusta, ME.*
- Cary, A. 1899. Forest management in Maine. Reprint from: *J. Assoc. Engin. Soc.* 23(2).
- Cary, A. 1902. Management of pulpwood forests. In: *4th Rept. Maine Forest Commissioner, Augusta, ME.*
- Clapp, E. H., and C. W. Boyce. 1924. How the United States can meet its present and future pulp-wood requirements. USDA Bull. No. 1241. 100 p.
- Davis, R. B. 1966. Spruce-fir forests of the coast of Maine. *Ecol. Monog.* 36(2): 79-94.
- Davis, W.C. 1989. The role of released advance growth in the development of spruce-fir stands in eastern Maine. Ph.D. dissertation, Yale Univ. 104 p.
- Dimond, J. D., R. S. Seymour, and D. G. Mott. 1984. Planning insecticide application and timber harvesting in a spruce budworm epidemic. *USDA For. Serv. Agr. Handb.* 618. 29 p.
- Eyre, F. H., ed. 1980. Forest cover types of the United States and Canada. *Soc. Amer. Foresters.* 148 p.
- Ferguson, R. H., and F. R. Longwood. 1960. The timber resources of Maine. *USDA For. Serv. NE For. Exp. Sta.* 75 p.
- Ferguson, R. H., and N. P. Kingsley. 1972. The timber resources of Maine. *USDA For. Serv. Resource Bull. NE-26.* 129 p.
- Fowells, H. A. 1965. Silvics of the forest trees of the United States. *USDA For. Serv. Agr. Handb.* 271. 762 p.
- Frank, R. M. 1987. Growth response of potential spruce and fir crop trees by precommercial thinning treatments and by fertilization treatments. Unpublished progress report for the period mid-growing season of 1976 to the mid-growing season of 1986. *USDA For. Serv., Orono, ME.* 9 p.
- Frank, R. M., and L. O. Safford. 1970. Lack of viable seeds in the forest floor after clearcutting. *J. Forestry* 68(12):776-778.
- Frank, R. F., and J. C. Bjorkbom. 1973. A silvicultural guide for spruce-fir in the Northeast. *USDA For. Serv. Gen. Tech. Rep. NE-6.* 29 p.
- Frank, R. F., and B.M. Blum. 1978. The selection system of silviculture in spruce-fir stands — procedures, early results, and comparisons with unmanaged stands. *USDA For. Serv. Res. Pap. NE-425.* 15 p.
- Graves, H.S. 1899. Practical forestry in the Adirondacks. *USDA Bull.* 26. 86 p.
- Hart, A. C. 1963. Spruce-fir silviculture in northern New England. p. 107-110 in *Proc. 1963 SAF Annual Convention, Boston, MA.*
- Hopkins, A.D. 1901. Insect enemies of the spruce in the Northeast. *USDA Bull.* 18 (new series). 48 p.
- Hosmer, R. S. 1902. A study of the Maine spruce. In: *4th Rept. Maine Forest Commissioner, Augusta, ME.*
- Ireland, L. C., J. B. Dimond, J. L. Stone, J. Falk, and E. Baum. 1988. The spruce budworm outbreak in Maine in the 1970s — assessment and directions for the future. *Maine Agr. Exp. Sta. Bull.* 819. 119 p.
- Jacobson, G.L., Jr., T. Webb, and E. C. Grimm. 1987. Patterns and rates of vegetation change during the deglaciation of eastern North America. p. 277-288. In: Ruddiman, W. F. and H. E. Wright, Jr., eds. *The Geology of North America, v. K-3. North America and adjacent oceans during the last glaciation.* Geol. Soc. Amer., Boulder, CO.
- Ker, M. F. 1987. Effects of spacing on balsam fir: 25-year results from the Green River spacing trials. p. 58-75. In: Murray, T. S. and M. D. Cameron, eds. (1987).
- Hart, A. C. 1963. Spruce-fir silviculture in northern New England. p. 107-110 In: *Proc. Soc. Amer. Foresters, Boston, MA.*
- Leak, W. B. 1975. Age distribution in virgin red spruce and northern hardwoods. *Ecology* 56:1451-1454.

- Leak, W. B. 1982. Habitat mapping and interpretation in New England. USDA For. Serv. Res. Pap. NE-496. 28 p.
- Lorimer, C. G. 1977. The presettlement forest and natural disturbance cycle of northeastern Maine. *Ecology* 58:139-148.
- McCormack, M. L., Jr. 1984. Interaction of harvesting and stand establishment in conifers in northeastern North America. p. 233-239. In: Corcoran, T. J. and D. R. Gill, eds. Proceedings - Recent advances in spruce-fir utilization technology. Soc. Amer. For. Publ. 83-13. 222 p.
- McCormack, M. L., Jr. 1985. Vegetation problems and solutions - Northeast. p. 315-326. In: Proc. S. Weed Sci. Soc. Houston, TX.
- McCormack, M. L., Jr. and R. A. Lautenschlager. 1989. An aerial technique to adjust conifer stocking-modifications and results. Suppl. to Proc. NE Weed Sci. Soc. 43:27-29.
- MacLean, D. A. 1984. Effects of spruce budworm outbreaks on the productivity and stability of balsam fir forests. *For. Chron.* 60:273-279.
- MacLean, D. A. 1985. Effects of spruce budworm outbreaks on forest growth and yield. p. 148-175. In: Sanders, C. J. et al. (1985).
- Maine Forest Service. 1988. Report of the 1986 midcycle resurvey of the spruce-fir forest in Maine. Maine Dept. Conservation, Augusta, ME. 51 p.
- Maine Forest Service. 1989. Silvicultural practices report for 1988. Augusta, ME. 6 p.
- Manley, S.A.M. 1971. Identification of red, black and hybrid spruces. *Can. For. Serv. Publ. No. 1301.*
- Manley, S.A.M. 1972. The occurrence of hybrid swarms of red and black spruces in central New Brunswick. *Can. J. For. Res.* 2:381-391.
- Manley, S.A.M., and D.P. Fowler. 1969. Spruce budworm defoliation in relation to introgression in red and black spruce. *For. Sci.* 15:365-366.
- Marquis, D. A. 1991. Stand development patterns in Allegheny hardwood forests, and their influence on silviculture and management practices. (this volume)
- Meyer, W. H. 1929. Yields of second-growth spruce and fir in the Northeast. *USDA Tech. Bull. No. 142.* 52 p.
- Millers, L., D. S. Shriner, and D. Rizzo. 1989. History of hardwood decline in the eastern United States. *USDA For. Serv. Gen. Tech. Rep. NE-126.* 75 p.
- Morris, R. F., ed. 1963. The dynamics of epidemic spruce budworm populations. *Entom. Soc. Can. Memoirs* 31. 332 p.
- Mott, D. G. 1980. Spruce budworm protection management in Maine. *Maine Forest Review* 13:26-33.
- Murray, T.S., and M. D. Cameron, eds. 1987. Proceedings of the precommercial thinning workshop. *Can. For. Serv., Maritimes. Fredericton, N. B.* 105 p.
- Murphy, L. S. 1917. The red spruce - its growth and management. *USDA Bull. 544.* 100 p.
- Needham, T.D., and T.S. Murray. 1991. Proceedings of the conference on natural regeneration management. Fredericton, N. B., March 17-19, 1990. *Forestry Canada - Maritimes, Fredericton, N. B.*
- Newton, M., M.L. McCormack, Jr., R.L. Sajdak, and J.D. Walstad. 1987. Forest vegetation problems in the Northeast and Lakes States/Provinces. p. 77-104. In: Walstad, J.D. and P.J. Kuch, eds. *Forest Vegetation Management for Conifer Production.* Wiley and Sons, NY. 523 p.
- Oosting, H.J., and W.D. Billings. 1951. A comparison of virgin spruce-fir forests in the northern and southern Appalachian system. *Ecology* 32:84-103.
- Oliver, C.D. 1981. Forest development in North America following major disturbances. *For. Ecol. Mgt.* 3:153-168.
- Oliver, C. D. and B. C. Larson. 1990. *Forest Stand Dynamics.* McGraw-Hill, Inc. 467 p.
- Osawa, A. 1989. Causality in mortality patterns of spruce trees during a spruce budworm outbreak. *Can. J. For. Res.* 19:632-638.
- Osawa, A., C.J. Spies, and J. B. Dimond. 1986. Patterns of tree mortality during an uncontrolled spruce budworm outbreak in Baxter State Park, 1983. *Maine Agr. Exp. Sta. Tech. Bull. 121.* 69 p.
- Place, I.C.M. 1955. The influence of seedbed conditions on the regeneration of spruce and balsam fir. *Can. Dept. North. Affairs and Nat. Res., For. Branch Bull 117.* 77p.
- Powell, D. S., and D. R. Dickson. 1984. Forest statistics for Maine, 1971 and 1982. *USDA For. Serv. Resource Bull. NE-81.* 194 p.
- Reams, G. A., and M. M. P. Huso. 1990. Stand history: an alternative explanation of red spruce radial growth reduction. *Can. J. For. Res.* 20:250-253.
- Royama, T. 1984. Population dynamics of the eastern spruce budworm *Choristoneura fumiferana.* *Ecol. Monogr.* 54:429-462.

- Sanders, C.J., R.W. Stark, E.J. Mullins, and J. Murphy. 1985. Recent advances in spruce budworms research. Proceedings of the CANUSA spruce budworms research symposium. Bangor, Maine, Sept. 16-20, 1984. Can. For. Serv., Ottawa. 527 p.
- Seymour, R. S. 1980. Vulnerability to spruce budworm damage and 100-year development of mixed red spruce-fir stands in north central Maine. Ph.D. dissertation, Yale Univ. 160 p.
- Seymour, R. S. 1985. Forecasting growth and yield of budworm-infested forests. Part I: Eastern North America. p. 200-213 In: Sanders, C. J. et al. (1985).
- Seymour, R. S. 1986. Stand dynamics and productivity of northeastern forests – biomass harvesting considerations. p. 63-68. In: Smith, C. T., C. W. Martin, and L. M. Tritton, eds. Proc. 1986 Sympos. on the productivity of northern forests following biomass harvesting. USDA For. Serv. Gen. Tech. Rep. NE-115. 104 p.
- Seymour, R. S., and C. J. Gadzik. 1985. A nomogram for predicting precommercial thinning costs in overstocked spruce-fir stands. N. J. Appl. For. 2:37-40.
- Seymour, R.S., and R. C. Lemin, Jr. 1988. SISTIM —A new model for simulating silvicultural treatments in Maine. Abstr. p. 1147. In: Ek, A. R., S. R. Shifley, and T. E. Burk. Forest growth modelling and prediction. USDA For. Serv. Gen. Tech. Rep. NC-120. Vol. 2., p. 580-1149.
- Seymour, R.S., and R. C. Lemin, Jr. 1989. Timber supply projections for Maine, 1980-2080. Maine Agr. Exp. Sta. Misc. Rep. 337. 39 p.
- Seymour, R.S., P.R. Hannah, J.R. Grace, and D.A. Marquis. 1986. Silviculture – the next 30 years, the past 30 years. Part IV. The Northeast. J. Forestry 84(7):31-38.
- Smith, D.M. 1972. The continuing evolution of silvicultural practice. J. Forestry 70:89-92.
- Smith, D.M. 1981. The forest and Maine's future. p. 79-87. In: Proc. Blaine House Conf. Forestry. Augusta, ME, Jan. 21-22, 1981.
- Smith, D.M. 1986. The Practice of Silviculture (Ed. 8). Wiley and Sons, NY. 578 p.
- Swaine, J.M., and F.C. Craighead. 1924. Studies on the spruce budworm (*Cacoecia fumiferana* Clem.). Can. Dept. Agric. Tech. Bull. 37 (new series). 91 p. + Appx.
- USDA Forest Service. 1985. Insects of eastern forests. Misc. Publ. 1426. 608 p.
- Weiss, M.J., and I. Millers. 1988. Historical impacts on red spruce and balsam fir in the northeastern United States. p. 271-277. In: Proc. US/FRG research symposium: effects of atmospheric pollutants on the spruce-fir forests of the eastern United States and the Federal Republic of Germany. USDA For. Serv. Gen. Tech. Rep. NE-120. 543 p.
- Westveld, M. 1928. Observations on cutover-pulpwood lands in the Northeast. J. Forestry 26:649-664.
- Westveld, M. 1931. Reproduction on the pulpwood lands in the Northeast. USDA Tech. Bull. 223. 52 p.
- Westveld, M. 1946. Forest management as a means of controlling the spruce budworm. J. Forestry 44:949-953.
- Westveld, M. 1951. Vegetation mapping as a guide to better silviculture. Ecology 32:508-517.
- Westveld, M. 1953. Ecology and silviculture of the spruce-fir forests of eastern North America. J. Forestry 51:422-430.
- Zon, R. 1914. Balsam fir. USDA Bull. No. 55. 67 p.