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Silviculture for Acadian Spruce-Fir Forests

Production Forestry: Managing for High Timber Yields

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Silviculture for Acadian Spruce-Fir Forests No. 3

History

High-yield forestry first began to interest Maine landowners in the mid-1970s, when a regional symposium was held to discuss its potential (Northeastern Forest Experiment Station 1977). Practices began in earnest by the mid-1980s, stimulated largely by two developments. First, widespread presalvage harvest clearcutting created extensive areas of young stands dominated by competing vegetation that required herbicide treatments to release overtopped conifers. Second, a wood-supply analysis for Maine first released in 1980 and updated in 1983 (Seymour 1985) showed that high-yield silvicultural practices needed to be greatly expanded to avert spruce-fir fiber shortages by 2010. Herbicide release peaked in the late 1980s, but remains a common practice, with over a million acres treated in Maine (Fig. 3.1). Precommercial thinning (PCT) and planting activities peaked about a decade later, during the latter part of the tenure of industrial ownership in Maine where lands were managed with the sole purpose of supplying large paper mills and sawmills. Practices depicted in Figure 3.1 are not additive, because virtually all the PCT stands were released about a decade before thinning.

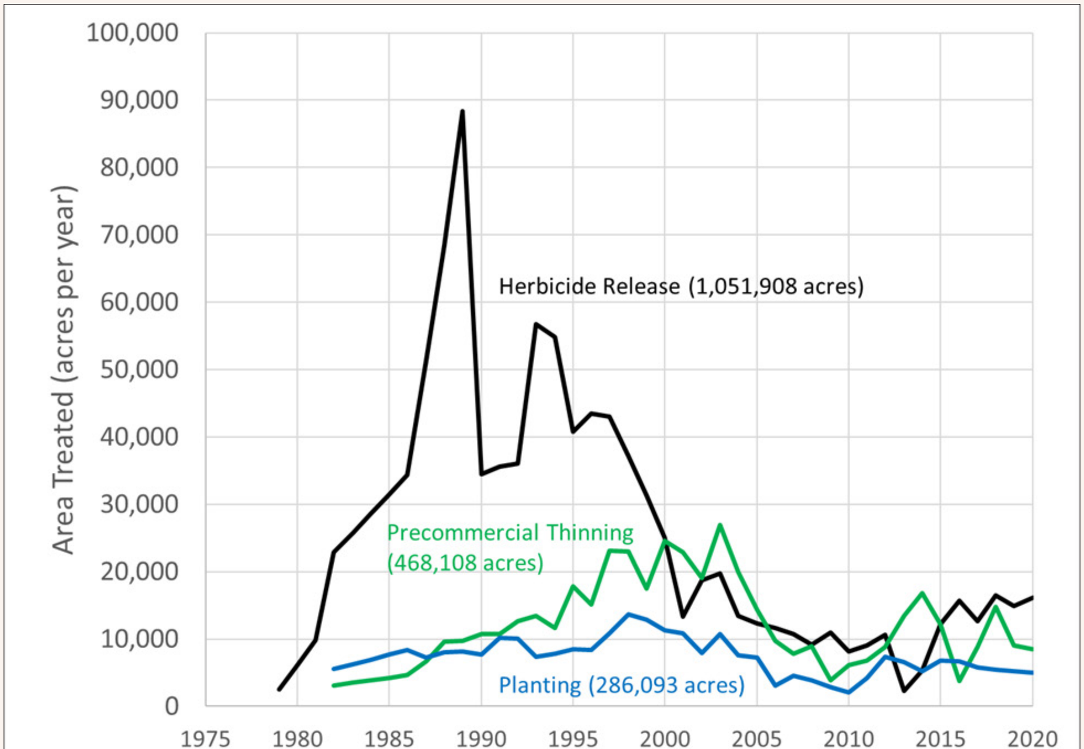

Figure 3.1 Area treated by herbicide release, precommercial thinning, and planting from 1978 to 2020, Maine. Data compiled by Kenneth Laustsen and Robert Wagner largely from records maintained by the Maine Forest Service.

Principles

To achieve high yields from managed northern conifer stands using even-aged silvicultural systems, interventions must be carefully timed and rigorously prescribed at five stages of stand development defined by dominant stand height (Table 3.1). Each step is discussed below.

Table 3.1 Key steps and practices to ensure high timber yields when managing northern conifers

Stand Height (ft)	Silvicultural Intervention(s)
1–5	Regenerate to **ensure full stocking**, either with the shelterwood method or by planting.
1–3	If regeneration becomes overtopped by competing vegetation (*Rubus* spp., short-lived intolerant hardwoods), release the conifers with an **aerial herbicide application.**
8–15	Reduce stem density, adjust crop-tree spacing, and alter species composition away from balsam fir, during the sapling stage using **precommercial thinning (PCT)**. Not needed if stocking is optimal (see Table 3.3).
30–70	Devise and implement a **commercial thinning schedule** that maintains the stand relative density below 0.55 (to preempt losses from mortality), and above 0.3 to avoid losing productivity from understocking. The final thinning serves as a shelterwood establishment cutting.
>70	Schedule the **final harvest at the age of peak mean annual increment.** Mean annual increment is the total yield of the stand at a given age (standing volume plus the sum of all thinnings) divided by the age.

Ensure Full Stocking

To achieve maximum yield from a forest stand, all growing space must be occupied by crop trees at some chosen spacing. This can be visualized as a network of square grid cells with dimensions equal to the spacing. Figure 3.2 shows a 20 x 20 = 400-cell grid with squares 7 feet on a side, populated with a random distribution of 889 trees per acre, the density equivalent to a 7-foot square spacing. The random point locations were constrained to be no closer than 3.3 feet from each other, as might result from a precommercial thinning prescription with these

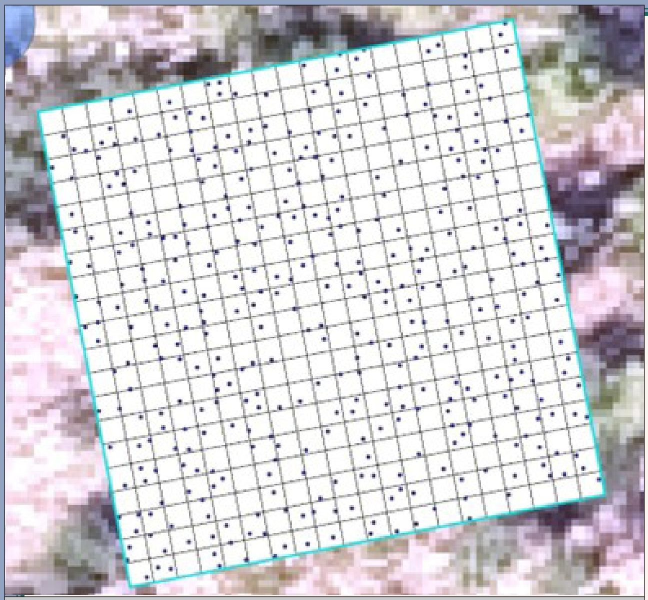

Figure 3.2 Illustration of regeneration stocking, showing a random distribution of 889 trees per acre (7x7-foot spacing) on 7x7-foot grid cells. Stocking at this scale is 77%.

parameters. Over this entire grid, 91 cells have no crop tree, and are thus unstocked at this scale. Stocking in this example would thus be 309/400, or 77.2%, which means that timber yield when the stand reaches crown closure and begins to self-thin will be 77.2% of that predicted by a yield table or model based on 100% stocking.

Naturally regenerated stands of northern conifers will rarely have stocking levels much higher than this, because damage to saplings during the overstory removal harvest eliminates the advance regeneration in the machine paths. Highly variable pit-and-mound topography on poorly drained soils will also produce such a pattern, owing to trees' inability to establish in the wet areas between mounds.

To survey the stocking of young stands, design a series of line transects with a sampling interval that will yield 100 or more sample points over the entire stand of interest. Use random azimuths, not a fixed grid relative to the haul road, to avoid sample lines coinciding with harvest trails. At each point, simply tally the presence of each species present within the radius for the chosen density (Table 3.2). Using a lightweight pole cut to the length of the plot radius expedites this fieldwork. The stocking of each species is simply the number of plots with one or more individuals present divided by the total number of plots taken. If the regeneration is short (under 3 feet tall) and not free-to-grow because it is overtopped by competing vegetation, this should also be recorded as an indication of the need for an immediate release treatment.

If stand density (trees per acre) is needed, then all stems must be counted by species, a much more time-consuming task. The main reason for doing so is to assess the future need for precommercial thinning and to predict the cost of such a treatment. Instead of stem counts, experienced foresters can employ categories related to future treatment needs (Table 3.3).

When classifying sample plots for possible PCT, especially on plots in the "moderately dense" category, consider not only overall density but also if PCT would result in a silvicultural cleaning to alter composition away from fir. When tallying an unstocked ("void") plot, record whether the plot is non-stockable for some reason that cannot be overcome silviculturally (e.g. with

Table 3.2 Suggested plot sizes for assessing stocking at spacings between 6 and 10 feet.

Spacing (feet)	Trees per Acre	Plot Area (sq ft)	Plot Radius (feet)
6	1210	36	3.39
6.6	1000	44	3.72
7	889	49	3.95
8	681	64	4.51
9	538	81	5.08
10	436	100	5.64

fill planting), such as severe soil compaction or rutting from recent harvesting, or natural site features such as exposed bedrock or water-holding depressions.

Herbicide Release Treatments

Herbicides are pesticides designed to kill or damage weeds that compete for resources needed by a crop plant. Herbicides are the main tool used in the science and practice of forest vegetation management, the sub-discipline within silviculture that manages the course and rate of forest succession to achieve specific silvicultural objectives, usually wood production (Wagner 1994). The development of effective and economical herbicide treatment regimens has played a critical role in advancing high-yield production forestry worldwide, and a voluminous body of

Table 3.3 Suggested stocking classes for assessing recently regenerated stands for weeding and precommercial thinning.

Category	Plot Condition	Treatment Implication
Void	Unstocked	Fill planting if this is the dominant condition over the block
Weeds	Conifers present but overtopped by competing vegetation	Weeding via herbicide release to avoid forest type conversion
Optimal	1 crop tree clearly dominant and free to grow	Let grow–PCT not needed
Moderately dense	2-5 desirable trees vying for dominance, some differentiation	PCT desirable to maintain optimum stand development or change species composition
Overly dense	>5 trees crowded and competing, differentiation weak or absent	PCT essential to avoid long delay to merchantability

scientific studies attests to their efficacy (Wagner et al. 2006). In Maine, simulations by Bataineh et al (2013) showed large increases in stumpage values at ages 70-90 in herbicide-treated plots, especially when combined with subsequent PCT, owing to the much higher volume of valuable softwood sawlogs.

As described at length in the Natural Regeneration installment of this Silviculture for Acadian Spruce-Fir series (ASF No. 5), herbicide release is usually unnecessary when employing the extended shelterwood method, where desirable saplings are 4-5 feet tall when released. However, if overstory removal cutting occurs prematurely when advance regeneration is absent or short, competition from early successional weeds will invariably overtop the conifers. Without intervention, such stands will experience forest-type conversion from conifers to an overstory dominated by paper birch, aspen, and red maple, with some conifers surviving in the lower strata (Olson et al. 2012, Fig. 3.3). As detailed in ASF No. 5, this was the common condition during the 1970s and 1980s, and by the mid-1980s, most landowners in Maine recognized that silvicultural weeding via aerial herbicide release treatments was essential on most sites to maintain coniferous stocking. Between 1979 and 2010, over a million acres were sprayed in northern Maine (Fig. 3.1, Bataineh et al 2013). The most recent data for Maine (Maine Forest Service 2020) show 16,000 acres treated annually, about 12% of the area associated with even-aged regeneration harvests.

Figure 3.3 Untreated control plot from the Austin Pond study (Olson et al. 2012) at age 30, showing pure hardwood overstory with scattered conifers in the understory.

To determine whether weeding is needed, survey the stand as described above to verify that adequate conifer stocking is present to occupy the growing space once the weeds are killed. Surveys should wait until the third growing seasons after the final harvest to ensure that all weed species that originate from the seed bank (*Rubus* spp., pin cherry) have sprouted. If conifer stocking is under 50-60%, then killing all deciduous vegetation will result in an understocked condition. The preferred option in this case is to manage the sapling vegetation with motormanual precommercial thinning, where some hardwoods are left as crop trees in a managed mixedwood stand. If conifer stocking is even lower (below 40%), and the hardwood species composition is low-value or not well adapted to the site conditions, then release spraying followed by fill planting of the voids is another option.

Most herbicide release treatments are applied aerially using helicopters with precision guidance systems. Applications are timed late in the growing season, after conifers have set buds and hardened off, but before deciduous vegetation drops its leaves, typically early to mid-September before any killing frost. Treatments should wait until at least the third growing season after harvest to ensure complete germination of all seed-bank species. Glyphosate is by far the most widely used herbicide, sometimes with a small amount of Oust (sulfometuron-methyl) to maintain longer-term control of herbaceous vegetation. Imazapyr can damage spruce (*Picea*) species and should be avoided. Most conifers are resistant to glyphosate once dormant, except eastern white pine (*Pinus strobus*) which can be severely damaged if sprayed directly.

Precommercial Thinning

Management of natural northern conifer stands has always been plagued by delayed development of merchantable trees caused by overly dense natural regeneration. Early precommercial thinning (PCT), or spacing as it is sometimes called, during the early sapling stage delays self-thinning for decades and reduces the time required for crop trees to reach merchantable size (5" dbh) by 20 years on average sites. Precommercial thinning was first introduced to the Maritime Provinces of Canada in the late 1960s (Eddy 1987) and by 2005, 453,000 acres had been treated in Nova Scotia alone (Nicholson 2007).


Figure 3.4 . Scandinavian spacing saw widely used for precommercial thinning.

In 1960, the Canadian Forest Service established long-term trials of precommercial thinning on high-site, fir-dominated sapling stands on the Green River watershed in northwestern New Brunswick. After 44 years, there was little difference in total stemwood production among thinning treatments versus unthinned controls, but a 23% gain in merchantable volumes at spacings of 6 and 8 feet, which did not differ from each other (Pitt and Lanteigne 2008). In Maine after 32 years, spacing individual crop trees to 8 feet yielded higher stocking (basal area) of merchantable conifers and red spruce alone than the unthinned controls. Growth response following removal of geometric swaths over 62% of the stand (5-foot rows cut, 3-foot rows left) did not differ from the control, but releasing crop trees within these rows yielded similar conifer stocking to the unconstrained 8-foot spacing but had fewer red spruces as crop trees (Weiskittel et al. 2011). Trials in Nova Scotia showed large gains in merchantable and sawlog volumes, a 7-37%

increase in spruce stocking, and 3-9-fold improvements in harvest piece size (volume per tree) at age 45, 30 years after spacing (Nicholson 2007).

Efficient precommercial thinning in dense conifer stands is made possible by the clearing or brush saw, a circular blade at the end of a shaft, powered by a small gasoline motor worn in a harness (Fig. 3.4). Clearing saws were developed in Sweden, where such motormanual spacing is used to treat over a million acres per year (Berglund 1987). Silviculturally, this treatment is both a thinning (density reduction of conifers) and cleaning (change in composition away from fir and hardwood competitors in favor of red spruce). Worker productivity in spacing depends mainly on stand density and tree size. For stems under 20 feet tall, productivity drops from 0.47 acres per productive hour at 2,000 trees per acre to 0.15 acres per hour at 10,000 trees per acre, eventually reaching a lower asymptote at about under 0.1 acres per hour at very high densities over 40,000 trees per acre (Seymour and Gadzik 1985). Other factors that lower productivity and increase costs are sites with many large surface boulders and blowdowns that slow worker progress. Early attempts to mechanize this work using large mechanical swath cutters followed by motormanual spacing of the residual strips were unsuccessful, owing to frequent breakdowns and unacceptable damage to potential crop trees (Seymour et al 1984, Ryan 1987).

Brush saws cease to be efficient when cutting many stems over 3 inches at the stump, so treatments should be timed before reaching this stage. However, if stands are thinned before crown closure and the onset of crown recession, it may be impossible to sever the tree low enough to kill it. The ideal window is within the height range of 8-15 feet, which occurs at a stump age of 15 years if starting with small advance regeneration, or 3-5 years after overstory removal in an extended shelterwood that releases 5-foot-tall saplings (Fig. 3.5).

A typical PCT prescription has the following elements:

1. The desired **spacing** between residual crop trees. Spacing is determined by working backward from a target density obtained from a stocking guide or density management diagram. Workers select the most dominant tree at this spacing and cut all others subject to following constraints.

Figure 3.5 . Residual red spruce trees left in a recent precommercial thinning.

2. A **species ranking**. This gives the worker a ranked list of species to favor over others lower in priority, other things being equal. Typically, red spruce is favored over fir owing to its longer life span, higher product value for sawlogs, and greater resistance to pests and diseases.
3. Definition of **relative heights** or dominance status that can reverse the species ranking. For example, "favor spruce over fir only if spruce is at least X percent as tall as the fir." In practice, X has ranged from very low (favor spruce at any cost) to 100% (no discrimination).
4. Specification of **"Invisible Species"**. To the workers, this means simply ignoring any tree of this species, meaning that it cannot be either a crop tree or competition to one, and should thus always be kept. This practice is used to prevent inadvertent eradication of slower-growing, rare species such as hemlock, northern white-cedar, and even red spruce that exist only in subordinate crown positions.

Figure. 3.6 . Eastern white pine crop tree eft of a 20-foot spacing in a matrix of spruce and fir spaced to 8 feet.

5. A requirement that cut trees be severed below the lowest living branch whorl, to prevent lower branches from turning up when released.
6. A constraint that no crop trees be left closer than X to each other, where X is half to two-thirds of the nominal spacing.
7. Some more advanced prescriptions specify wider spacings for 'two-rotation' species that will be carried longer than the short-lived fir. One example is eastern white pine, which is left at 3x the spacing of the common species that comprise the main prescription (Fig. 3.6). As the examples below illustrate, it is also highly recommended to use this concept for red spruce to ensure that there are at least 200 trees per acre (15-foot spacing, 2x the matrix species well distributed after commercial thinnings at age 50 when the fir matures.

Although precommercial thinning is usually used to create very regular even-height stands associated with high-yield systems, the practice can also be employed to manage more diverse species mixtures where promoting biodiversity is also an objective. This has been done experimentally in the AFERP ecological silviculture study, where gap regeneration often includes 10 or more species (Seymour 2023). After 15-20 years, gaps develop a highly stratified mixed-species structure, and simple spacing prescriptions or even variable-density thinning rules will oversimplify the resulting residual stand relative to ecological benchmarks. Instead, crop-tree selection rules should vary by vertical stratum. Any A-stratum paper birch and aspen are spaced at 45-60 feet, favoring stems that are not overtopping more valuable (white pine) or rare (red spruce) trees in lower strata. Any white pine, red maple, yellow birch or red oak in the B stratum are retained on a 20-25 foot spacing; hardwood sprout clumps can be thinned to a single stem. Finally, the lower C stratum of shade-tolerant species is spaced to 6-10 feet, favoring spruce and sugar maple over balsam fir, beech, and hemlock. Rare species in the lowest stratum such as northern white-cedar are treated as invisible.

Forty years of research and experience in Maine has demonstrated that PCT will produce harvestable trees (5-7" dbh) 20 years after treatment, at age 30 on a typical site, whereas allowing the dense sapling regeneration to develop naturally delays this time to operability at least 20 years more to age 50 or older. Even so, the high early cost (well over $200 per acre) and the long period of discounting future revenues appear to make PCT uneconomical at the stand level using interest rates above 4% (Bataineh et al 2013). However, landowners with imbalanced forest age structures often find that an expanded PCT program can generate an immediate increase in the long-term sustainable harvest level through the phenomenon of the allowable-cut effect (Erdle 1999). By generating higher future inventories decades sooner than without thinning, the existing growing stock need not last as long and can thus be harvested at a higher annual level immediately. The resulting increased harvest revenues are often many times the cost of the annual PCT program applied to generate them, and thus easy to justify.

Commercial Thinning

Compared to precommercial spacing, commercial thinning – defined as the partial harvest of merchantable trees prior to the final harvest to optimize stocking and preempt mortality from self-thinning – is a relatively new practice in the northern conifer region and was not studied historically until 2000 when a large-scale study was installed by the Cooperative Forestry Research Unit throughout northern Maine (Wagner and Seymour 2000). Study installations in the Commercial Thinning Research Network (CTRN) covered two distinct conditions common at that time: older (ages 45-75) stands dominated by red spruce on low- to average sites with no history of density management, and younger (ages 21-40), fir-dominated stands on high sites that were treated with precommercial thinning at about age 10. Treatments in the no-PCT stands were different thinning methods (low, crown, dominant) each with two removal intensities (33%, 50%) based on the relative density (Wilson et al 1999) at the time of establishment. Treatments in the PCT stands were crown thinnings that varied in timing (0, 5, or 10 years after plot establishment) at the same removal rates. Using 15-year data from the PCT stands projected forward with a growth model, Heisl et al (2017) found little difference in the net present value among the different rates and timings. Evidently, the higher stem volumes, higher sawlog percentages, and lower harvesting costs in the later thinnings were offset by the longer discounting period using a 4% interest rate.

Wagle et al (2022) compared cumulative yields after 18 years, and found no difference among timing treatments in either total or merchantable volumes (growing stock plus thinning removals) in the PCT stands, although the ending stands thinned at year zero had significantly more sawlog volume than those thinned later. Given that these comparisons are made at an age well below the peak mean annual increment, results could change with further measurement and analysis. In the stands without PCT, light (33% removal) low or crown thinnings did not differ from the controls, whereas heavy (50%) crown and both dominant thinnings exhibited lower yields owing to mortality from windthrow.

In a commercial thinning trial in two young (age 19-24) high-site spruce plantations in northwestern New Brunswick, Pelletier and Pitt (2008) found that three different 40% removal treatments did not differ from the unthinned controls in yields up to age 40. All thinnings maintained live-crown ratios above 40% and height-diameter ratios below 75 until age 40. Mean annual increments at age 40 were 8 m3 per ha (1.3 cords per acre) per year and rising, suggesting a peak at age 50 or later.

Although research support is limited, enough experience has accumulated over the last two decades to offer the following guidance when devising commercial thinning prescriptions:

1. A history of PCT allows the first commercial entry to be made 20 years sooner than if the stand has no history of density control. On average or better sites, PCT stands will be operable at ages 25-30 (15-20 years after PCT), at heights of 30-35 feet with a relative density of about 50% (Wagle et al. 2022; Fig. 3.7).
2. Without PCT, stands will not be operable until at least 50 feet tall, at ages 50 with relative densities over 60%

Figure 3.7 Spruce-pine stand spaced as in PF 6 after 20 years of stand development, ready for a first commercial thinning.

3. When first operable, PCT stands will often lack much differentiation, with all trees occupying upper crown classes. Entries are thus mainly crown thinnings; tree selection rules should widen the spacing between the best crop trees and favor spruces over firs. Removal rates of up to 50%, to relative densities as low as 25%, appear to be feasible without subsequent windthrow or reduced growth, even if the stand is dominated by fir (Wagle et al. 2022).
4. By the time they are operable for commercial thinning, stands with no PCT history will be experiencing rapid self-thinning and be highly differentiated. In this case, low thinnings with a removal rate no greater than 40% are recommended to avoid windthrow.
5. Cut-to-length (CTL) harvesting systems, with in-woods processing and forwarding, are highly recommended to minimize the trail footprint that can arise with grapple skidding. CTL systems also appear to be more economical (Heisl et al. 2017) and will result in better product merchandising. Trails in first commercial thinnings should be under 12 feet wide and occupy no more than 10-15% of the stand; otherwise, future yields will be negatively impacted.

Thinning Schedules

Optimizing timber yields in northern conifer stands requires that thinnings be timed appropriately and that residual stand densities be aligned with the landowner's product objectives. Because northern conifer stands often regenerate very densely, differentiation and product yields will be delayed by decades if these stands are not thinned precommercially. Conversely, thinning heavily can result in large trees, but if overdone, will reduce total stand yields because the growing space is not fully occupied and increases the risk of blowdown. Rigorous density management over a rotation must therefore specify both the timing of thinnings, and residual densities at each stage– the concept of a thinning schedule.

To facilitate the rigorous development of thinning schedules, two quantitative tools are essential: a stocking guide or density management diagram to prescribe specific residual densities based on particular stand conditions, and a growth and yield model to "grow" the stand and predict timber yields over the rotation with and without thinning.

Stocking Guide

To support the process of developing thinning prescriptions, we have developed a new stocking guide (ASF No. 4) based on several decades of data collected since the first guide (Frank and Bjorkbom 1973) was created. The new stocking guide is based on a Reineke-style density management diagram (DMD) using a maximum Stand Density Index [SDI, the number of trees per acre (TPA) at a quadratic mean diameter (QMD) of 10 inches] = 542 (Appendix). The Reineke

DMD was mapped into the familiar stocking guide format of basal area (BA) over TPA with QMD isolines. The traditional A, B, and C lines are replaced by four density management zones, defined by relative density (RD):

1. The Zone of Imminent Competition-based Mortality (ZICM), defined as any combination of BA and TPA above a RD of 55%, the point at which self-thinning begins, and below a RD of 67%, which defines the average self-thinning trajectory of fully stocked stands (Wilson et al 1999). Because merchantable trees are being lost to mortality in this zone, thereby reducing net growth, it could be considered "overstocked" from a timber management perspective.
2. The Zone of Optimal Density Management (ZODM), defined here as the density region between RDs of 30% and 55% (Smith and Woods 1997). Stands in this zone will exhibit optimal growth of timber products without suffering losses to self-thinning mortality.
3. A Low-Density Management (LDM) zone, defined as the density region between 15% and 30% relative density. In this zone, crop trees grow rapidly but stand yields will be lower than within the ZODM.
4. The Understocked zone, defined as the density region below 15% RD. A RD of 15% corresponds approximately to the lower limit of crown closure for stands that are managed early and develop long crowns; thus, any density below this cannot fully utilize the available growing space.

Thinning Schedule Specifics

The purpose of thinning is to keep stocking within the range of relative density encompassing the ZODM once the trees are merchantable. The first choice is the residual density (and equivalent spacing between crop trees) in precommercial thinning. Based on markets and other management objectives, choose a QMD that the stand will grow to when it is at the upper limit of the ZODM, which is the point on the stocking guide where the 55% RD line (the upper limit of the ZODM) intersects the chosen QMD. This is the point during stand development when the first commercial thinning will be made. For example, to grow the maximum number of 5-inch dbh trees without losing any to self-thinning mortality, observe that the 5-inch QMD line and the 55% RD line intersect at about 900 trees per acre (a 7x7-foot spacing). To grow 6-inch dbh trees, PCT would need to reduce density to about 700 trees per acre (8x8-foot spacing). Before PCT, the young PCT-age stand will have a high density well off the diagram to the right. After PCT, the stand will appear to be grossly understocked (because 80-90% of the stems are cut), but this is of no consequence for timber yields because the stocking guide is used here only to define the future target when merchantable at a RD = 55%.

- Determining the optimum spacing and density for a plantation follows the same procedure as above, except that trees are simply planted at the chosen density.
- If no PCT is done, the stand will reach the 67% RD self-thinning line well before any trees are merchantable size, and enter the diagram on the upper right, reaching a QMD line about 20 years later than if precommercially thinned.

Once trees are merchantable and the stand is fully stocked at 55% or above, then commercial thinning is needed to avert self-thinning mortality. Ideally, commercial thinnings should reduce the stocking down to the lower ZODM limit (30% RD), but this must be constrained by the need to maintain stability and windfirmness in the residual trees. At this point, the height-diameter ratio (H/D), measured in the same units, must be assessed. H/D applies to the potential residual crop trees (likely the upper crown classes) only; do not include understory or overtopped stems in its calculation. Experience worldwide reviewed by Wilson and Oliver (2000) demonstrates that any H/D over 80 should be considered potentially unstable if thinned too heavily. Model predictions discussed below suggest that without PCT, H/D will be about 100 at 5 inches QMD (Fig. 3.8) and thus unstable. In this event, do not remove more than 35% of the stocking, including areas in harvest trails. Residual stocking will exceed the lower ZODM limit, but priority should be given to ensuring the residual growing stock remains windfirm.

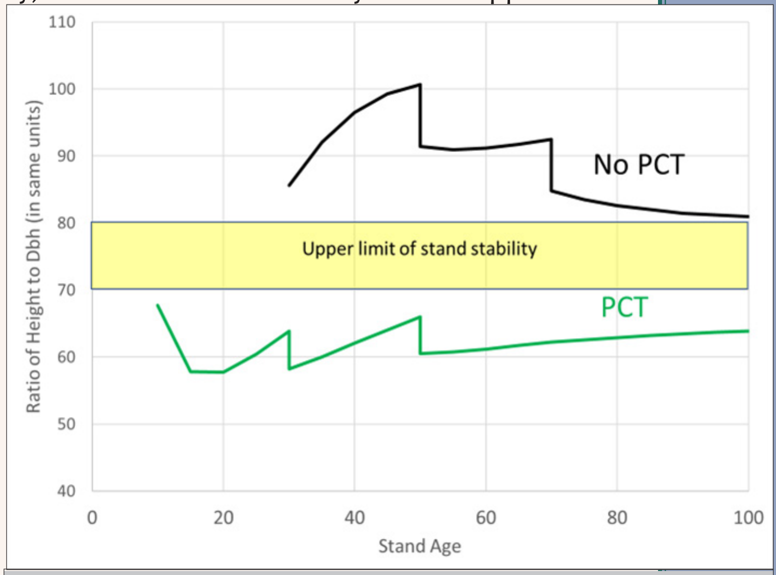

Figure 3.8 Contrasting height-diameter ratios with and without precommercial thinning.

With early PCT, the H/D will be in the safe zone (<70) when the stand reaches 55% RD, so in most cases, it can be safely thinned all the way down to 30% stocking. On poorly drained sites, removals should not exceed 40% of the pre-harvest BA or be no lower than 35% RD, whichever results in a higher residual stocking, given their enhanced susceptibility to windthrow.

Crop Tree Selection – Thinning Methods

In a plantation monoculture, simple low thinning on the chosen spacing is appropriate, focusing removals mainly on the lower crown classes (intermediates, overtopped). In naturally regenerated mixed stands with fir and spruce, every effort should be made to retain spruce and remove competing firs, while adhering to the chosen residual-tree spacing. Other things being equal, always favor crop trees with the higher live crown ratio (LCR). However, do not remove spruces in a first entry simply because their LCR is small; such trees respond well to release and will be in the main canopy by the next entry. The better the site quality, the more fir will likely be ahead of spruce, so such thinnings are best characterized as crown or dominant thinnings, preferentially removing firs that are taller, larger in dbh, and more dominant than spruces within the chosen spacing distance away. Where firs are competing only with other firs, low thinning is appropriate, with the caveat that any fir tree 10 inches or larger should probably be harvested given the increasing probability of rot and risk of stem breakage.

Prescriptions must also address other species where present. In general, any species that stratifies above the tolerant conifer matrix can be retained if it has the potential to produce higher-value products if grown longer. White pine and paper birch are good examples. Hardwoods of pulpwood quality should be removed unless a biodiversity objective requires their retention. Any species left as "invisible" in a prior PCT will likely still be in the lower strata and can continue to be ignored; if these are abundant, then the harvester operator will likely need to cut some to access the merchantable wood being removed.

Examples

To illustrate the application of the stocking guide to formulate and display thinning schedules, two rotation-long scenarios were generated using the Nova Scotia GNY stand growth model (Steenberg et al 2023), one with early PCT, the other without PCT. Stand composition is pure red spruce with a site index of 52. [Actual composition will almost always include balsam fir, but yields in GNY are very similar.] The PCT stand assumes a 7-foot spacing at age 10 (about 900 TPA) reduced to 75% stocking to account for imperfect growing space occupancy in naturally regenerated stands. Further details about each scenario follow:

Early PCT . Here the stand develops without mortality, at a density (reduced for actual stocking) of about 690 trees per acre until it reaches the upper bound of the ZODM at age 30, with a QMD = 5.8 inches dominant height = 31 feet, and RD of 54% (Dashed line, Fig. 3.9). Commercial thinning from below removes 35% of the BA and 51% of the merchantable TPA to a residual BA of 75 square feet per acre, equal to a RD of 30% at the lower limit of the ZODM. Thinning harvests 334 TPA containing 779 cubic feet (9.2 cords) per acre of merchantable wood, 69% studwood, 23% pulpwood and 8% sawlogs.

After this first thinning, the stand again grows upward without mortality for 20 years to a RD of 51%, QMD = 8.9 inches, dominant height = 49 feet, and a BA of 144 at age 50. Another 35% BA removal of 151 TPA yields 1283 cubic feet (15.1 cords) of larger wood consisting of 75% sawlogs, 20% studwood, and 5% pulp. The diagram shows stand development with no further harvesting to age 100. The merchantable mean annual increment peaks at about age 75, but drops very little until age 100 suggesting much flexibility in the rotation (Fig. 3.11). In practice, a shelterwood establishment cutting would be well timed at age 70 (BA = 143, RD = 45%), with the overstory removal cutting 10 years later at age 80. [This step cannot be simulated with GNY because it allows only two commercial thinnings.]

No PCT. In this scenario, stand development prior to age 50 is off the diagram to the right, as it self-thins along the upper boundary of the ZICM at a RD of about 70%. At age 50 at a height of 49 feet, the stand is barely operable for commercial thinning, with a QMD = 5.3", BA = 165, and a RD of 72% Fig. 3.9, dotted line). Under these conditions, thinning all the way to the 30% ZODM boundary would be too extreme (over 50% removal) and likely result in severe windthrow. The height-diameter ratio, a measure of tree stability, is nearly 100 at this point, well over the usual stability threshold range of 70-80 (Fig. 3.8). Instead, a 35% removal was implemented to a residual BA = 96 and RD = 39%. This thinning removed 379 TPA, yielding 1,285 cubic feet (15.1

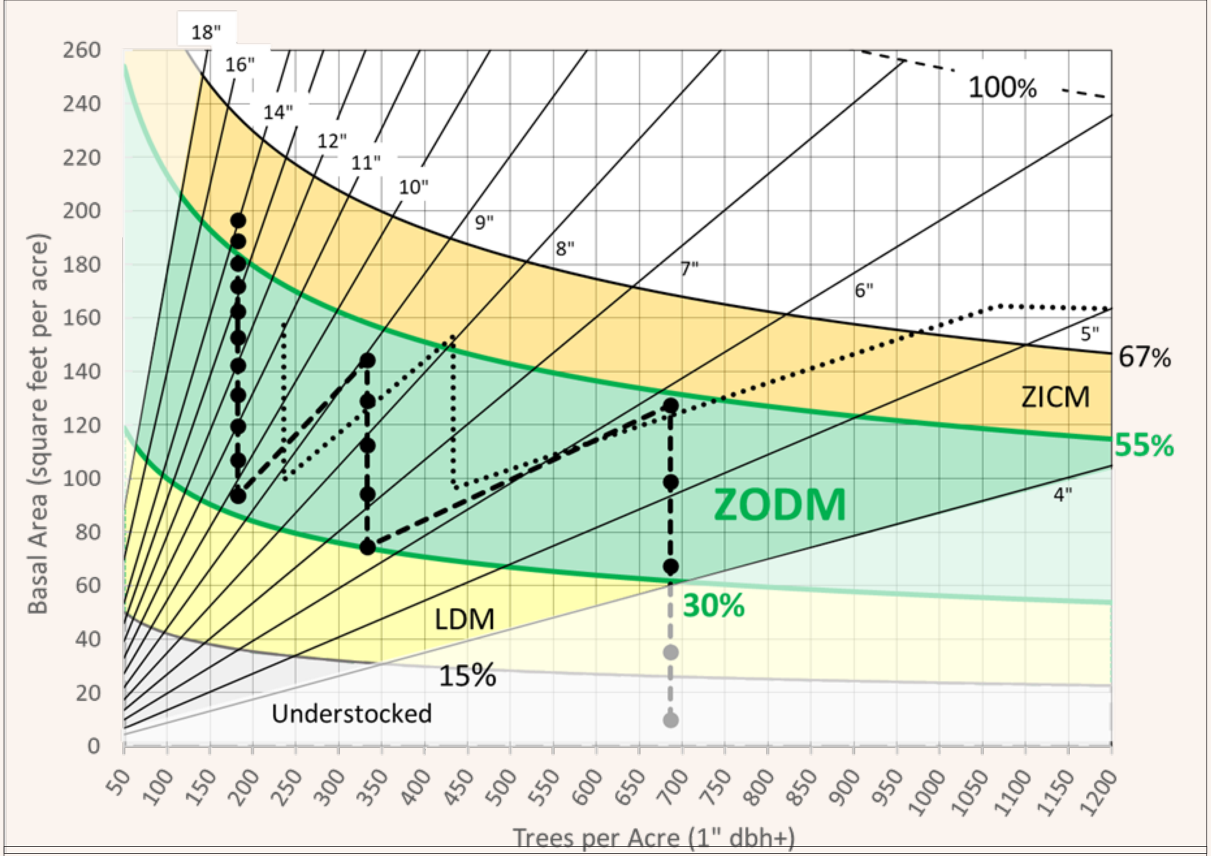

Figure 3.9 Contrasting thinning schedules plotted on a stocking guide. Dashed lines with dots had early PCT; dotted lines had no density management prior to commercial thinning. Management zones are based on relative density isolines converted from a Reineke-style density management diagram. (See Appendix xx for detailed explanation.)

cords) per acre, 42% pulpwood and 58% studwood. Note that although the QMD of this thinning is smaller than the first thinning in the PCT scenario, the yields here are higher because trees are 20 feet taller and contain at least another two 8-foot sections. Piece size in this harvest is 25 trees per cord, compared to 36 trees per cord in the first thinning of the PCT scenario.

Figure 3.10 Densely stocked even-aged spruce-fir stand at age 40, about 10 years away from being operable by commercial thinning.

After 20 years (age 70), the stand reaches a RD = 56% and BA = 153 at a QMD of 8.1”. Another 35% thinning removal reduces RD to 35%, again a bit above the lower ZODM limit to maintain stand stability because the height-diameter ratio is still over 90. This thinning removed 151 TPA, yielding 1,751 cubic feet (20.6 cords) per acre, 10% pulpwood, 47% studwood, and 42% sawlogs. Because this stand is now old enough to bear seed, this entry could serve as the shelterwood establishment cutting. However, the stand could easily be carried another 20-30 years without sacrificing timber yield, with a final harvest at ages 90-100.

Many foresters believe that such dense stands without a history of PCT (Fig. 3.10) will stagnate by age 40 and will never be operable. Visually, such stands are dominated by thousands of small dead trees, but in reality, the stand is usually differentiating well and the merchantable trees are still growing, albeit not as rapidly in diameter as if PCT had been applied 30 years prior. By age 50, such stands will be operable with modern CTL harvesting systems and will yield high volumes of small-diameter wood. Clearcutting such stands at age 40 would yield about only 20 cords of very small and expensive-to-harvest wood (37 trees per cord), but the stand is still 25 years away from the peak MAI, and would not regenerate to conifers owing to a complete lack of advance regeneration in the stem-exclusion stage.

Transitioning to Shelterwood Regeneration

Once overstory trees reach seed-bearing age, any commercial thinning will also result in the establishment of advance regeneration of the overstory species. In the CTRN, fir-dominated stands treated with early commercial thinning had much more abundant small fir regeneration than unthinned treatments after ten years at age 30 (Olson et al. 2014). Spruce regeneration remained deficient there, but was abundant after CT in older (>age 50) spruce-dominated stands. In the archetype scenarios above, neither would have adequate advance regeneration after two commercial thinnings. Small fir advance growth would likely be present, but securing spruce in a competitive height class (see Regeneration Section) requires a third entry designed as a shelterwood establishment cutting.

Rotation Lengths

The final step in ensuring maximum yields is the timing of the final harvest to coincide with the peak mean annual increment (MAI). MAI quantifies the average annual yield over the rotation; it is calculated by adding the standing volume to any yields from past commercial thinnings, and then dividing by the stand age. Doing this repeatedly for advancing ages yields a peak, which is the rotation age that maximizes stand yield and produces the highest annual allowable harvest.

Fig. 3.11 shows the MAIs for the two scenarios above (green curves), compared to alternatives with the same stand origin (PCT or not) but with no commercial thinning (black curves). Regardless of stand origin, two commercial thinnings extend the age at which the peak occurs. CT also increases MAI slightly for PCT and over 0.2 cords per acre per year without PCT. Without

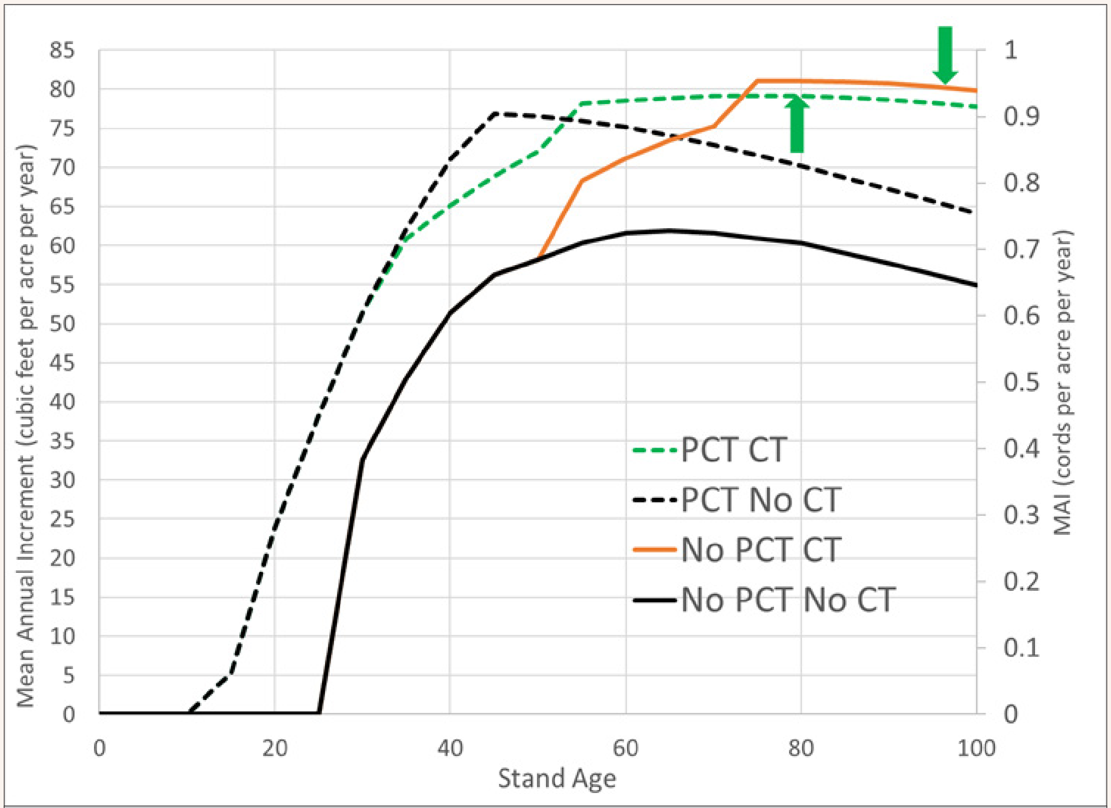

Figure 3.11 Comparisons in mean annual increments over a 100-year rotation for stands with and without precommercial and commercial thinning. Green arrows show suggested rotation ages that both maximize yields and allow for competitive red spruce regeneration.

CT, MAI peaks prematurely because stands enter the ZICM zone and experience mortality of merchantable trees. Note that the curves for the CT scenarios are quite flat, giving managers the flexibility to meet regeneration objectives by extending final harvests (green arrows, Fig. 3.11) long enough to ensure adequate, competitive red spruce regeneration without sacrificing yields.

Conclusions and Caveats

Both thinning schedules reviewed above will work in practice only if the stocking of species other than fir is sufficient to leave a RD of at least 30% after the thinning at age 50. Some fir can live longer, but this species is at high risk of loss from stem decays and mortality from the balsam woolly adelgid beyond this age. If the stand was PCTed, this objective is met by a density of 182 TPA (15-foot spacing), whereas without PCT, one would need 425 TPA (10-foot spacing), more than twice as many trees to stock the growing space adequately. This highlights the importance of favoring spruce over fir at every possible stage.

Thousands of acres were PCTed during the 1980s and 1990s with little or no discrimination against fir specified in the species-ranking prescription (Seymour 1992, Olson et al 2014). Thirty years later, as these stands were treated with commercial thinning, residual stocking of spruce and other species was insufficient to constitute a fully stocked residual stand. (Fig. 3.12). This exemplifies a crucial point about PCT prescriptions that attempt to favor spruce over fir with an inadequate relative height requirement. If the rule is "favor spruce if it is two-thirds as tall as a competing fir" and all the spruce are only half as tall as the fir, the PCT will effectively eliminate spruce. In such cases, either designate spruce as "invisible" (leave all spruces regardless of size, and space firs relative only to each other) or leave the stands untreated, as many spruces will survive and eventually outcompete the fir later in stand development.

Figure 3.12 Pure balsam fir stand at age 25, spaced when young without a prescription rule to favor spruce over fir.

Planting

Although natural regeneration of reproductively mature and well-stocked northern conifers is straightforward and dependable, there are cases where artificial regeneration better achieves forest production targets. Some stands become so heavily dominated by balsam fir that natural regeneration to other longer-lived conifers is not possible. Other stands once dominated by conifers but now occupied by off-site or transitional hardwoods can be restored only via artificial means. Large landowners primarily in northern Maine have been planting small acreages for over 40 years (Fig. 3.1), and related technologies and practices continue to evolve and improve.

Planting stock has long been dominated by containerized seedlings grown in greenhouses, primarily at production facilities in Canada where artificial regeneration is more common. Historically, seedlings were planted on fresh clearcuts with no site preparation other than slash removal during harvesting. Herbicide release was then applied two or three years later. Some owners also implemented cleanings with brush saws at age 10 to ensure that planted seedlings were free of competition from natural conifer regeneration and any hardwoods not controlled by the release treatment.

In recent years, site preparation has become more common. Although expensive, disc trenchers (Fig. 3.13) are effective at creating rows of scarified and mounded mineral soil at one dimension of the chosen plantation spacing. Planting in mineral soil is desirable for many reasons, including lack of local competition, better contact of roots to a stable supply of soil water, and prevention of attack by Hylobius congener, a seedling debarking weevil that thrives in fresh slash, stumps, and undisturbed organic soil horizons. Chemical site preparation is also now in use, with a mix of herbicides (oust, imazapyr) that eliminate all woody and herbaceous competition and thus eliminate the need for more costly silvicultural cleanings.

Figure 3.13 New white spruce plantation, established at a density of 700 trees per acre after site preparation with herbicides (to kill competing vegetation) and a disk trencher (to create favorable planting microsites). Inset shows disk trencher.

In northern Maine, all species of spruce, including the exotic Norway spruce (*Picea abies*) have been planted. White spruce is favored on most upland well-drained sites and is sometimes combined with red spruce. Norway spruce will out-yield the native spruces but will grow well only on the well-drained fertile uplands that naturally support northern hardwoods. Black spruce was formerly planted widely owing to its greater resistance to spruce budworm, but is now limited to more poorly drained sites that did not regenerate naturally.

The density at which plantations are established has consistently ranged between 700-900 TPA, based on stocking guides and density management diagrams (Wilson et al 1999) that show stands at this density begin to self-thin at about 5 inches QMD, the point at which commercial thinning can be implemented if markets for small diameter trees are available. The almost complete loss of spruce-fir pulpwood markets has led to planting and spacing densities at the lower end of this range, which will produce slightly larger 6-inch dbh trees at the time of the first commercial thinning. Lower densities also foster lower commercial thinning costs (owing to larger piece size) and improved windfirmness owing to their lower H/D ratios.

Artificial regeneration of northern conifers is a highly specialized discipline involving genetic improvement, seed production and collection, nursery and greenhouse culture, logistics of seedling handling, and hiring and managing planting contractors. Those interested in pursuing these details should consult reference works covering these and other topics in more detail (e.g., Wagner and Colombo 2001).

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2024

Production Forestry, Managing for High Timber Yields

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