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SILVICULTURE FOR ACADIAN SPRUCE-FIR FORESTS

Mult-aged Silviculture Systems

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Silviculture for Acadian Spruce-Fir Forests No. 6

Multiaged Silvicultural Systems

The silvicultural system is a planned sequence of treatments for a forest stand over the lifespan of the dominant tree species. Systems are classified mainly by the age structure of the stand to be created and maintained, and secondarily, by the regeneration method employed. Older publications (Frank and Bjorkbom 1974) considered only the polar ends of the age spectrum: either even-aged structures managed with intensive thinnings for production, or all-aged structures managed according to a balanced dbh distribution using the BDq approach (O'Hara 2014). As practice has become more sophisticated and ecologically grounded over the past three decades, it has become apparent that most viable approaches lie between these extremes, typically multi-aged systems (Ashton and Kelty 2018) that maintain two or three cohorts and a mixed species composition adapted to the site (Seymour 2024a).

Even-aged systems designed for high yields of commodities are covered in the Production Forestry section (No. 3) of this series. Here, we focus on systems intended to restore and maintain diversity in composition and structure, with wood production as one of many objectives. There are four basic options, covered in order of structural complexity from the simplest to most elaborate. Terminology follows Raymond et al. (2009) and Ashton and Kelty (2018), based on the number of age cohorts maintained and their spatial pattern. Systems based on the clearcutting or seed-tree regeneration methods are not considered for reasons discussed in the Natural Regeneration section (No. 5) of this series.

Option A. Extended Shelterwood with Reserves *(two cohorts)*

This option maintains a two-aged stand structure in which stocking is dominated by the younger cohort (Raymond et al 2009). Thinnings and other intermediate treatments are directed at the younger, dominant cohort as if it were essentially a single-cohort stand. Regeneration is recruited via an establishment cutting that is applied uniformly throughout the stand. Once regeneration reaches sapling size, an incomplete overstory removal cutting (OSR) is made, leaving reserve trees selected from the older cohort (Fig. 6.1). The OSR is designed to capture any non-LIT species that have reached ecological maturity, and optionally, any now-mature older trees that may have been left by the previous OSR one rotation

Figure 6.1. Two-aged variant of the irregular shelterwood system, with well stocked sapling layer and scattered large reserve trees.

previous. Reserves are of two types: ecologically or financially immature trees of LIT (long-lived, intermediate or tolerant) species that will remain windfirm and develop into seedbearing status, and larger (and likely older) legacy trees left in prior disturbances. Immature reserves can be harvested in future entries once mature; larger legacy trees are retained permanently. Stocking of reserves is typically below 30% relative density, in the low-density management zone of the stocking guide.

If residual stocking of immature growing stock exceeds 30%, then this cohort may dominate post-OSR stocking after 10-20 years. Such a treatment sequence and condition are more aptly categorized under the continuous cover variant (Option B).

Option B. Continuous-Cover Irregular Shelterwood *(three cohorts)*

The continuous-cover variant is arguably the most flexible and commonly applied option, though until recently, such practices have been labeled differently. Its European analogue is the Swiss femelschlag (Spurr 1956; Puettman et al. 2008). No single cohort dominates the stocking. Stand entries have both tending and regeneration objectives, like all multi-aged silvicultural systems. Cutting cycles are irregular; entries are made as driven by the condition of the growing stock and to maintain free-growing regeneration, not by any fixed schedule. Although horizontal structure can be patchy with small gaps scattered about, such gaps are not the focus as in Option C (Fig. 6.2).

This system naturally results from a silvicultural paradigm focused on favoring immature growing stock while capturing volume and value in short-lived non-LIT species (fir, paper birch), implemented by individual tree marking. No specific quantitative targets are needed; foresters strive to achieve some stocking of high-quality trees in the sawtimber (oldest cohort), poletimber (middle cohort), and tall advance regeneration (youngest cohort). Because the areas of each are not balanced (unlike selection variants), harvest yields will be irregular over time. Harvests would rarely exceed 50% of the preharvest relative density, and thus maintain windfirm residual structures.

Figure 6.2. Continuous cover variant of the irregular shelterwood, where the older, mature cohorts dominate stocking but sapling regeneration is also continuously present and recruited at each cutting cycle.

To promote biodiversity objectives, permanent reserves should be retained to provide habitat features, enhance carbon storage, and provide future inputs to the downed wood pool. If the relative density of such trees reaches 10% or more, such stands will have value as late-successional habitat while still maintaining moderate timber incomes.

Continuous cover treatments are best suited for stands that already have an irregular height structure with at least two cohorts having significant stocking. More uniform stands are best treated with either Option A or C, which can then transition to this variant over future rotations.

Prescription elements for continuous-cover treatments include a species-specific marking guide that defines the kinds of trees to favor or remove, and the percentage of each to remove. Patches of well established regeneration should be released, but such areas should never be the dominant condition over the stand. If that occurs or is inevitable, then such stands should be considered under Option A.

Option C. Gap-based Irregular Group Shelterwood *(three or more cohorts)*

Under the gap-based variant, advance regeneration is recruited in defined gaps within the stand, rather than uniformly throughout. Instead of stand age structure changing temporally as in a uniform shelterwood, group shelterwood systems vary spatially, and can contain all stages of the shelterwood sequence: unregenerated matrix awaiting treatment; two-storied patches following establishment cutting; and free-to-grow sapling regeneration after removal of the overstory except reserves (Fig. 6.3). These conditions also prevail in the continuous-cover variant, but at a finer scale that is not mappable or tracked over time.

It is essential to retain a light to moderate stocking of residual trees in gaps as they are regenerated (Fig. 6.4). Some trees may be retained long-term as reserves; others are left as temporary overwood to provide shade and seed sources where regeneration is not well established. If tall advance regeneration of northern conifer LIT species is not present, then retention in the gaps should be sufficient to ensure that no spots are in direct sunlight for very long during mid-day, to prevent drying of the soil surface and assist in seedling survival and establishment. Experience has shown that retention in gaps can be much lower (10-30%) than in larger blocks and yet remain windfirm (Carter et al 2017).

Gap-based irregular shelterwoods are best suited to situations where the goal is to convert uniform, single-cohort stands to a multiaged structure over several cutting cycles. It is also

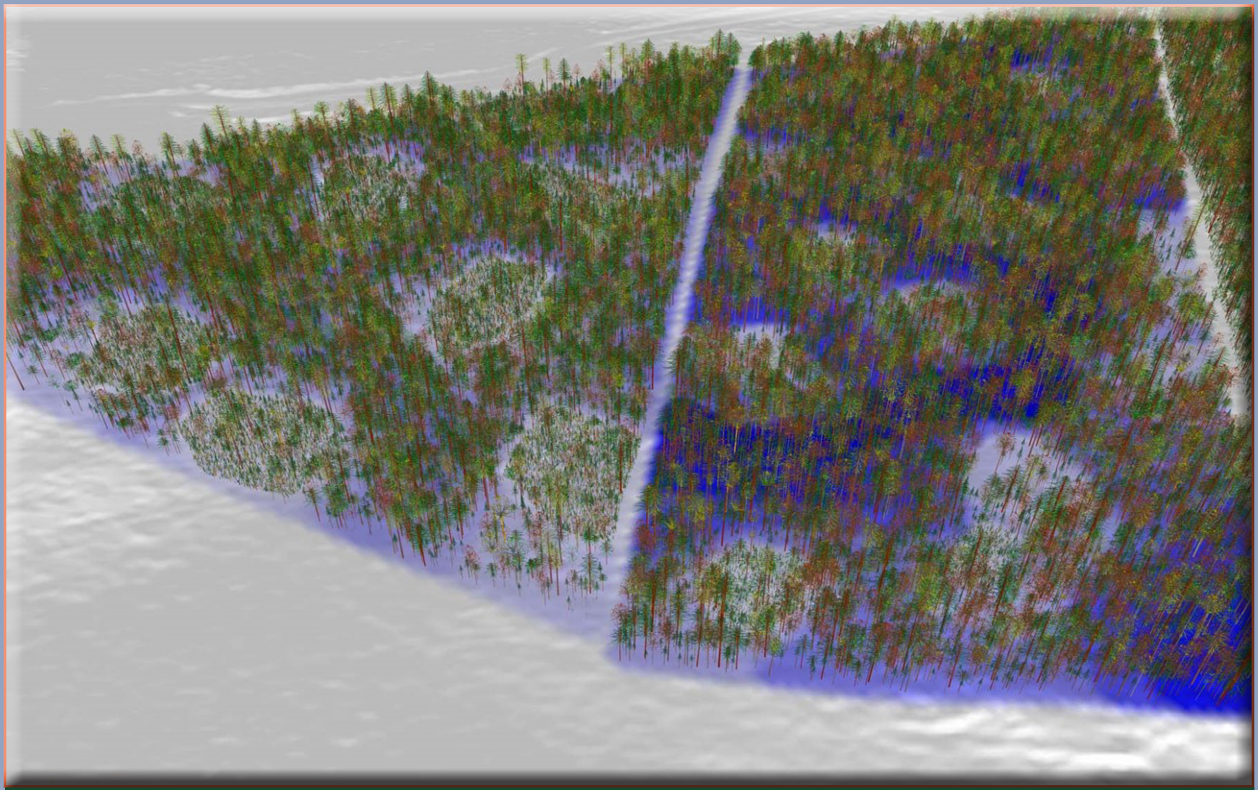

Figure 6.3. Spatial pattern of cohorts in an expanding gap, irregular group shelterwood variant.

well suited for stands where advance regeneration has become established in distinct gaps as a result of past disturbances or gap harvests. Because the conversion to young cohorts will take many decades, the residual matrix forest must be dominated by LIT species. If the conversion is scheduled over a period of five or more cutting cycles (thus creating five or more cohorts), and gaps are small and very numerous, this should be considered an example of the group selection system (Option D).

Prescription elements must include the percentage of stand area to become harvest gaps, the sizes of gaps (best expressed as a range, not a fixed value), the stocking and composition of gap retention trees, and whether the matrix area between gaps is also to be treated. The cutting cycle is also a variable and need not be a constant; this choice will determine how widely or closely spaced in time the future age cohorts develop. Marking and layout are simpler than other variants because the focus is solely on harvest gaps and the retention therein.

Although not essential, gap-based systems demonstrate several advantages if the initial gaps are expanded in future entries rather than creating new gaps in other portions of the stand. Ecologically, such expansion takes advantage of "edge effects" whereby advance regeneration develops in the diffuse light zones around the gap periphery. Operationally, harvesting machinery does not travel within areas of established regeneration, resulting in much less damage than in a typical OSR of a uniform shelterwood where 15-20% may be lost. European foresters have long applied such a system, known as the Bavarian femelschlag, in which the groups under regeneration are expanded at each entry until they coalesce (Spurr 1956). The AFERP study on the Penobscot Experimental Forest provides a long-term example of this system known as the Acadian femelschlag that illustrates these advantages (Seymour 2024a).

Figure 6.4. Retention of spruce reserve trees in a gap under regeneration

Option D. Balanced Selection Cutting (Single-tree, Group; four or more cohorts)

The options described above are relatively simple approaches to multi-aged silviculture in northern conifers that take advantage of their different longevities and shade tolerance without undue operational complications in prescription, layout, and harvesting, and as such, are adequate for most purposes on larger ownerships. However, they are only crude approximations of the natural dynamics of these forests which may have 10-20 cohorts in an old-growth stand (Fraver et al. 2009; see Section 7 of this series, Ecological Forestry). Also, because their within-stand age structures are not balanced (equal areas in every cohort, equally spaced in time), individual stands will not produce regular harvests. If rigorous emulation of natural disturbances or sustained yield of products is a stand-level objective, then selection cutting is the only system that will suffice.

Selection systems are classified into two variants: single-tree selection, in which the separate age cohorts develop in the space left by the removal of a single mature tree, or group selection, where age cohorts are aggregated within the area of several large trees. Groups can range up to about 0.1 acre, the area of a circular opening of about one tree height in diameter, which

Figure 6.5. Small group selection cutting on the Umbagog National Wildlife Refuge.

will maintain some shade over the entire zone at all times. Openings could of course be larger with appropriate retention within, as described above for the gap-based shelterwood variant.

Selection systems present operational issues that do not arise with irregular shelterwood variants, owing primarily to the need to create many regularly spaced (in time) age cohorts within the effective rotation of the largest trees being grown. For example, if the goal is to create a stand structure with age cohorts ten years apart, with a species that requires 120 years to mature, then each cohort would occupy 8.3% of the stand area once the stand reached balance. Harvesting this small percentage on a short 10-year cutting cycle is very difficult with contemporary harvesting systems. Extending the cutting cycle to 15 years, and reducing the number of planned cohorts to eight, is probably the minimum viable option.

Marking and layout of group selection treatments (Fig. 6.5) requires the forester to keep a running tally of the number and area in groups so that the desired target (e.g., 15%) is met. Groups should be concentrated in areas of mature growing stock with advance regeneration present so that they regenerate promptly. Unlike Option C, individual groups are generally not mapped or tracked over time because they are too numerous and small to relocate. The unregenerated matrix forest between groups is also tended, but should not be thinned below about 40% relative density to inhibit or delay regeneration there. If the matrix is harvested more heavily, the entire stand will become like a uniform shelterwood and thus difficult to create and maintain the desired age diversity.

Single-tree selection cuttings are the most complex multi-aged silvicultural option. Areas are not tracked, so dbh is used as a surrogate for age, under the presumption (that is often false) that large trees are old and small trees are young. The prescription process requires a detailed pre-harvest stand table which is compared to a so-called target structure, typically expressed as a stand table by two-inch dbh classes (Nyland 20007). The target structure has often been

Figure 6.6. Single-tree selection system after 9 entries on a 5-year cutting cycle on the Penobscot Experimental Forest.

defined as a negative exponential distribution with a constant ratio (the "q-factor") between adjacent classes, although there is no special biological rationale supporting such a method (O'Hara 2014, Ashton and Kelty 2018). If the actual stocking in a two-inch dbh class exceeds the target value, then a removal percentage is calculated and applied during marking. Sometimes classes are grouped into larger (four or six-inch dbh classes) and converted to basal area to simplify the marking. The target structure also has a total stocking (usually basal area) and maximum dbh that serve as overall constraints during marking.

The long-term sustainability of single-tree selection systems is governed by the recruitment into the sapling dbh classes and their subsequent ingrowth into merchantable poletimber. After 40 years of single-tree selection at the Penobscot Experimental Forest, the poletimber size classes showed a deficit (Seymour and Kenefic 1998; Fig. 6.6), but more recent assessments show this deficit has lessened if individual species are not considered. Saplings are heavily dominated by hemlock and fir despite 70 years of favoring large red spruces in the sawtimber size classes.

Decision Criteria

The choices among silvicultural systems must be informed by many ecological factors, and tempered by operational constraints. Before prescribing treatments, foresters should assess the following:

1. Site Quality
   a. Determine soil drainage and position on catena – are hardwoods adapted? Wetlands?
2. Number of age cohorts (height classes) present

3. Stocking of all species and LIT species
   a. If overall relative density > 50%, then self-thinning is imminent
   b. Is some kind of partial entry (<50%) possible leaving at least 30% relative density of LIT species?
   c. If LIT stocking is low, is the goal to improve it artificially if needed via enrichment planting?
4. Presence of advance regeneration
   a. None (stem exclusion)
   b. Uniform
   c. Patchy
5. Ecological maturity and health of older cohorts
   a. Is some kind of entry warranted immediately, or can it wait?
6. Danger of wind damage from partial harvesting
   a. h/D ratio of upper crown classes
   b. soil drainage
   c. landscape exposure
7. Quality of growing stock
8. Presence of "special features" (snags, legacy trees, large down wood, etc)
9. Availability of suitable logging systems (are light harvests feasible?)
   a. D and E require the ability to cut no more than 25% per entry, ideally less, without losses for trails.

Given the complex interactions of the above criteria, it is not possible to create a detailed rubric of recommended choices. In general, the more complex systems will yield greater biodiversity benefits, higher timber yields, and greater carbon storage over time than the simplest system (option A). The three-cohort irregular shelterwood systems (B and C) are simpler to implement and maintain than the more complex selection systems and may be sufficient for most situations. However, if close emulation of natural patterns is paramount, then some kind of selection system with more than three cohorts (Option D) is essential because northern conifer forests experiencing natural gap dynamics have many more cohorts than this.

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