# Managing For Old-Growth Structure in Northern Hardwood Forests

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**Introduction**

Recent research on sustainable forestry in the northern hardwood region of the United States and Canada has focused on "structure" (Keeton 2004) or "disturbance-based" (Seymour et al. 2002) silvicultural approaches. This includes managing for late-successional forests, which are vastly under-represented relative to the historic range of variability for this region (Mladenoff and Pastor 1993, Cogbill 2000, Lorimer 2001). An untested hypothesis is that silviculatural practices can accelerate rates of late-successional forest stand development (Franklin et al. 2002), promote desired structural characteristics, and enhance associated ecosystem functions more than conventional systems. I am testing this hypothesis using an approach, termed "Structural Complexity Enhancement (SCE), that promotes old-growth characteristics (Tyrrell and Crow 1994b, McGee et al. 1999) while also providing opportunities for timber harvest (Table 1). SCE is compared against two conventional uneven-aged systems advocated regionally for sustainable forestry (Mladenoff and Pastor 1993, Nyland 1998).

**Table 1**. Structural objectives and the corresponding silvicultural techniques used to promote those attributes in Structural Complexity Enhancement

| Structural Objective | Silvicultural Technique |
|---|---|
| Multi-layered canopy | • Single tree selection using a target diameter distribution<br>• Release advanced regeneration<br>• Establish new cohort |
| Elevated large snag densities | • Girdling of selected medium to large sized, low vigor trees |
| Elevated downed woody debris densities and volume | • Felling and leaving, or<br>• Pulling over and leaving |
| Variable horizontal density | • Harvest trees clustered around "release trees"<br>• Variable density marking |
| Re-allocation of basal area to larger diameter classes | • Rotated sigmoid diameter distribution<br>• High target basal area (34 $m^2$/ha.)<br>• Maximum target tree size set at 90 cm dbh |
| Accelerated growth in largest trees | • Full and partial crown release of largest, healthiest trees |

The objectives of SCE include multi-layered canopies, elevated large snag and downed coarse woody debris (CWD) densities, variable horizontal density, and re-allocation of basal area to larger diameter classes. The later objective is achieved, in part, using an unconventional marking guide based on a rotated sigmoid target diameter distribution. Rotated sigmoid diameter distributions have been widely discussed in the theoretical literature (O'Hara 1998), but their silvicultural utility has not been field tested. Sigmoidal form is one of several possible distributions in eastern old-growth forests (Leak 1996 and 2002, Goodburn and Lorimer 1999). These vary with disturbance history, species composition, and competitive dynamics. The distribution offers advantages for late-successional structural management because it allocates more growing space and basal area to larger trees. If the rotated sigmoid distribution proves sustainable in terms of recruitment, growth, and yield, it would suggest that silviculturalists have greater flexibility in managing stand structure, biodiversity, and other ecosystem functions in the northern forest region than previously recognized.

**Methods**

The study is replicated at two mature, multi-aged, northern hardwood forests in Vermont. There are three experimental manipulations. The first two are conventional uneven-aged systems (single-tree selection and group-selection) modified to increase post-harvest structural retention and to represent best available practices. Prescriptions are based on a target residual basal area of 18.4 $m^2$/ha, max. diameter of 60 cm, and q-factor of 1.3. Group-selection cutting patches are each approximately 0.05 ha in size. The third treatment is Structural Complexity Enhancement (SCE). The marking guide is based on a rotated sigmoid target diameter distribution applied as a non-constant q-factor. The marking guide is also derived from a target basal area (34 $m^2$/ha.) and maximum diameter at breast height (90 cm) indicative of old-growth structure. Accelerated growth in larger trees is promoted through full (4 or 3-sided) and partial (2-sided) crown release. Prescriptions for enhancing snag and downed woody debris volume and density are based on pre-harvest CWD volume and literature-derived targets. On one SCE unit at each of the two study area, downed logs are created by pulling trees over, rather than felling, to create pits and exposed root wads.

Each of the first two treatments (uneven-aged) is replicated twice; the third (SCE) is replicated four times. Two un-manipulated control units are located at each of the two study areas. Treatment units are 2 ha in size and separated by 50 meter (min.) buffers. Experimental manipulations (i.e. logging) were conducted on frozen ground in winter 2003. Sample data were collected from five 0.1 ha permanent sampling plots established in each treatment unit. Forest structure data, including leaf area index (LAI), detailed measurements of individual trees, and coarse woody debris (CWD) densities and volumes, have been collected over two years pretreatment and two years post-treatment. A before/after/control statistical approach was used to analyze sample data. Fifty year simulations of stand development were run in NE-TWIGS, comparing alternate treatments and no treatment scenarios.

## Results

### *Residual stand structure*

Post-harvest basal area, relative density, canopy closure, and LAI were significantly *(*$\alpha = 0.05$*)* higher under SCE. Canopy closure was most variable across group-selection units. There were significant differences ($P < 0.001$) in LAI responses among treatments. Single-tree and group selection cuts reduced LAI by 19.8 and 29.9% respectively. LAI reductions were lowest in SCE units (9.4%), indicating high retention of vertical complexity. LAI was significantly more spatially variable for both SCE ($P = 0.031$) and group-selection ($P = 0.010$) compared to single tree selection; within-treatment variance was not significantly different between SCE and group-selection units ($P = 0.296$). These results are indicative of the high degree of horizontal structural variability expected for both group-selection and SCE, achieved in the later through variable density marking and clustered harvesting around crown-release trees. SCE shifted residual diameter distributions to a form statistically indistinguishable from the target rotated sigmoid form. Continued reallocations of basal area and stem density into larger size classes, yielding a rotated sigmoid distribution spanning a full range of diameter classes, are thus likely over time.

### *Crown release and vertical development*

Marking guides were used to crown release 45 dominant trees per ha. on average in SCE units. When combined with the average pre-treatment number (20 per ha) of large trees (> 50 cm dbh), this exceeds our future target of 55 large trees per ha. The excess provides a "margin of safety" to accommodate canopy mortality. Crown release is likely to accelerate growth rates in the affected dominant trees by 50% or more based on previous modeling (e.g. Singer and Lorimer 1997). Crown release also resulted in spatial aggregations of harvested trees, creating canopy openings and variable tree densities. Elevated light availability associated with this effect is likely to promote vertical differentiation of the canopy through release and regeneration effects.

### *Coarse woody debris enhancement*

SCE prescriptions resulted in substantially elevated densities of both downed coarse woody debris and standing snags. The structural complexity enhancement treatments increased coarse woody debris (> 30 cm dbh) densities, on average, by 10 boles/ha for snags and 12 boles/ha for downed logs. Snags were created primarily by girdling diseased, dying, or poorly formed trees. Pulling trees over was successful in most cases at creating large exposed root wads and pits. There were statistically significant differences ($P = 0.002$) between treatments with respect to downed CWD recruitment. Post-harvest CWD (logs > 10 cm diameter) volumes were 140% higher on average than pre-harvest levels in SCE units; mean CWD volume increased 30% in conventional uneven-aged units.

### *Projected stand development*

Stand development projections suggest that total basal area under SCE will, on average, approach 34 $m^2$/ha after 50 years of development. This is >50 % higher than the mean for the conventional uneven-aged units. However, this difference is an artifact of the higher residual basal area left by SCE. The projections showed no significant differences in absolute growth rates between treatment scenarios. However, when projected development is normalized against the null scenario (development expected with no treatment), the simulations indicate that conventional systems increase cumulative basal area increment (CBAI) more, at least at the stand level. Both SCE ($P < 0.05$) and conventional treatments ($P < 0.01$) are projected to significantly accelerate tree growth rates above that expected with no treatment based on NE-TWIGS modeling. SCE is projected to significantly enhance rates of large tree recruitment over no treatment scenarios. There will be an average of 17 more large trees (> 50 cm dbh) per ha than there would have been without treatment after 50 years in SCE units. There will be 29 fewer large trees/ha on average in the conventional units than would have developed in the absence of timber harvesting.

**Discussion**

Silvicultural techniques can be used effectively to promote old-growth structural characteristics in northern hardwood and mixed northern hardwood-conifer forests. Both the uneven-aged and structural complexity enhancement (SCE) systems tested maintain high levels of post-harvest structure and canopy cover. However, SCE maintains, enhances, or accelerates develop of CWD, canopy layering, overstory biomass, large tree recruitment, and other structural attributes to a greater degree. The higher levels of structural retention associated with SCE are indicative of lower intensity, minimal impact forestry practices.

Both SCE and conventional uneven-aged treatments will result in accelerated tree growth rates according to NE-TWIGS projections. Since the conventional treatments had significantly lower residual basal areas, this result is consistent with previous research on growth responses to stocking density in northern hardwoods (Leak et al. 1987). However, an important effect of SCE is the promotion of large tree recruitment, whereas this process is impaired under conventional treatments that include maximum diameter limits. Projected basal area is also higher after 50 years of development under SCE due to greater post-harvest structural retention.

SCE resulted in significantly elevated CWD densities and volumes. However, it remains uncertain whether this effect will persist until natural recruitment rates increase, or, alternatively, whether CWD enhancement in mature stands has only transient or short-term management applications. Most of the newly added CWD is un-decayed. It is likely than decay class distributions will shift over time towards well-decayed material. As time passes, this will render silviculturally enhanced CWD increasing available as habitat and as a nutrient source (Gore and Patterson 1985, Tyrrell and Crow 1994a).

**Table 2.** Potential applications of SCE as an approach to incorporating old-growth structure into managed forests

SCE has a variety of useful applications, ranging from restoration to low intensity timber management. However, the degree of implementation and the number of stand entries will vary by application (Table 2). Forest managers have the flexibility to manage for a wide range of structural characteristics and associated ecosystem functions. Uneven-aged systems provide some but not all of these or provide them to a more limited extent. Maximum diameter limits significantly retard the potential for large tree (live and dead) recruitment based on the results. Stand development is thus continuously truncated by multiple uneven-aged cutting entries. The results show that SCE's marking guide can be used to successfully achieve a rotated sigmoid diameter distribution. Unconventional prescriptive diameter distributions, such as the rotated sigmoid, combined with higher levels of residual basal area, very large (or no) maximum diameters, and crown release are alternatives for retaining high levels of post-harvest structure and for promoting accelerated stand development.

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