Productivity and financial viability of natural disturbance-based management in the Acadian Forest

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Natural disturbance-based silvicultural systems that group removals into small gaps create a significant amount of interior edges that increase growth of remaining trees and promote advance regeneration. These growth increases make these systems comparable to traditional even- and uneven-age systems in merchantable yields over a rotation.

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Project Summary

In eastern forests, silvicultural systems that are designed to emulate natural disturbance regimes are implemented by removal of individual or small groups of trees that create canopy gaps in the forests. These gaps inherently increase growth of trees along the edge of gaps and promote regeneration well into the uncut matrix. The importance of accounting for edge creation from canopy openings when modeling long-term forest dynamics of natural disturbance-based silvicultural (NDBS) systems is not well understood . This has been a barrier to wider implementation of NDBS systems by some public and many private land managers. To address this issue, we used data from the Acadian Forest Ecosystem Research Program, a long-term, NDBS experiment in the Penobscot Experimental Forest in Bradley, ME, that uses expanding canopy gaps to approximate the natural disturbance patterns of northeastern United States and eastern Canada. We combined use of resampling methods and forest simulation models, namely the northeast variant of Forest Vegetation Simulator (FVS-NE), to estimate: 1) the proportion of a stand that lies in close proximity to a harvest gaps (i.e., an edge) that may experience increase growth and regeneration response; 2) the impact of a range of increased growth rates in edges on the long-term forest dynamics of NDBS systems; and 3) the resulting potential production and financial returns of NDBS systems relative to conventional even- and uneven-aged systems.

Observed growth from the AFERP over its first 10 years showed that there were pronounced increases within-stand differences in growth and regeneration patterns by position relative to harvest gaps edges. For example, although it varied significantly by species, edge conditions increased growth of trees and regeneration by 20% over the rates in the uncut matrix. Simulations of edge dynamics differed markedly between the two expanding-gap systems, but edge conditions could occur across as much as 52% of the stand area and those conditions could persist for multiple cutting cycles. Therefore, accounting for differences in edge creation patterns over time and increased edge growth rates in gap-based NDBS systems should have significant effects on long-term yields.

However, we observed only increases in projected yields of merchantable products in long-term stand dynamics projections using FVS-NE. These increases are likely severely understated due to limitations in the current FVS model structure. Despite these limitations, our preliminary production and financial analysis of gap-based NDBS systems suggests they will likely be a viable forest management tool capable of yielding competitive returns relative to conventional even- and uneven-aged treatments in the Northern Forest Region.

Background and Justification:
The Case for NDBS Systems

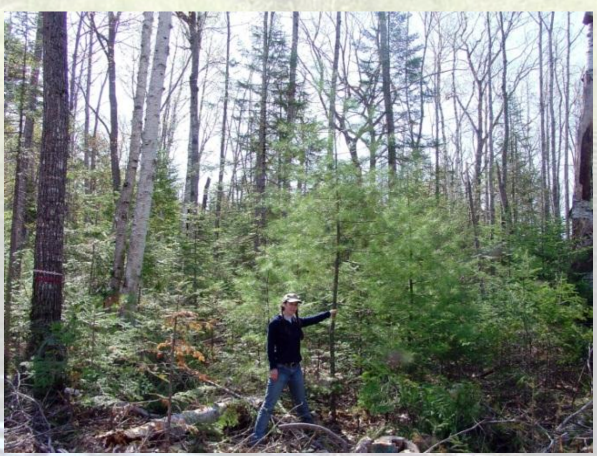
Concerns over biodiversity have spurred interest in developing silvicultural systems that increases the variability of structures, and resulting habitats, across the landscape (Seymour and Hunter 1999, Seymour et al. 2006, Long 2009). This has led to a paradigm shift on some public lands where management now avoids the regulated structures that have been demonstrated to provide sustained timber flow, to structures that are based on patterns of natural disturbances in those systems. Conceptually, these natural disturbance-based silvicultural (NDBS) systems are thought to act as a course-filter approach to biodiversity conservation in that ecosystems managed to disturbance-adapted species assemblages will result in higher ecosystem resilience (Drever et al. 2006, Long 2009).

However, justification for NDBS systems rarely mentions sustainable production of timber or any other commodity goods from the forest (Seymour et al. 2006). This may be in part to the complexity of modeling NDBS behavior with our growth and yield models; these contemporary systems do not have the long-term growth and yield data that traditional, more uniformly applied systems do. This disconnect between ecological theory and economic reality has resulted in little application of NDBS systems by some public agencies and most of the private sector. There exists a large need to demonstrate the socioeconomic feasibility of NDBS systems in many parts of North America (Long 2009).

Background and Justification:
The Importance of Gaps

Within northeastern forests, disturbance regimes are predominately at a intra-stand scale, creating small canopy gaps by the death of individual to groups of trees. These gap-creating disturbances occur on a 50-200 year return interval and are dispersed randomly across the landscape (Fraver et al. 2007, Runkle 1982, D'Amato and Orwig 2008).

To emulate this pattern, gap-based NDBS systems have been employed. Studies of responses within canopy gaps are common, generally confirming that gaps greatly increase growth of regeneration, but there is a dearth of research on the responses of regeneration and overstory trees in edges around these gaps. These "low-contrast" edges likely respond quite differently than those studies in high-contrast forest ecotones that transition from forests to grassland, agricultural fields and other non-forested conditions.



Gaps create conditions not only in the gap, but in the uncut edge (left) that increase growth of advanced regeneration.

Banal et al. (2007) estimated that canopy gaps increased growth of understory saplings in areas adjacent to the gap by 30-210% (right).

Table 2 – Basal area growth of saplings, 5 years after the introduction of gaps

	Gap density			
	10%	20%	35%	50%
Sapling basal area (m^2)				
BA with gaps 310	12.7	14.5	17.3	21.8
BA control 310	11.2	11.2	11.2	11.3
BA 305	6.2	6.2	6.3	6.3
BA growth added by gaps	30.0	66.0	124.5	210.0

The values represent the average for the 10 replicates, and are calculated from Eq. (1).

Background and Justification:

A Modeling Disconnect

Recently harvest gap (foreground) and uncut matrix (background) conditions within a stand are normally averaged by FVS for projections.

Many of our current growth and yield models are unable to easily simulate gap behavior without extensive calibration. For example, our most widely used forest growth and yield model, the Forest Vegetation Simulator (FVS), is aspatial and makes the inherent assumption that intra-stand variability has negligible impacts on long-term stand dynamics. Although FVS has been quite adequate for predicting growth for many uniformly applied silviculture systems, as heterogenity increases in composition, time and space, such as for many NDBS systems, FVS's predictions become increasingly suspect. Spatial models do exist (e.g., SORTIE), but they are not commonly used by forest managers because they often emphasize succession or physiology, have costly data requirements, lack allometric and economic components, have limited harvest options and/or are at the inappropriate scale.

Study Objectives

We addressed the following questions:

1. How much interior edge is created in complex, gap-based, NDBS systems?

2. Do edge-induced growth increases affect growth and yield predictions for those systems over the course of a rotation?

3. What are the resulting estimates of production and financial returns of NDBS systems relative to conventional even- and uneven-aged systems?

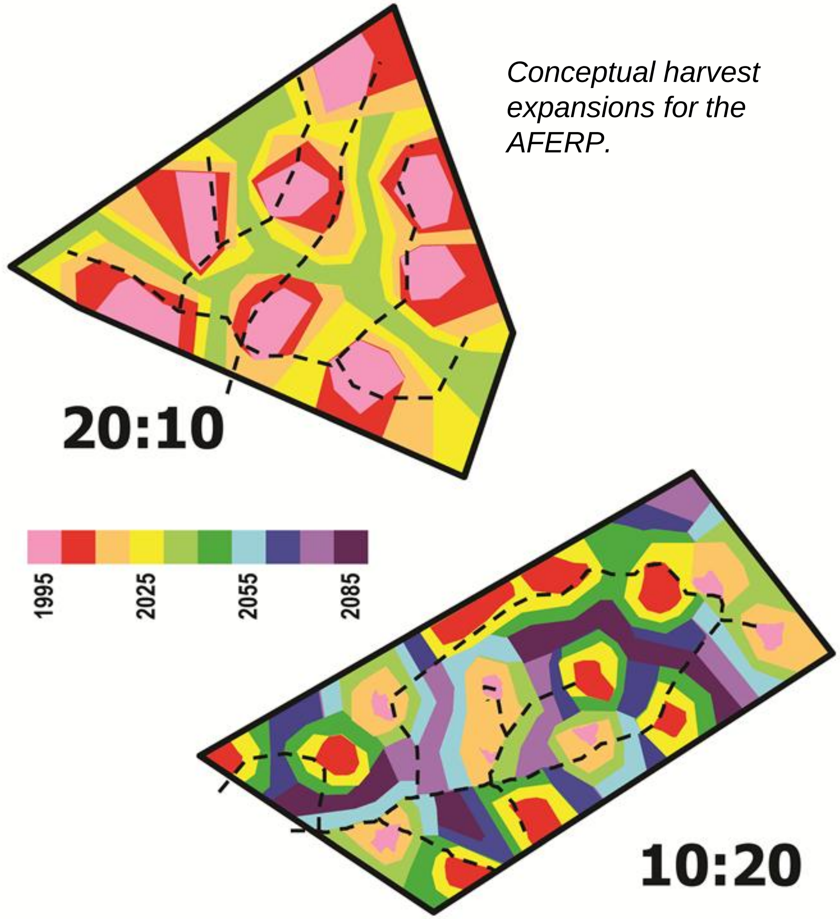
Methods:
Study Area

The Acadian Forest Ecosystem Research Program (AFERP) is the longest-running example of NDBS in the Northern Forest Region. Located in the Penobscot Experimental Forest near Bradley, ME, AFERP has three replicated treatments, both implemented on a 100-yr rotation and with 10-year cutting cycles:

- 20:10 – 20% of stand harvested for first 5 entries in 0.2 ha gaps or expansions. Stand rests for last 5 entries.
- 10:20 – 10% of stand harvested in 0.1 ha gaps or expansions. Expansions alternate between two gap cohorts.
- Unharvested control

Both harvest treatments make explicit allowances for retention of structure; 10% of pretreatment basal area (~3.7 m^2 ha^{-1}) is reserved long-term, with an additional 20-60% retained for special features (e.g., vernal pools) or regeneration.

Additional details of AFERP design and inventory systems can be found in Saunders et al. (2005, 2012).



Conceptual harvest expansions for the AFERP.

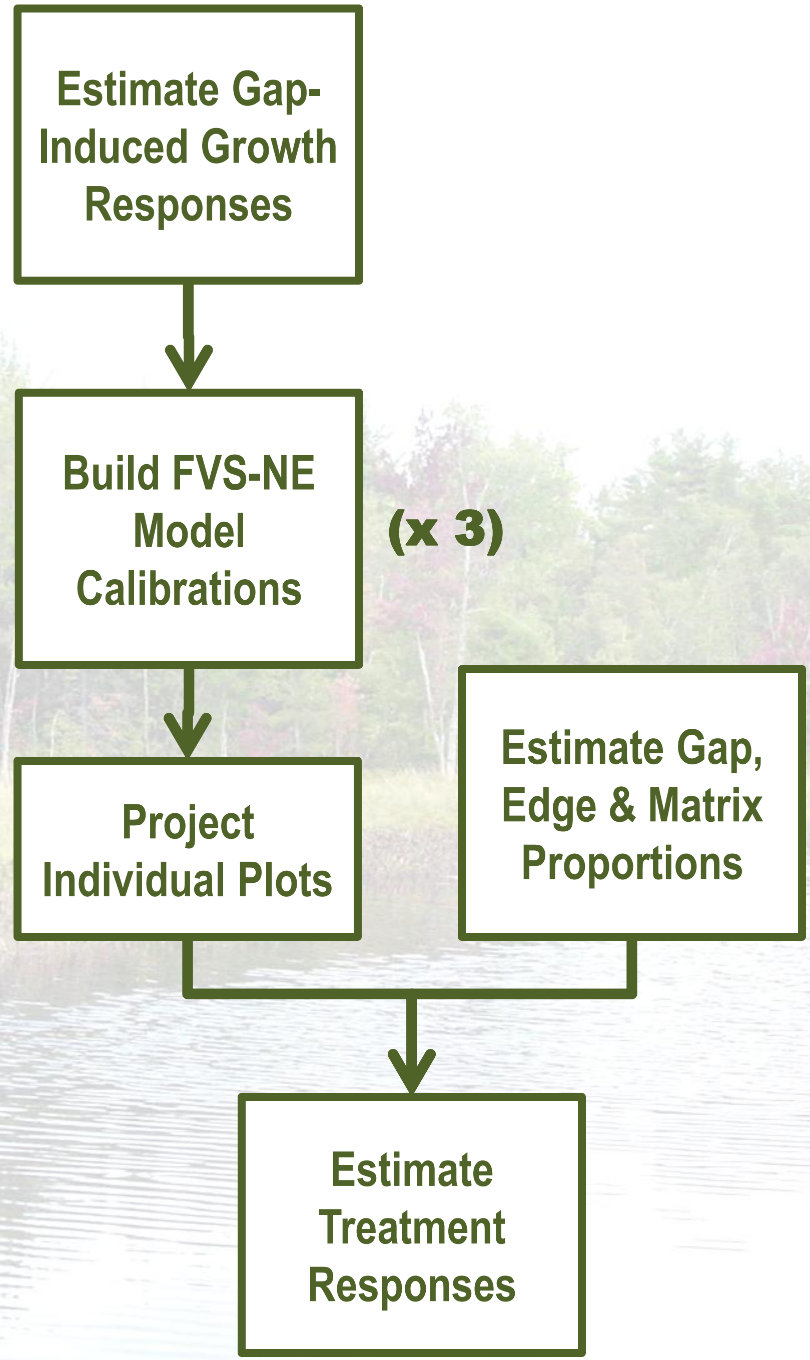
Closeup view from the ground (left) and above (below) of AFERP gaps.

Methods:
Modeling Overview

Data from the first ten years of AFERP was used to calibrate the northeast variant of FVS (FVS-NE) for comparing longer-term stand development patterns, including rotation-length yields and financial performance.

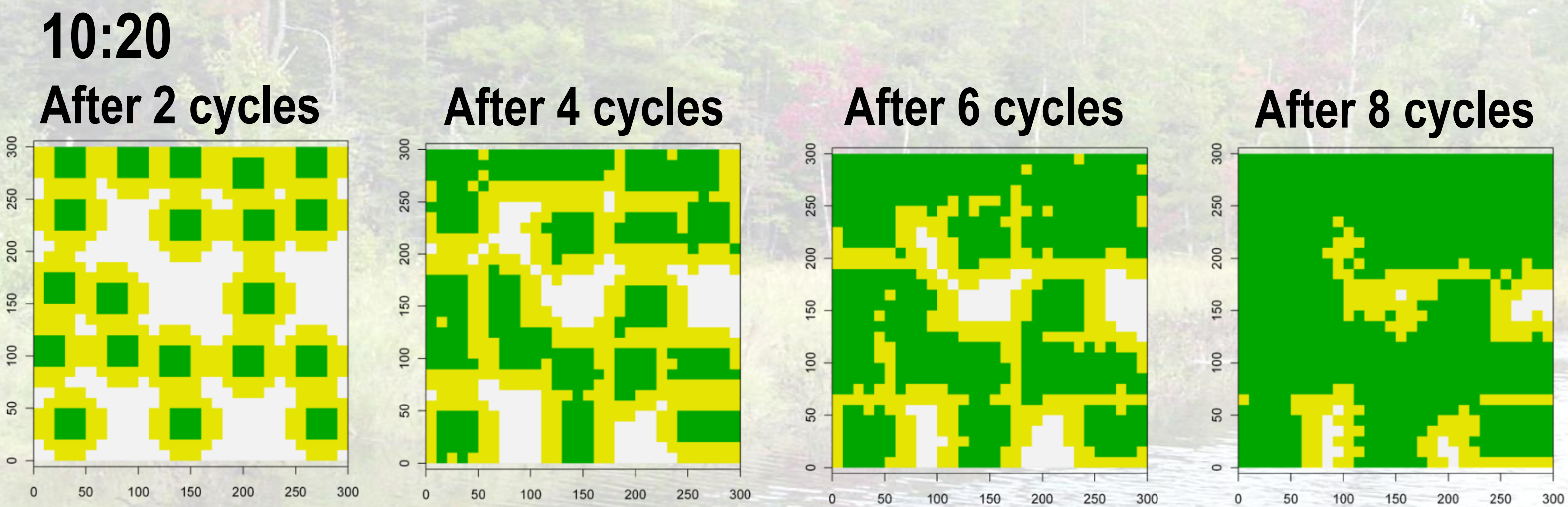
For this effort, several steps had to be taken to estimate yields in the AFERP treatments:

1. Estimate proportion of stand in gap, edge (i.e., uncut areas within 1 mature tree height of gap edge) and matrix strata by treatment and cutting cycle
2. Build FVS-NE calibration routines for edge growth
3. Project individual plots (n = 180) forward with FVS-NE for each cutting cycle and for each gap/edge/matrix condition
4. Estimate observed growth increases within edge strata over that predicted from FVS-NE
5. Recombine plot-level results in a Monte-Carlo approach to estimate treatment-level responses



Methods:
Modeling Details

We developed a discrete space model that attempted to mimic the harvest patterns of the AFERP treatments to estimate area in each stratum. Random points were picked for starting gaps, and successive gaps were expanded asymmetrically in two random directions or symmetrically in all four directions. Runs were repeated 1000 times for each AFERP.



Rotation-length yields and financial performance were also estimated for the unharvested control and comparable even-aged (two-stage shelterwood w/harvests at Year 0 to 24 m^2ha^{-1} and Year 10 to 0 m^2ha^{-1}) and uneven-aged (single tree selection with B = 23 m^2ha^{-1}, max D = 50.8 cm and q = 1.5). These treatments were also run at the plot-level and results combined in a Monte Carlo approach for final treatment estimates. In this analysis, edge effects for both NDBS systems were held at 20%.

Results:
Observed Growth Effects in Edges

Although we did not detect significant, stand-level differences in basal area growth and density among the control, 20:10, and 10:20 treatments, within-stand growth and regeneration responses differed strongly by strata. Regardless of treatment, gaps and edges increased sapling recruitment and regeneration stocking of most species, with a notable exception of balsam fir. Diameter growth rates of overstory trees in edges were intermediate of those in the uncut matrix or gaps (i.e., the reserve trees) , with the exception of white pine which did not differ significantly by spatial position in the treatments.

These results suggested the presence of a positive edge effect on both overstory growth, by +15 – 45% for some species, and sapling recruitment.

Species	Matrix	Edge	Gap
White Pine	0.51 ± 0.04^{a}	0.52 ± 0.04^{a}	0.57 ± 0.10^{a}
Red Maple	0.16 ± 0.00^{a}	0.20 ± 0.01^{b}	0.27 ± 0.03^{c}
Spruce	0.15 ± 0.01^{a}	0.24 ± 0.03^{b}	0.26 ± 0.08^{ab}
Balsam Fir	0.11 ± 0.00^{a}	0.16 ± 0.01^{b}	0.25 ± 0.02^{c}
Hemlock	0.26 ± 0.01^{a}	0.33 ± 0.03^{b}	0.42 ± 0.06^{b}

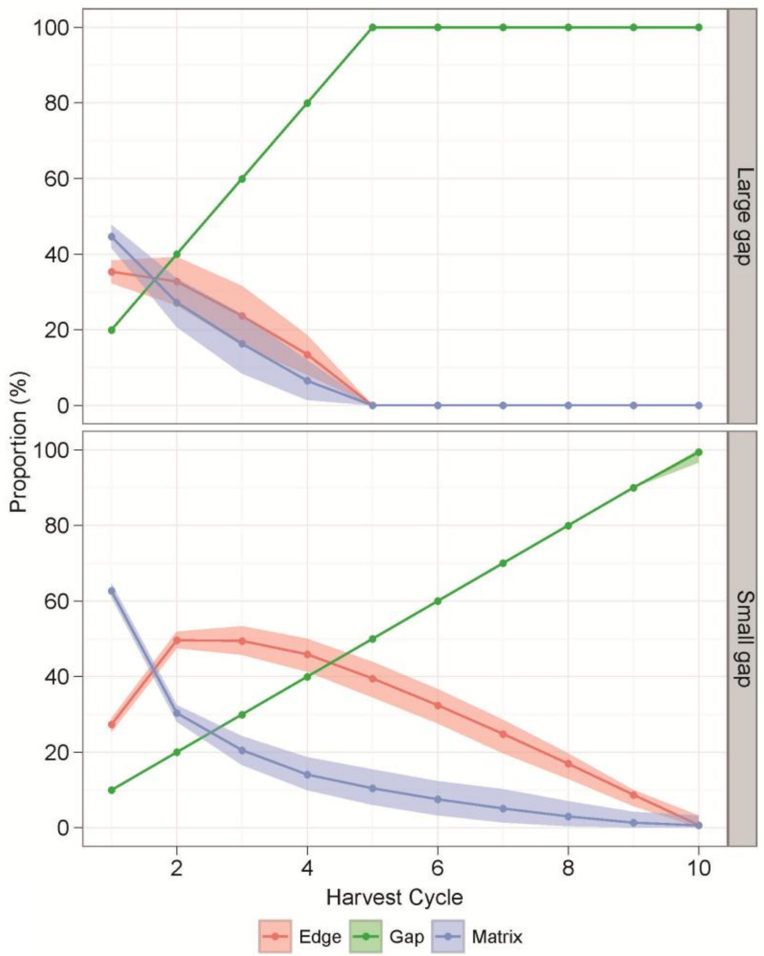
Mean diameter growth rate (cm yr^{-1}) for selected species by strata within AFERP stands ($\pm$ 1 standard error) (left). Within species, strata with the same letter do not have significantly different growth rates at a = 0.10 and using two-sample t-tests.

Results:
Edge Area and Persistence

The discrete space model estimated the area in edge peaked after the first two entries of the 20:10, at 27.2 – 38.8% of stand area and declining rapidly during successive entries. The 10:20 peaked slightly later, from the 2nd through the 4th entries, at 42.7 - 52.4% of stand area and declining more slowly.

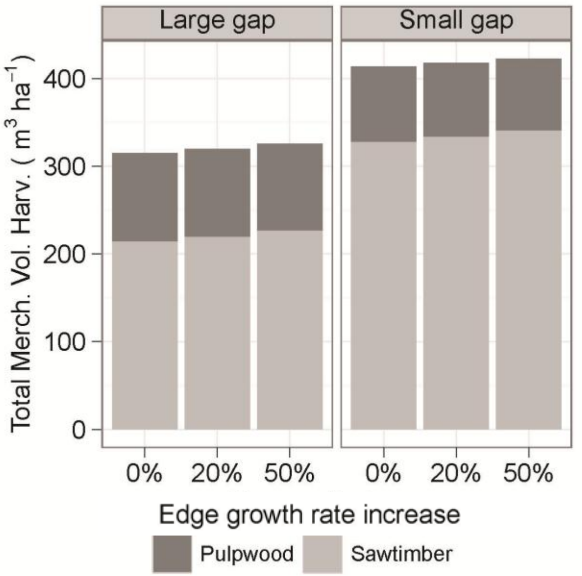
The longevity of the edge condition also differed. In the 20:10, 48.6 – 58.5% of edge area created in the first two entries persisted for 20+ years. In the 10:20, 23.0 -37.4% of edge area persisted for 40+ years.

Together, these results suggest that edge conditions are not only widespread in these NDBS systems, but also persistent.

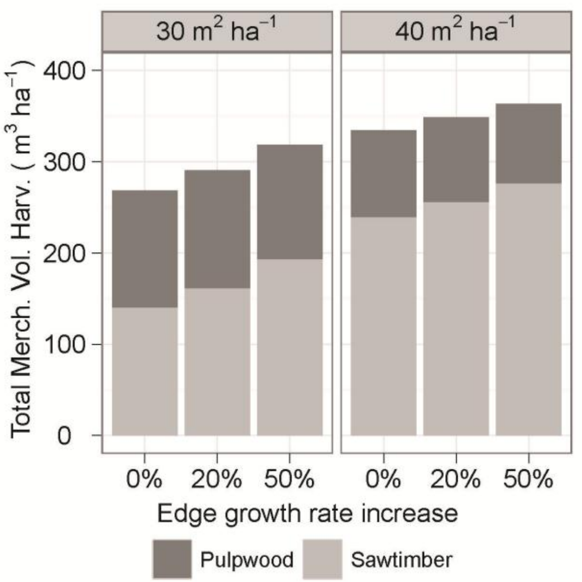


Changes in proportions of matrix, edge, and gap strata over time for the 20:10 (large gap) and 10:20 (small gap) treatments. Solid lines indicate mean proportions, while shading indicate the simulated 2.5 and 97.5 percentiles.

Results:
Edge Effect Sensitivity Analysis



Simulated changes in total harvest over the rotation for the 20:10 (large gap) and 10:20 (small gap) treatments (above), and for a subset of plots starting at low stocking (30 m^2 ha^{-1}) and high stocking (40 m^2 ha^{-1}) (below).

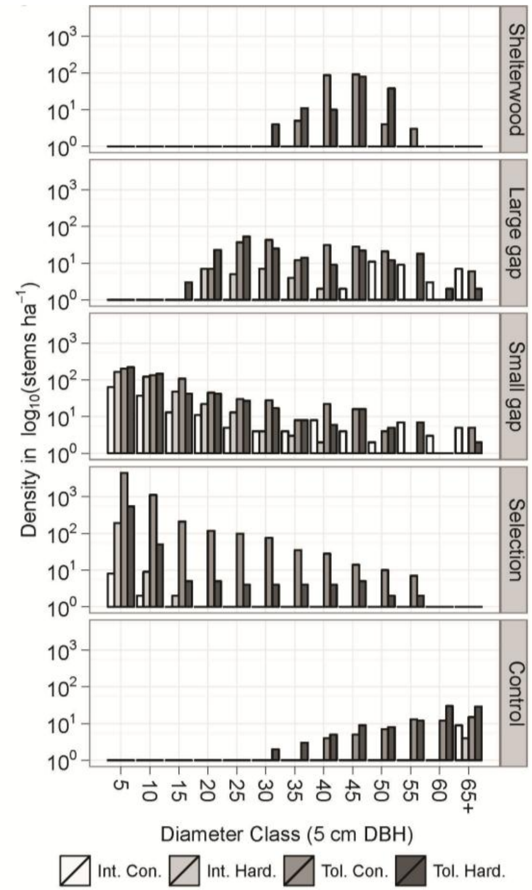


Using the treatment-specific patterns of edge creation and persistence from the discrete space model, we conducted sensitivity analysis of edge effect by simulating growth increases of 0%, 20% and 50% over FVS-NE projections within edge areas.

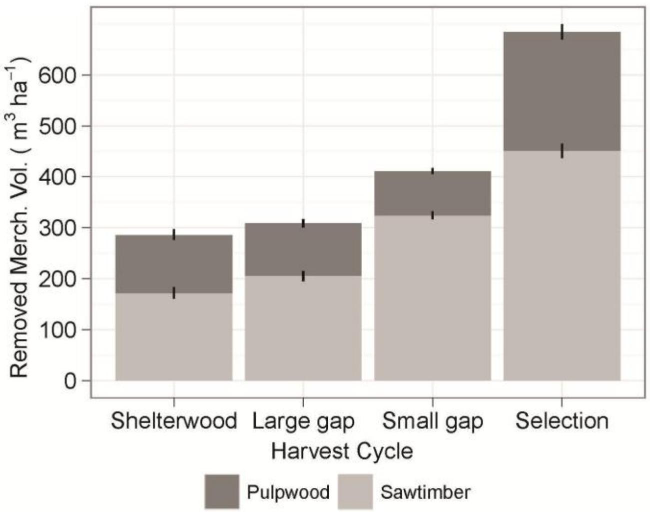
Initially, edge effects do not appear to significantly affect rotation-length estimates of total merchantable harvest (left, top) or most other parameters for either treatment; yields increased no more than 4.0% in our simulations. However, this appears to be a limitation to the FVS-NE model in that the model initially sets a maximum basal area in a projection that cannot be altered by changing species composition or competition condition (which occurs in edges). We reran the analysis on two subsets of plots: 1) low stocking condition (mean = 30 m^2 ha-^{1}) and 2) near full stocking (mean = 40 m^2 ha^{-1}). Growth increases for low stocking ranged from +15.2 – 37.9%, while those for near full were only +6.9 – 15.4% (left, bottom).

Results:
NDBS Comparison with Traditional Systems

Even with the limitations of FVS-NE, it still showed strong differences in structural development and species composition among the NDBS systems (i.e., 20:10 and 10:20), the traditional silvicultural systems (i.e., shelterwood and selection), and the unmanaged control. Controls were simulated to quickly reach full stocking and slowly increase in average tree size, becoming more and more dominated by tolerant hardwoods and softwoods over time. The shelterwood created a normal distribution of mostly tolerant species with the stand likely in early understory re-initiation by the end of the rotation. The selection had a wide distribution of tree sizes, as expected, with a few intolerant species in the smaller size classes; mature size classes were only tolerant species. Both NDBS systems, however, had very wide distribution of tree sizes *and* a mix of all tolerance classes in most size classes. This suggested that the NDBS systems, through spatial partitioning of regeneration effort into gaps, could create much more structurally variable stands than uniformly applied traditional systems.

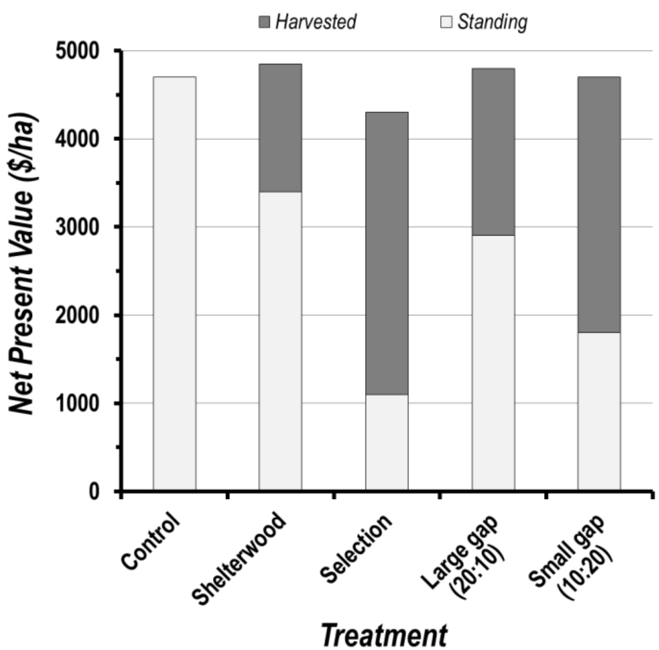


Diameter distribution by species group for the 2-stage shelterwood, 20:10 (large gap), 10:20 (small gap), single-tree selection, and control at the end of a 100-year rotation.



Above: Simulated full-rotation, merchantable yields from the four harvested treatments.

Below: Net present value (at a discount rate of 4%) of all harvested material and the rotation-end, standing volume for the five simulated treatments.



Results:

NDBS Comparison with Traditional Systems

Periodic annual increments were variable, but generally highest and most consistent in the selection treatment, lowest in the control, and intermediate but highly variable in the shelterwood and two NDBS systems.

Ending standing merchantable volume was greatest for the control (601 m^2 ha^{-1}), followed by the shelterwood (506 m^2 ha^{-1}), the 20:10 (465 m^2 ha^{-1}), the 10:20 (300 m^2 ha^{-1}) and the selection (202 m^2 ha^{-1}). Rotation length summaries of removed material suggested the inverse, that the selection had the largest yield and the shelterwood the least (left, top).

Financial analysis of the five scenarios (left, bottom) suggested that five treatments were comparable in value, but that the selection treatment captured more of the value in harvest. The two NDBS systems were notably better than the shelterwood, however.

Implications

There have been two approaches employed to emulate natural disturbances in eastern forests. The first uses modifications of a single-tree selection that have larger maximum tree sizes (Lorimer et al. 2009) and/or restorative treatments (Keeton 2006). While ecologically valid, single-tree selection is based on structure-based regulation that is complex, costly to administer and difficult to harvest without significant residual damage. Further the structural elements saved by NDBS modifications are usually the stems that make these systems economically viable.

The second has been the gap-based approaches typified by the AFERP. These systems have area-based regulation and are less complex and. However, it was questioned whether these systems could maintain structural complexity over the long-term or be economically viable. This study has shown that those concerns are likely unfounded; gap-based NDBS approaches maintain a wide diversity of tree sizes and species, and appear to be comparable in yield and economic returns to comparable traditional even- and uneven-aged systems. Northern Forest managers should have little fear to embrace these gap-based systems as part of their silvicultural portfolio.




Future directions

This study is only an initial attempt to forecast long-term dynamics in gap-based NDBS systems. As these experiments mature, more data will need to be collected to calibrate regeneration, sapling and overstory responses to the variable environmental conditions that are created with gap harvesting. In particular, there is a need to quantify low-contrast edge responses, like those created with gap-harvesting, across multiple ecosystem types. Specific to AFERP, the novel aspect of those systems, expanding the initial gaps to release the advanced regeneration in the edge strata that develops has yet to be quantified in detail.

This study also exposed a significant weakness of the FVS growth model when simulating complex stands. We feel that two major improvements are needed in the model: 1) a revision of the relatively inflexible basal area-based definition of maximum site capacity that cannot be modified within the projection; and 2) greater ability to stagnate the growth of immature cohorts. We are aware of efforts of scientists at both the University of Maine and the University of New Brunswick to develop growth models that do not have these weaknesses. When available, repeating this analysis, after calibrating with the most recent inventory data, would be warranted.

List of Products
Peer-reviewed publications

- Arseneault, J.E., Saunders, M.R., Seymour, R.S. and Wagner, R.G. 2011. First decadal response to treatment in a disturbance-based silviculture experiment in Maine. *Forest Ecology and Management* 262: 402-412.
- Saunders, M.R., Seymour, R.S., and Wagner, R.G. In press (est. 2012). The Acadian Forest Ecosystem Research Program: an example of disturbance-based silviculture in the Northeast. Pages xxx-xxx in: Kenefic, L.S., and Brissette, J.C. *The Penobscot Experimental Forest: 60 years of research, education and demonstration (1950-2010)*. Gen. Tech Rep. NRS-XX. U.S. Department of Agriculture, Forest Service, Northern Research Station, Newtown Square, PA. xx pp.
- Arseneault, J.E., and Saunders, M.R. Incorporating canopy gap-induced growth responses into spatially implicit growth model projections. *Ecological Modeling*. In revision.
- Arseneault, J.E., and Saunders, M.R. Potential financial and production costs of natural disturbance-based silviculture: a case study from the Acadian Forest Ecosystem Research Program. *Forest Ecology and Management*. In review.

List of Products
Presentations

- Saunders, M.R. and Arseneault, J.E. 2011. Estimating growth impacts of edges in gap-based silvicultural systems. 8th North American Forest Ecology Workshop, Roanoke, VA, June 19-23.
- Saunders, M.R., Arseneault, J., Olson, M., Seymour, R., and Wagner, R. 2009. First decadal response to treatment in AFERP. 7th North American Forest Ecology Workshop, Logan, UT, June 22-26.
- Saunders, M.R. 2008. Natural-disturbance based management in North America: application of the femelschlag to mixed-conifer forests. Waldbau-Institut (Institute of Silviculture), Universität Freiburg, Freiburg, Germany, March 12.
- Olson, M.G., Wagner, R.G., Seymour, R.S., and Saunders, M.R. 2008. The Acadian Forest Ecosystem Research Program (AFERP): 10-year results from the expanding-gap experiment. Oct. 17-18, Orono, ME.
- Seymour, R.S., Saunders, M.R., Ray, D.G., Olson, M., and Wagner, R. 2007. Multi-aged silviculture in the Acadian Forest of northeastern North America – the case for area-based stand structures. 6th North American Forest Ecology Workshop, Vancouver, BC, Canada. June 18-22.

List of Products
Other

- Arseneault, J.E. 2011. An approach to modeling disturbance-based silviculture regimes in the Forest Vegetation Simulator. M.S. thesis. Department of Forestry and Natural Resources, Purdue University, West Lafayette, IN. 144 p.
- Arseneault, J.E. 2010. Effects of canopy openings on adjacent forest matrix. 2010 Forestry and Natural Resources (FNR) Graduate Research Symposium, West Lafayette, IN, April 16.
- Saunders, M.R., Arseneault, J., Olson, M., Seymour, R., and Wagner, R. 2009. First decadal response to treatment in AFERP. Page 140 in Patsy Palacios, comp. 7th North American Forest Ecology Workshop, Logan, UT, June 22-26. 204 p. Online at http://www.nafew2009.org/PDF/NAFEWProgram.pdf.
- Olson, M.G., Wagner, R.G., Seymour, R.S., and Saunders, M.R. 2008. The Acadian Forest Ecosystem Research Program (AFERP): 10-year results from the expanding-gap experiment. Oct. 17-18, Orono, ME. 105 p. Online at http://www.crsf.umaine.edu/pdf/ECANUSA/ECANUSA_2008_Proceedings_web.pdf.