Silvicultural Discipline to Maintain Acadian Forest Resilience

Peter Salonius

ABSTRACT

Clearcut harvesting decreases structural complexity, eliminates old and genetically superior legacy trees, extirpates mature-forest floor vegetation, and creates hot and dry postharvest microclimates. The short-lived, exposure-tolerant, boreal tree species that regenerate in large forest openings are believed to be less able, than the late-successional Acadian species they replace, to adapt to the climate warming expected during the next forest rotation. A strip silviculture design is presented that includes limited canopy opening, "no-traffic" areas, maintenance of "full-cycle" survivors, and programmed return harvest intervals that approximate natural gap disturbance as a means of arresting the further increase of boreal species and restoring Acadian species on the landscape. Within the confines of this silvicultural discipline, two management options are described to accommodate extremes of future energy availability.

Keywords: Acadian forest, harvest design, microclimate, certification, energy

The Acadian Forest Region is situated between the deciduous forest to the south and west and the boreal forest to the north and includes elements of both (Loo and Ives 2003). Catastrophic, stand-replacing disturbances were rare, and normal natural disturbance was characterized by small gap-producing events (Lorimer 1977, Wein and Moore 1977). Shade-tolerant, mixed-wood forest types have been incrementally diminished by a combination of high-grade logging for softwood sawtimber (Koroleff 1954) that has removed softwood seed sources, and large-scale clearcutting for pulpwood (Loo and Ives 2003), practices that are not based on natural disturbance and stand development (Seymour et al. 2002). Short-rotation clearcutting has led to increasing representations of formerly rare, large-opening opportunist species (Erickson et al. 1999) that are more common in boreal ecosystems. Plantation silviculture with boreal conifers to enhance softwood fiber production has hastened such species transitions. Clearcutting has diminished the incidence of multiaged forests and large ultimate survivor trees that provide reservoirs of reproductive fitness and genetic diversity (Mosseler et al. 2003). Raised rotten-wood nursery microsites, which prevent the smothering of small-seeded species regeneration (Koroleff 1954), have become rare. Exposure-resistant boreal forest species are expected to be less able to adapt to the significant northward shift of life zones that is forecast (Thompson et al. 1999).

Silvicultural investment decisions, based on predictions of future market conditions, must be made in the context of the inevitability of future energy scarcity (Youngquist 1999), which is expected to diminish demand for conventional forest commodities and preclude their transport to distant markets. Silvicultural variants of a strip harvest protocol are presented that promote uneven-aged forest structure and high species diversity and are appropriate for energy-abundant or energy-scarce futures.

Alternatives to Conventional Large-Block Harvesting

Although average clearcut block size on New Brunswick Crown timber licenses (on public land) is below 50 ha, canopy openings up to 100 ha still are permitted on the landscape (New Brunswick Department of Natural Resources and Energy 2000). Species able to recolonize the center of large harvested areas may be a small subset of the total preharvest species assemblage (Matlack 1994). Duffy and Meier (1992) referred to legislation for public lands in the United States that may necessitate greatly altered harvesting protocols to maintain the diversity of forest herbaceous communities.

Annual allowable cut calculations assume that existing site productivity will sustain current levels of harvesting indefinitely; however, current silviculture may be lowering long-term site productivity (Hale et al. 1999). Further intensification of plantation and precommercial thinning operations have been recommended to double the harvest of boreal softwood species on Crown land in New Brunswick (Jaakko Pöyry Consultants 2002) during the next rotation, when stress is expected on these species as life zones move north as a result of climate warming. Oliver (1999) suggested that all policy directions require government intervention and that decisions will be necessary that lead to either intensive plantation forestry on a limited landbase coupled with reserves or to integrated management where high intensive silviculture costs are replaced by harvest methods based on ecological understanding. Benson (1990) suggested that most of the large, less productive forests in Canada would be best managed extensively with inexpensive natural regeneration achieved by modified harvesting. Protection from exposure to drying winds and late spring frosts, similar to that afforded by natural gap replacement dynamics, can be provided by single-tree, group and patch selection harvesting or by strip cuts with width less than twice tree height (Aussenac 2000). Moist air flowing from large expanses of intact forest surrounding narrow harvest openings that

Received March 30, 2005; accepted October 12, 2005.

Peter Salonius (psaloniu@nrcan.gc.ca) Canadian Wood Fibre Centre, Canadian Forest Service, Natural Resources Canada, PO Box 4000, Fredericton, NB E3B 5P7, Canada.

replaces air rising as a result of solar heating avoids excessive seedling transpiration stress compared with dry air in large open areas. Patch or strip harvesting approximates the moist microenvironment in natural gaps that accommodates the requirements of the late-successional tree species assemblages found in presettlement forests (Lorimer 1977). Diverse temperate species assemblages should be much better adapted to the warmer climates predicted for the future (Rizzo and Wiken 1992) than the boreal species assemblages that tend to replace them after large canopy-opening harvests.

Strip Harvesting or Selection

Smith et al. (1997) referred to the practical difficulties of operating in uneven-aged stands that are managed by selection management. The creation of small harvest openings by single-tree selection produces low diversity, shade-tolerant tree species assemblages (Crow et al. 2002), whereas larger harvest openings provide for the needs of a greater diversity of species (Niese and Strong 1992). Harvesting by mechanical systems, which has largely replaced manual felling, is a more practical, more easily organized and inexpensive option in strip harvesting than in single-tree, group, or patch selection harvesting. There has been considerable "two and three pass" strip harvesting, with equal widths of cut and leave strips, conducted in New Brunswick during recent years with the goal of increasing the representation of late-successional exposure-prone species in the regeneration assemblage. John Major (Canadian Forest Service, personal communication, July 22, 2004) has found that such layouts produce regeneration microclimates that are very similar to the dry ones in adjoining clearcuts. All mature forest structures are removed in these simple strip layouts, when leave strips are cut after several decades. When strip clearcutting is done to more closely approximate natural regeneration microclimates, the widths of strips should be chosen to simulate natural gap diameters while strip lengths must be determined by extraction logistics and topography. Strip orientation generally is chosen to be, as much as possible, perpendicular to the winds that produce the bulk of the wind-throw damage in the area.

Strip harvesting imposes an easily organized discipline on the harvest and avoids the necessity of intensive tree marking by forest managers. Single-tree or small patch selection relies on repeated harvest entries that require a considerable amount of the landscape for permanent extraction trails. Strip clearcutting is conducted once during a rotation so that the strip serves as its own extraction trail. Machine operators, accustomed to large-block harvesting, willingly view strip harvests as regularized, narrow, clearcuts or elongated patch cuts. Injury to residual timber in single-tree or small patch selection harvesting is a concern (Guldin 1996, Lansky 2002).

"No-Travel" Permanent Leave Strips

The large-block clearcutting of past decades has left only small and isolated populations of mature forest as reservoirs of genetic diversity and reproductive fitness; this has been found to increase levels of inbreeding and genetic drift (Mosseler et al. 2003). Clearcutting in 90% of the harvesting in Canada's Maritime Provinces (Canadian Council of Forest Ministers 1992) has increased the incidence of such small and isolated populations, lowering the possible contribution of old-growth legacies to forest health and diversity in future generations. Old-growth elements can be provided by the designation of "no-travel" permanent leave strips, separating neighboring operational strips that are scheduled for complete renewal harvesting. Side selection improvement harvesting into "no-travel" leave strips can be performed in conjunction with the clearcutting of adjacent narrow operating strips (Guldin 1996).

Legacy Tree Value

Conventional clearcut, seed tree, shelterwood, strip and patch harvests are not based on natural models of disturbance because they leave little aboveground structural legacy after regeneration is established. Legacy, "full-cycle", seed trees are dominants and codominants that can be marked never to be cut. One of the more demanding forest certification standards (Silva Forest Foundation 2000), based on Forest Stewardship Council guidelines, specifies that at least 10% of the dominants and codominants of each tree species should be reserved from cutting. Complete conversion of old-growth and mature forests to younger stands reduces the numbers and diversity of arthropod predators and increases the probability that herbivores will escape population regulation by the few surviving predators that disperse into young stands (Schowalter 1995). Large sugar maple trees have been shown to augment the water content of surface soils at night during dry periods by "hydraulic lift" from deep soil layers, significantly altering moisture availability for themselves and their associates during periods of daytime transpirational demand (Dawson 1996). Large, living old trees harbor bark-dwelling mosses, liverworts (Keddy and Drummond 1996), and epiphytic nitrogen-fixing lichens (Franklin et al. 2002) the colonies of which create unique habitats for other members of the diverse mature forest biota. Up to 40% of forest bird populations can be dependent on cavities in large standing dead trees (Hunter 1990). As dead trees fall to the ground and rot, coarse woody debris provides denning sites for small (Buskirk 1992) and large mammals (Hagen and Grove 1999), moist shelter for wet-bodied reptiles and amphibians (Ford et al. 2002), and other diverse biota such as obligate epixylic liverworts, which are dependent on wood in the later stages of decay to maintain viable populations (Lesica et al. 1991). Permanently forgoing the harvest of a portion of the best trees will be difficult for production-oriented foresters to accept (Hagen and Grove 1999). A regimen of designating some large legacy trees to grow old and die would begin to contribute to the old-growth structural components that Crow et al. (2002) found lacking in second-growth forests.

Approximating Natural Disturbance

The demanding certification standards of the Silva Forest Foundation (2000) require that no more than 20% of the canopy be removed in any one entry to maintain intact forest character. Duffy and Meier (1992) suggested that present logging cycles are too frequent to allow fully functioning forest herbaceous communities to reestablish before the next harvest intervention.

Although there has been considerable interest regarding the shape and amount of edge presented by reserves (Kunin 1997), the citing and sizing of reserves to conserve biodiversity becomes a process of condemning many species to ultimate extinction in these isolated patches (Diamond 1975). Reserves, which are essentially islands in a sea of unnatural disturbance, can not be expected to conserve the biodiversity of Acadian forests that are characterized by gap regeneration. If the distance that the harvest-altered microclimate penetrates into the residual uncut stand depends on the difference between their microclimates, then a reasonable goal would be

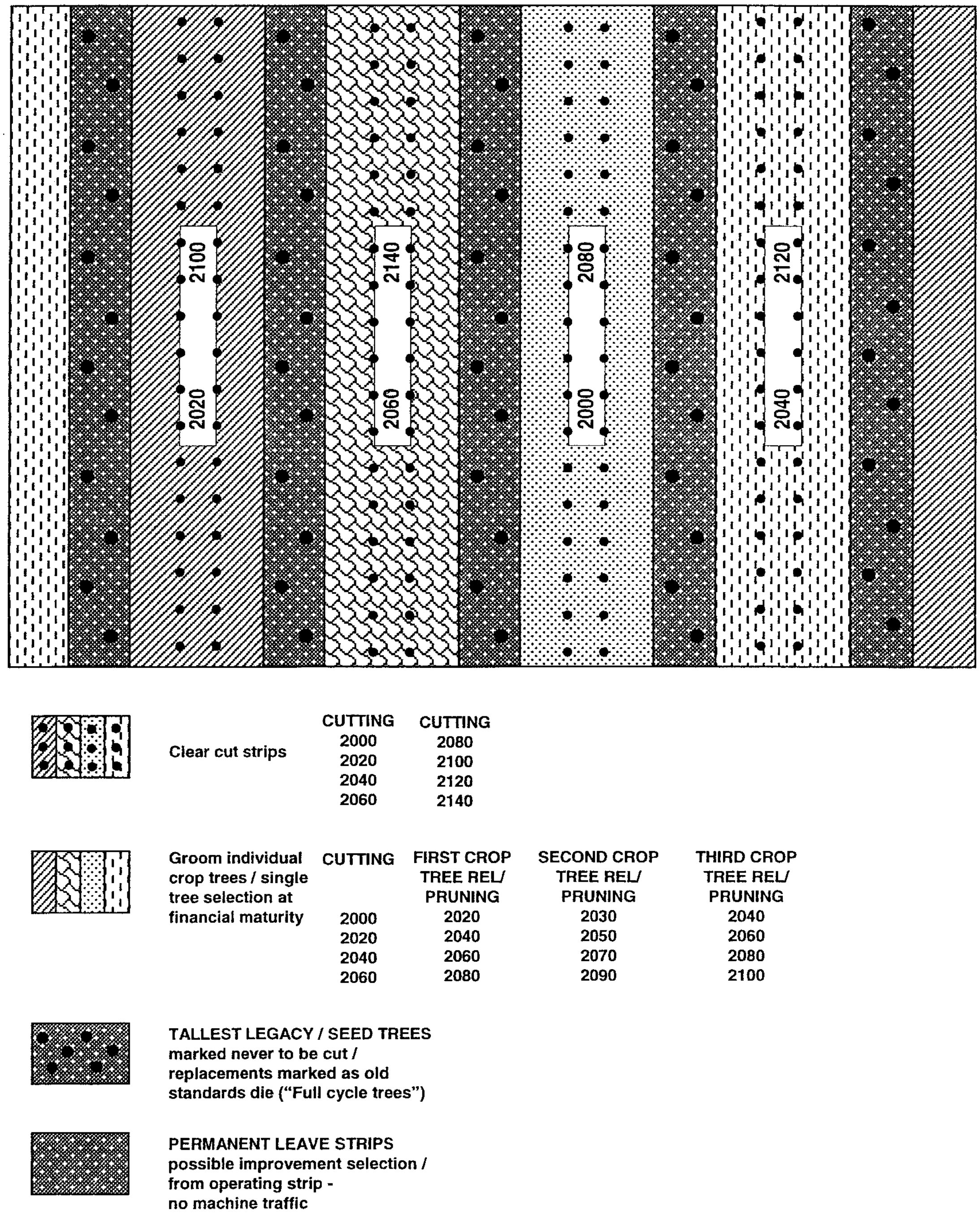

Figure 1. Light regular entry strip harvesting: natural disturbance approximation/microclimate maintenance/grooming.

to create as little postharvest microclimate alteration as possible in forest types that are normally driven by gap disturbance. Moen and Jonsson (2003) showed that circular, retained forest patches within a harvested landscape had less edge and proportionally more closed-forest microclimate than rectangular patches with the same area. However, when designing harvest gaps within an intact forest landscape, rectangular-shaped strips should minimize the core area of the opening and lessen the alteration of the normal forest microclimate that is produced, even as the amount of edge is maximized. York et al. (2004) and others (Harper et al. 2005) have been concerned with the ecological influence that the edges of large forest openings have on the environment of remnant forest interiors; York (personal communication, May 11, 2005) has suggested that it may be possible to assume, if the short axis of a rectangular opening is less than canopy height, that there is very little effect on the environment of the surrounding uncut forest.

Hunter (1990) described the zones in a triad management system as intensively managed, extensively managed, and reserve. There is no provision in the intensively managed forest farm zones of triad management for slow-spreading species that evolved under gap regeneration conditions and that can not function in large openings or under tight, closed canopy, regenerating forest (Matlack 1994). There is a growing consensus that biological diversity and, ultimately, long-term site productivity can not be maintained by reserves (Hansen et al. 1991). Gladstone and Ledig (1990) suggested that increased high-yield wood production on forest farms and

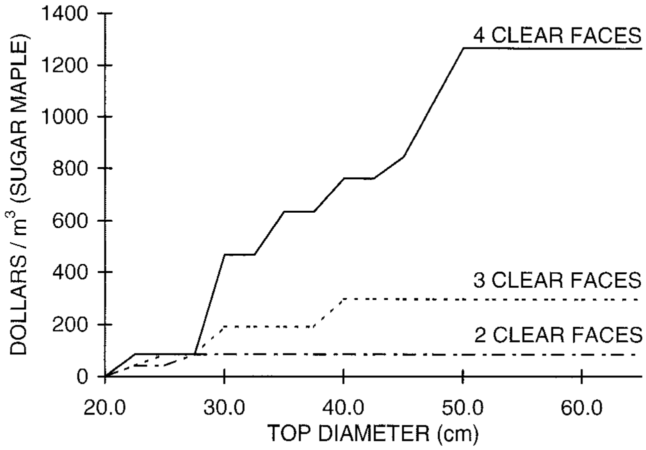

Figure 2. Sugar maple log value by grade and diameter.

complete recovery of aboveground biomass can spare native forest; however, complete biomass removal has since been shown to considerably lower long-term site productivity in many areas relegated to forestry use, because of the export of scarce nutrients in postharvest slash and thinnings (Hakkila 2004).

Management for Quality Timber and Profits in Energy-Abundant Conditions

The silviculturally intensive, light, regular entry, strip harvesting management for high-quality Acadian forest sites proposed here (Figure 1) has less than 20% of the canopy removed in any 20-year period, with a harvest return interval into previously cut strips of at least 80 years. This protocol should approximate Acadian gap-replacement dynamics as well as any patch harvest method. No special effort to preserve advance regeneration, in the clearcut operating strips, is visualized; however, the proscription against machine entry into the no-travel permanent leave strips is aimed at preserving advance regeneration and mature forest–associated vegetation on that portion of the landscape. Management foresters, whose focus is short-term economics and annual allowable cut calculations, balk at the prospect of leaving a component of the most valuable trees on the landscape and at the requirement for constant upkeep of access roads that is occasioned by the need to perform regular harvesting operations over time as opposed to completing harvesting operations in a specific area within a few years.

Silviculture, to minimize stem defects in regenerating strips, may involve early or late intervention when a few promising high-quality candidate trees are subjected to some number of crown-release (Miller 2000) and pruning treatments before final harvest at maturity. Intensive silviculture, involving repeated crown release and pruning of a few trees that are groomed from the early pole stage onward to produce high-quality veneer and sawtimber, is analyzed here. The appreciation in value of timber volume from sugar maple stems of three grade categories (Figure 2) is taken from the market-based tabular data of Mills and Lamson (1999). The price differentials for each volume unit as stem size increases creates a rationale for delaying the harvest of individual high-quality stems that still are growing rapidly. Alternative silviculture that approximates natural Acadian forest disturbance might be used if it could be shown to be profitable.

The light, regular-entry, strip harvesting protocol (Figure 1) is flexible as concerns operational and permanent no-travel leave strip widths, percentage of dominants and codominants retained as legacies, repeat harvesting frequency, and silvicultural manipulations performed between renewal harvests, as long as the need to approximate natural forest gap microclimates is recognized. Local geographic patterns and site conditions may require considerable modifications to idealized geometric designs.

In the particular example strip layout chosen here (Figure 1), the combination of paired 24-m-wide operational strips and adjacent 12-m-wide permanent leave strips, both 500 m long, produces 1.8-ha working units. Hardwood and softwood regeneration (poles) is over 4 m tall when the first entry is made in 2000 to begin grooming individual stems, 20 years after the strip was clearcut in 1980. Candidate crop trees are chosen, submitted to light crown-touching release to maintain their dominant or codominant status and rapid growth rate, pruned, and marked with paint. Excessive crown release at any of the several stand entries described here would encourage epicormic branching that would produce lower log quality at harvest. An 8-m spacing between groomed trees and between groomed trees and the edge of the permanent leave strip would produce 125 high-quality candidates in each 1.8-ha working unit. Maintenance of large distances, between candidate crop trees and between the crop trees and the edge of the leave strip, is required to accommodate the wide crowns that are characteristic of large dominants and codominants at maturity and also movement of machinery between rows of crop trees and between the crop trees and the edge of leave strips, should selection management of individual crop trees for maximum financial maturity (high-grade harvest) and/or partial improvement side-selection harvesting within the leave strips be chosen in the future.

Profit Calculations for Simple Simultaneous Harvest of All Groomed Trees at 80 Years

Land taxes, management costs, and protection expenses, which would lower the positive cash flow calculated, are not included because of the difficulty in forecasting these amounts during an entire rotation. Financial calculations are summarized in Table 1. Detailed calculation steps are as follows:

Preconditions

- Clear felling occurred in 1980.
- 2000: Choose, crown release (to waste), prune to 2-m height, and paint crop trees (poles).

Estimate 12 minutes/tree × 125 = 25 hours

= 3 days labor × $200/day = $600

2010: Repeat crown release (to waste) and prune painted crop trees to 4.2 m.

Estimate 7.5 minutes/tree × 125 = 15.63 hours

= 2 days labor × $200/day = $400

Discounted to 2000 at 5% interest = $245.56

2020: Repeat crown release (some salable pulpwood) and prune painted trees to 6.4 m.

Estimate 7.5 minutes/tree × 125 = 15.63 hours

= 2 days labor × $200/day = $400

Discounted to 2000 at 5% interest = $150.76

Net present value of silvicultural costs ($600.00 + $245.56 + $150.76) = $996.32 (Table 1).

- 2030: Repeat crown release (salable pulpwood defrays silvicultural costs).
- 2040: Repeat crown release (salable pulpwood and small sawlogs defray silvicultural costs).
- 2050: Repeat crown release (salable pulpwood and sawlogs defray silvicultural costs).
- 2060: Clearcut entire strip.

Assumptions.—Low-end sale prices (Figure 2) were chosen to make the financial analysis conservative.

Veneer

Delivered price is $700/mbf or $296.64/m^3 − $100/mbf or $42.38/m^3 for contracted high-grade harvesting − $100/mbf or $42.38/m^{3}for 1-day trucking (8 mbf or 18.88-m^3 load). The landowner receives $500/mbf or $211.89/m^3 (stumpage).

Sawlogs

Delivered sawlog price is $210/mbf or $88.99/m^3. Working split is ⅓ to harvest, ⅓ to truck, and ⅓ to landowner. The landowner receives $70/mbf or $29.66/m^3 (stumpage). As harvesting and trucking costs have been taken into account, further profit calculations consider only income and silvicultural costs.

Sales

Veneer.—Butt (bottom) 10-ft (3.05-m) logs, with average 22-in. (55.88-cm) top = 0.215 mbf (International Log Rule) or 0.50732516555 m^3.

0.50732516555 × $211.89

= $107.50/log or $13,437.50 for 125 logs

Sawlogs.—Second (top) 10-ft (3.05-m) logs, with average 17-in. (43.18-cm) top = 0.125 mbf (International Log Rule) or 0.29492516525 m^3.

0.29492516525 × $29.66

= $8.75/log or $1,093.75 for 125 logs

Net present value (2000$) = $13,437.50 + $1,093.75 − $996.32 = $13,534.43 for the 1.8-ha working unit, or $7,519/ha or an equivalent annual cash flow of $397.22/ha after compounding 5% interest rate over 60 years.

These calculations (Table 1) treat profitability very conservatively by assigning only the butt logs as veneer. The assignment of somewhat generous potential log sizes is seen as being justified by the regular crown release on rich sites that is exercised here. This profitable, intensive silviculture, incurring considerable long-term investment, could be considered if future market conditions are forecast to be an extension of the present economy that is dominated by exponential population growth, economic expansion, and increasing global trade, all of which depend on cheap and abundant energy.

Table 1. Cash-flow calculations when all groomed trees were harvested at 80 yr old.

	2000	2010	2020
Silviculture costs	−600.00	−400.00	−400.00
Net present value of			
Silviculture costs ($2000 at 5%)	−600.00	−245.56	−150.76
Net present value ($2000) of:			
Veneer logs	+13437.50		
Sawlogs	+1093.75		
Net present value ($2000)	+13534.93		

Management for Biomass and Forest Restoration

As geological energy resources are depleted, forest products will increasingly be valued for space heating and electricity production as well as a source of liquid fuels for transport, such as biomass-based methanol (Doty 2005). Prices offered for combustible waste (sawdust, wood, and bark) from forest product manufacturing are already approaching those offered for raw pulpwood in New Brunswick as pulp and newsprint mills close due to global oversupply and the increasing value of the Canadian dollar, against its US counterpart, which is caused mainly by the escalating value of Canadian fossil fuel exports. Given the prospect of increasing demands on the forest for biomass fuel, investments to increase softwood growth rates and form factors can be expected to decrease. Freed from the pressure to produce specific forest products, forest managers may choose to concentrate their efforts on maintaining ecological diversity and forest health by altered harvesting methods, because industry is not particular about the type of wood it uses as fuel or as a feedstock for organic chemical production. The basic, light, regular entry strip harvesting aspects of the silviculture in Figure 1 (without crown release and pruning) would move the management of the working forest, on even low-quality Acadian forest sites, toward better maintenance of biodiversity and ecological health while allowing the harvest of most of the wood grown. These strip cut layouts with large full-cycle trees marked never to be cut (Figure 1), established now in Acadian forest types, would extend the current development of patch and two and three pass strip harvesting. Easily identified linear age-class boundaries could serve as guiding monuments for future managers who may wish to maintain the reserve elements in the permanent no-travel leave strips at the time of the next harvest.

Because of the intense utilization levels in recent history and the decreased age of the existing forest, the establishment of a light regular entry strip cut layout may necessitate entries into the first designated strips as soon as small pulpwood or biomass harvests are feasible to initiate the long-term harvesting discipline, designed to produce a multiaged forest, which has been proposed here. As stands age and regular strip harvesting is performed on designated strips in order, an uneven-aged condition with scattered gaps (Smith et al. 1997) will develop. As the number of operational/leave strip pairs in a harvest sequence set exceeds the four and the return harvest interval equals or exceeds the 80 years in the example (Figure 1), the proportion of the landscape under some type of continuous-canopy condition will increase. If there were 100 operational/leave strip pairs, only one would be cut each year if the harvest return interval was set at 100 years. This human-orchestrated approximation of gap replacement dynamics, reimposed by designated harvest strips and extended return intervals, would produce forest microclimates similar to presettlement conditions from the standpoint of the organisms and biological processes (many of which are unknown) that constitute fully functioning Acadian forest ecosystems. Conventional small reserves are islands in a landscape of unnatural disturbance that condemn many species to ultimate extinction (Diamond 1975, Matlack 1994). The adoption of altered forest harvesting that preserves and restores biodiversity, by approximating natural disturbance patterns, should alleviate the constantly increasing political pressure for the creation of more small isolated ecological reserves. The assertion of Freedman et al. (1994) that biological diversity can be preserved only in ecological reserves appears to this author to be a "museum" strategy that will be unsuccessful in the long run.

Restoration strategies and remedial underplanting to increase species richness should not attempt to predetermine which species will predominate (Salonius and Beaton 1997). Diminished light levels cause a lowering of early successional vegetation biomass accumulation (York et al. 2004). Tree species with some shade tolerance are able to grow through the competition that develops after strip harvesting.

Alleviation of Financial Constraints

Altered forest harvesting behavior, which requires scattering the harvest, longer rotations, and the maintenance of some legacy trees on the landscape, would almost certainly result in decreased sales and lower harvest levels for landowners in the short term. Erickson et al. (1999) stated that short-rotation management, motivated by long-term risk, short-term profits, and high discount rates, may result in harvest practices that are ecologically detrimental; these authors suggested that government incentives may be necessary to influence forest landowners to alter harvest practices and rotation lengths to preserve biodiversity and forest health. Such altered behavior on Crown land, owned by the public and leased to corporations, might be required in exchange for decreased royalty (stumpage) payments. Future energy shortages and devolution toward a solar-based economy may influence harvesters to cut early and often, further decreasing the structural and biological diversity of Acadian forests. As future operators enter formerly established strip layouts, they may choose to obliterate the designated old-growth reserve elements in permanent no-travel leave strips with never-to-be-cut legacies, unless they are influenced to maintain these restorative protocols by monetary incentives (private land) or regulation (public land). They will, however, when confronted by these readily identifiable linear designs, have to think about the reasons for their establishment.

Summary and Conclusions

The light, regular entry, strip harvesting management methodology, proposed here for both rich and low-quality Acadian forest sites, includes permanent no-travel leave strips that harbor legacy, full-cycle seed trees marked never to be cut. This protocol provides for some old-growth-like structural complexity and regeneration microclimates that approximate those found in natural gaps that should enhance the richness of tree, shrub and herbaceous species that is characteristic of mature Acadian forests. The enhancement, maintenance, and restoration of temperate Acadian tree species and the lesser vegetation species associated with mature stages of this forest type should improve the ability of the vegetation complex to thrive during the climate warming that is expected during the next century. This harvesting regime would reintroduce the diverse stand structures that have been almost eliminated by decades of reliance on large clearcut block harvesting, and it would offer a silvicultural discipline that creates, rather than limits, future options.

Light, regular entry, strip harvesting methodology accommodates various intensities of silvicultural investment, designed for the production of high-quality timber or simple biomass, as market projections are formulated in the context of energy availability scenarios, which may produce economic conditions that are much different from those to which the forest industry has become accustomed during the "Petroleum Interval."

Literature Cited

Aussenac, G. 2000. Interactions between forest stands and microclimate: Ecophysiological aspects and consequences for silvilulture. *Ann. For. Sci.* 57:287–301.

Benson, C.A. 1990. The potential for integrated resource management with extensive forest management: Reconciling vision with reality—the extensive management argument. *For. Chron.* 66:457–460.

Buskirk, S.W. 1992. Conserving circumboreal forests for martens and fisher. *Conserv. Biol.* 6:318–320.

Canadian Council of Forest Ministers. 1992. *Compendium of Canadian forestry statistics.* Canadian Council of Forest Ministers, Ottawa, Ontario, Canada. 121 p.

Crow, T.R., D.S. Buckley, E.A. Nauertz, and J.C. Zasada. 2002. Effects of management on the composition and structure of northern hardwood forests in Upper Michigan. *For. Sci.* 48:129–145.

Dawson, T.E. 1996. Determining water use by trees and forests from isotopic, energy balance, and transpiration analyses: The roles of tree size and hydraulic lift. *Tree Physiol.* 16:263–272.

Diamond. J.M. 1975. The island dilemma: Lessons of modern biogeographic studies for the design of natural reserves. *Biol. Conserv.* 7:129–146.

Doty, F.D. 2005. *Fuels for tomorrow's vehicles.* Available online at www.dotynmr.com/PDF/Doty_FutureFuels.pdf; last accessed, Feb. 14, 2007.

Duffy, D.C., and A.J. Meier. 1992. Do Appalachian herbaceous understories ever recover from clear cutting? *Conserv. Biol.* 6:196–200.

Erickson, J.D., D. Chapman, T.J. Fahey, and M.J. Christ. 1999. Non-renewability in forest rotations: Implications for economic and ecosystem sustainability. *Ecol. Econ.* 31:91–106.

Ford, W.M., B.R. Chapman, M.A. Menzel, and R.H. Odum. 2002. Stand age and habitat influences on salamanders in Appalachian cove hardwood forests. *For. Ecol. Manage.* 155:131–141.

Franklin, J.F., T.A.Spies, R. Van Pelt, A.B. Carey, D.A. Thornburgh, D.R. Berg, D.B. Lindenmeyer, M.E. Harmon, W.S. Keeton, D.C. Shaw, K. Bible, and J. Chen. 2002. Disturbances and structural development of natural forest ecosystems with silvicultural implications, using Douglas-fir forests as an example. *For. Ecol. Manage.* 155:399–423.

Freedman, B., S. Woodley, and J. Loo. 1994. Forest practices and biodiversity, with particular reference to the Maritime Provinces of eastern Canada. *Environ. Rev.* 2:33–77.

Gladstone, W.T., and T.L. Ledig. 1990. Reducing pressure on natural forests through high-yield forestry. *For. Ecol. Manage.* 35:69–78.

Guldin, J.M. 1996. The role of uneven-aged silviculture in the context of ecosystem management. *West. J. Appl. For.* 11:4–12.

Hagen, J.M., and S.L. Grove. 1999. Coarse woody debris: Humans and nature competing for trees. *J. For.* 97(1):6–11.

Hakkila, P. 2004. *Developing technology for large-scale production of forest chips: Wood Energy Technology Programme 1999–2003.* Technology Programme Rep. 6/2004, Final Rep., TEKES, National Technology Agency, Helsinki, Finland, ISBN 952-457-151-X.

Hale, C.M., J. Pastor, and K.A. Rusterholz. 1999. Comparison of structural and compositional characteristics in old-growth and mature, managed hardwood forests of Minnesota, U.S.A. *Can. J. For. Res.* 29:1479–1489.

Hansen, A.J., T.A. Spies, F.J. Swanson, and J.L. Ohmann. 1991. Conserving biodiversity in managed forests: lessons from natural forests. *Bioscience* 41:382–392.

Harper, K.A., S.E. MacDonald, P.J. Burton, J. Chen, K.D. Brosofske, S.C. Saunders, E.S. Euskirchen, D. Roberts, S.J. Malding, and P.-A. Esseen. 2005. Edge influence on forest structure and composition in fragmented landscapes. *Conserv. Biol.* 19:1–15.

Hunter, M.L. Jr. 1990. *Wildlife, forests and forestry: Principles of managing forests for biological diversity.* Prentice Hall, Englewood Cliffs, NJ.

Jaakko Poyry Consultants. 2002. *New Brunswick forests: Assessment of stewardship and management.* Prepared for the New Brunswick Department of Natural Resources and the New Brunswick Forest Products Association, Fredericton, NB, Canada. 59 p.

Keddy, P.A., and C.G. Drummond. 1996. Ecological properties for the evaluation, management, and restoration of temperate deciduous forest ecosystems. *Ecol. Appl.* 6:748–762.

Koroleff, A. 1954. Leaf litter as a killer. *J. For.* 52:178–182.

Kunin, W.E. 1997. Sample shape, spacial scale, and species counts: Implications for reserve design. *Biol. Conserv.* 82:369–377.

Lansky, M. 2002. Residual stand damage. P. 59–60 in *Low impact forestry: Forestry as if the future mattered*, Lansky, M. (ed.). Maine Environmental Policy Institute, Hallowell, ME.

Lesica, P., B. McCune, S.V. Cooper, and W.S. Hong. 1991. Differences in lichen and bryophyte communities between old-growth and managed second-growth forests in the Swan Valley, Montana. *Can. J. Bot.* 69:1745–1755.

Loo, J., and N. Ives. 2003. The Acadian forest: Historical condition and human impacts. *For. Chron.* 79:462–474.

Lorimer, C.G. 1977. The presettlement forest and natural disturbance cycle of northeastern Maine. *Ecology* 58:139–148.

Matlack. G.R. 1994. Plant species migration in a mixed-history forest landscape in eastern North America. *Ecology* 75:1491–1502.

Miller, G.W. 2000. Effect of crown growing space on the development of young hardwood crop trees. *North. J. Appl. For*. 17:25–35.

Mills, B., and N. Lamson. 1999. *BANTIC: The Brooks and Neil tree investment chart.* USDA For. Serv. Tech. Rep. NA-TP-03-99, Northeastern Area State and Private Forestry, Durham, NH. 4 p.

Moen, J., and B.G. Jonsson. 2003. Edge effects on liverworts and lichens in forest patches in a mosaic of boreal forest and wetland. *Conserv. Biol.* 17:380–388.

Moseler, A., J.E. Major, and O.P. Rajora. 2003. Old-growth red spruce forests as reservoirs of genetic diversity and reproductive fitness. *Theor. Appl. Genet.* 106:931–937.

New Brunswick Department of Natural Resources and Energy. 2000. *A vision for New Brunswick forests: Goals and objectives for Crown Land Management*. Fredericton, N.B. 47 p.

Niese, J.N., and T.F. Strong. 1992. Economic and tree density trade-offs in managed northern hardwoods. *Can. J. For. Res.* 22:1807–1813.

Oliver. C.D. 1999. The future of the forest management industry: Highly mechanized plantations and reserves or a knowledge-intensive integrated approach. *For. Chron.* 75: 229–245.

Rizzo, B., and E. Wiken. 1992. Assessing the sensitivity of Canada's ecosystems to climate change. *Clim. Change* 21:37–55.

Salonius, P., and K. Beaton. 1997. Restoring shade tolerants in an Acadian mixed wood site of degraded species diversity, 1997. P. 247–258 in *Proc. of the IUFRO interdisciplinary uneven-aged management symp.*, Sept. 15–17, 1997, Corvallis, OR, Emmingham, W.H. (comp.).

Schowalter. T.D. 1995. Canopy arthropod communities in relation to forest age and alternative practices in western Oregon. *For. Ecol. Manage.* 78:115–125.

Seymour, R.S., A.S., White, and P.G. Demaynadier. 2002. Natural disturbance regimes in northeastern North America—evaluating silvicultural systems using natural scales and frequencies. *For. Ecol. Manage*. 155:357–367.

Silva Forest Foundation. 2000. *Ecosystem-based certification*. Silva Forest Foundation, Slocan Park, BC, Canada. 33 p.

Smith, D.M., B.C. Larson, M.J. Kelty, and P.M.S. Ashton. 1997. *The practice of silviculture: Applied forest ecology*. John Wiley and Sons, Inc., New York. 527 p.

Thompson, R.S., K.H. Anderson, and P.J. Bartlein. 1999. *Atlas of relations between parameters and distributions of important trees and shrubs in North America.* US Geological Survey Pap. 1650 A&B. Available online at http://pubs.usgs.gov/pp/p1650-a/; last accessed, Feb. 14, 2007.

Wein, R.W., and J.M. Moore. 1977. Fire history and rotations in the New Brunswick Acadian Forest. *Can J. For. Res.* 7:285–294.

York, R. A., R.C. Heald, J.C. Battles, and J.D. York. 2004. Group selection management in conifer forests: Relationships between opening size and free growth. *Can. J. For. Res.* 34: 630–641.

Youngquist, W. 1999. The post-petroleum paradigm-and population. *Popul. Environ.* 20:297–315.