Forest Management on New Brunswick's Crown Lands

The Bryophyte Perspective

Kate Frego*, S. Haughian, K. Mathieson, L. McIntosh J. Mudge, M. Pokorski, A. Witkowski
Saint John
frego@unb.ca

Dr. Kate Frego teaches in the Biology Department of the University of New Brunswick. Her research and that of her students over the past decades has focused on the impacts of forest management in New Brunswick on bryophytes. Sean Haughian, Krystal Mathieson, Leah McIntosh, Joe Mudge, Mark Pokorski, and Amy Witkowski are all her current or former students who have studied the ecology of bryophytes in the Acadian Forest ecosystem.
*Authors' names are in alphabetical order

In an ideal world, humans would harvest natural resources, like trees, without losing or seriously harming other organisms or processes in the ecosystem. We don't live in an ideal world, but the most promising way to harvest trees is to ensure that our impacts mimic the natural events that occur in forest ecosystems: if the disturbance created by our actions is equivalent to natural disturbances, it seems safe to assume that populations of most naturally occurring organisms are adapted to survive, or recover from, such impacts. The first step in predicting impacts of a management strategy is to assess its ecological "equivalence" to natural disturbances of the region, by comparing their component characteristics (e.g. spatial extent, frequency, intensity to natural events). For example, much of the native biodiversity of the Acadian Forest region is well adapted to frequent, patchy, low-intensity disturbances, such as the deaths of clumps of trees due to insect infestation, wind and ice storms, but less so to extensive, high-intensity events, such as relatively infrequent forest fires that remove shade, topsoil and nutrients.

Studying impacts of disturbance

Comparison to natural disturbances allows us to predict the effects of different forest management practices, but these predictions can be verified only through observation of biodiversity responses: if biodiversity returns to its "natural" levels for that ecosystem after the disturbance, and if those levels are maintained across the landscape over multiple returns of the disturbance, then the disturbance can be said to be sustainable at its present spatial extent, frequency and intensity. "Natural" levels of biodiversity are determined by observation of pre-disturbance conditions and continuing observations of comparable but undisturbed sites. While it is easy to recognize catastrophic negative effects, experience has taught us that the accumulation of small effects can be just as serious, and can be difficult or impossible to reverse.

Although we still have much to learn about exactly how forest floor plants (and biodiversity more generally) respond to different combinations of high-intensity disturbances, such as those that occur in plantation forests, it is clear that forests with minimal human disturbance make larger contributions to native biodiversity. It is also clear that with more frequent or more severe disturbances, there is a corresponding decline in biodiversity. For example, we have found that NB plantations contain approximately 30% fewer moss and liverwort species (bryophytes) than naturally-regenerated forests.

Bryophytes: who cares?

Our research group has studied the impacts of forest management in NB, on the plants of the forest floor, focusing on a group of small, primitive, poorly understood plants: the bryophytes. The term "bryophyte" covers three groups: mosses, liverworts and hornworts (Figure 1). NB's Acadian Forest contains several hundred species, most of them less than 1 cm tall and very sensitive to drying. This is because, unlike the more advanced plants, bryophytes have no water-proof layer to prevent water loss, no true roots to absorb water from the soil, and no well-developed "pipelines" to move water internally. They thrive in the shady, cool, moist conditions of the forest floor where they may form small tufts or extensive turf, usually a mixture of many species intertwined (Figure 2, page 40).

Many bryophytes can propagate from small fragments of tissue, such as those snipped off by birds or rodents for bedding, or by specialized structures designed to enhance cloning; e.g. tiny fragile branchlets that detach easily. Long-distance travel is generally thought to be by reproductive spores, the bryophyte parallel of seeds, but simpler and small enough to be carried by air currents. When the spores germinate, most form a tangle of green filaments that resemble algae, before the first recognizable shoot and delicate leaves emerge. Reproduction requires that a flagellate sperm cell from one plant be splashed to another plant, so that it can swim to an unfertilized egg – a very precarious process! Success results in a distinctive structure, the sporophyte, with a long slender stalk supporting a capsule that, at maturity, releases spores, either gradually over years (most mosses, Figure 3a) or in a single burst (peat moss and liverworts; Figure 3b). For most species, we know almost nothing about the ecology of these juveniles: how far spores travel, what triggers (or prevents) their germination, or even how many are produced.

While our knowledge about their details is fairly limited, there is ample evidence that bryophytes are ecologically important components of the forest. In some forests, there may be as much carbon tied up in the bryophytes as in the trees. They provide habitat for numerous invertebrates, and nesting material for a variety of rodents and birds. Although

Figures 1 (a) - (c). Three common forest-floor bryophytes; From top: Figure 1(a) Conocephalum conicum; *Figure 1(b)* Lophocolea heterophylla, *a leafy liverwort; Figure 1(c)* Pleurozium schreberi, *a moss., Photos by M. Pokorski*

Clockwise from top left: Figure 2. A mixed colony of mosses Pleurozium schreberi *and* Ptilium crista-castrensis; *Figure 3(a)* Bazzania trilobata, *(liverwort); Figure 3(b)* Brachythecium sp *(moss); Figure 3(c)* Sphagnum sp *(peatmoss) each with attached sporophyte: a slender stalk topped by a capsule containing the developing spores.*
Photos by M. Pokorski

they are relatively indigestible for most organisms, they are eaten by slugs, snails, and some forest birds and rodents. At a broader scale, their extensive mats harbor nitrogen-fixing bacteria and absorb water, slowly releasing it to the feeder roots of trees and other rooted plants, thereby influencing water and nutrient cycles as well as soil temperature. Their influence on tree and shrub regeneration varies with species; some tree seeds and seedlings are inhibited by a thick moss layer, while the survival of others is enhanced.

What we have learned about forest management impacts

Forest management encompasses multiple activities – from harvesting, through regenerating and tending, to harvesting again (Figure 4a-e). Choices at each step have the potential for a range of impacts on the forest ecosystem. Our research group has worked to tease apart the effects on bryophytes of those forest harvesting options commonly used in NB forests.

Canopy removal. With tree extraction, the shade of the tree canopy is lost, and the forest floor experiences increased light intensity, and temperature and humidity fluctuations. Sensitive bryophyte species succumb quickly, while others may persist, depending on the degree of change. However, the degree of change varies with the proportion of trees removed, the understory layers retained, and the expanse of the cleared area. Foresters have developed a broader range of harvesting prescriptions to address multiple priorities. These include "variable retention", i.e. leaving clumps of mature trees either for potential nesting sites or as seed sources (e.g. clearcut with dispersed retention, Figure 4c). It can be more cost-effective to leave young trees of desirable (i.e. marketable) species, than to remove them and plant seedlings. We found that patches of natural vegetation only 1.5m tall are enough to maintain the temperature, humidity, and populations of many forest bryophytes. Even more effective are larger aggregated retention patches: islands of mature, intact forest within a clear-cut (Figure 4e). While serving the purpose of maintaining seed trees and advanced regeneration, these also preserve intact communities of forest floor biodiversity. However, these "arks" are not perfect: the conditions of closed forest are maintained only within the core, 25m or more from the island edge, and the islands themselves may ultimately be slated for harvest. In addition, sufficient area must be allocated to these retention patches to ensure that the most uncommon (and vulnerable) species are captured and conserved within them. We are currently assessing other patterns of dispersed retention harvest, in which various proportions of mature trees are left scattered through a clear cut.

Substrates. Not all changes occur above the bryophytes. In the process of removing the trees, machinery can crush patches of bryophytes or churn up the surfaces on which they grow. Logging also leaves various amounts of debris – coarse and fine branches, bark, leaves – that bury existing bryophytes. These direct impacts on the forest floor cause the greatest immediate loss of bryophytes in the harvest process. The most extreme example is scarification (Figure 4d, e): deliberate scraping of the soil to prepare the site for planting and increase success of planted tree seedlings. Typical forest bryophyte species do not usually colonize bare mineral soil -- they tend to occupy the rich organic substrates of thick humus and rotting logs found in forests -- so scarification tends to favour pioneer (non-forest) species. Liverworts in particular tend to be lost when their preferred substrates are disturbed. Foresters can reduce this mortality by minimizing the areas impacted by machinery tracks (limiting them to "skidder trails"), by encouraging advanced regeneration over planting whenever feasible, and by their choice of scarification equipment. For example, scarifying in trenches, or in relatively small patches at intervals for individual seedlings, is preferable to wholesale tilling.

Bryophyte diversity may be impacted by even more subtle changes in the available substrates. In managed forests, humus and rotting wood are less abundant, and the extraction of timber reduces the future supply (and diversity) of rotting wood. We are currently assessing substrate requirements, but we already know that individual units of rotting wood are transient in nature and offer diverse physical and chemical properties that change throughout the decay process. So far it seems that bryophyte diversity is strongly related to the degree of decay, and to the size and species of rotting logs. For example, well-rotted logs, and in particular large (diameter > 20 cm) hardwood logs, seem to support the most diverse communities. However, many industrial forestry operations (especially silviculture plantation forestry) skew forest composition towards softwoods, and leave behind only small stems (diameter < 10cm) after cutting. This effectively eliminates the future supply of optimal microhabitats. A current study is assessing additional roles of rotting wood, and the possibility of increasing conservation of bryophyte diversity by increasing rotting wood in silviculture plantations.

Thinning. Because harvested stands that are allowed to regenerate naturally are frequently overcrowded, resulting in poor tree growth, they are frequently thinned one or more times before they are harvested again (Figure 4b, c). The initial pre-commercial thinning is done by hand, strategically cutting saplings to optimize the spacing of the remaining trees. This low impact disturbance, which also leaves the debris on site, does not

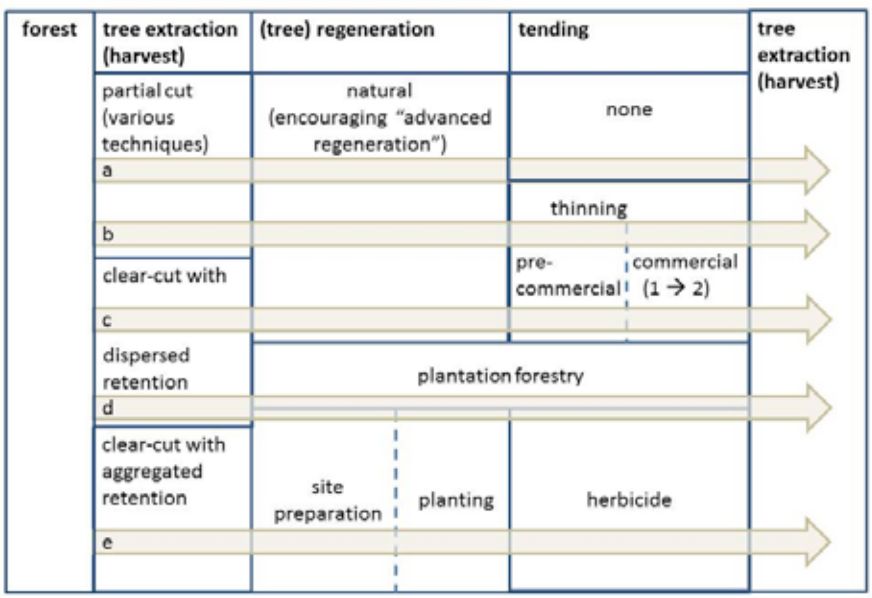

Figure 4 - Through each rotation (harvest cycle) of a managed forest, choices are made in terms of harvest, regeneration and tending of trees depending on a variety of ecological and economic factors. Each uses specific machinery, and produces a distinct suite of impacts on the forest flora and fauna. Five relatively common combinations are illustrated, from lowest to highest ecological impacts:
Partial harvest with natural regeneration – removal of selected trees, followed by natural regrowth of existing seedlings, with no further interference, or
b. with thinning to space trees for optimal growth.
c. Clear-cut with dispersed retention, natural regeneration - scattered seed trees and immature trees are left to harvest later. Pre-commercial thinning reduces crowding of natural regeneration, leaving slash on site; commercial thinning continues the process but does so by removing merchantable trees.
d. Clear-cut with dispersed retention, planted - similarly harvested, the site is prepared (e.g. tilled) and planted with seedlings of desirable species. Herbicide is often used to reduce growth of competing broad-leaved trees and shrubs in the silviculture plantation.
e. Clear-cut with aggregated retention – clear-cuts designed to retain patches of forest that contain mature seed trees, nesting sites, and immature trees; between them, the area is prepared, planted and tended as a silviculture plantation.

appear to affect the bryophyte community. One or more commercial thinnings may follow, using various harvesting machinery; besides reducing competition among the trees, this technique produces timber that is large enough to be marketable. We are currently evaluating the impacts of commercial thinning, which appear to be midway between pre-commercial thinning and clear-cutting.

Herbicide. Planted areas are often treated with herbicide (typically Vision®, with the active ingredient glyphosate) to reduce competing vegetation that might slow the growth of conifer seedlings (Figure 4d, e). Our laboratory studies on several species indicate that bryophytes are damaged by contact with the herbicide. The contradictory evidence from field studies (either no, or slightly positive, effects) may result from coarse aerial application, with many bryophyte patches escaping contact with the herbicide. The mechanism of the damage is also poorly understood, but it is possible the surfactant (wetting agent) added to the glyphosate preparation has its own negative impact on the bryophytes.

Shortened rotation. Genetic selection for faster-growing trees and optimized growing conditions (e.g. spacing of seedlings, and removal of competitors using thinning and/or herbicide) have allowed NB forest managers to reduce the rotation (time between tree harvests) to 40-60 yrs. – much less than the historical frequency of similar extensive natural disturbances in the Acadian forest. We do not yet know the impact of this increased frequency of disturbance, but we have a long term study in progress to determine how much time is needed for the bryophyte community to recover. Our best guess is that many forest mosses can either resume growth, or recolonize via airborne spores, within decades, but liverworts appear to require much longer. Some managed forests have lower liverwort diversity than unmanaged forests more than 60 years after the last operations; however, we cannot be sure what has been lost because we do not know what species were present before the harvest.

Where are the source populations?

If bryophyte species are to recolonize disturbed areas, viable reproductive units (usually spores) must come from some source within reasonable dispersal distance, and must experience conditions that allow them to germinate and become established. Expanses of NB's potential source populations – mature forests – have been removed by human expansion, as forests are cleared for agriculture, roads, and urban growth. Pristine or "old-growth" forests are all but gone. Potential areas that provide sources of bryophyte reproductive units become smaller and further separated as greater proportions of the remaining forested landscape are managed for timber extraction. What remains is the pool of bryophytes that persist in several categories of forested land across the province:

Conservation Forest areas, e.g. Protected Natural Areas (PNAs); forested buffers around watercourses, water-bodies, and wetlands; old forest communities; and old forest wildlife habitats -- are generally not harvested, although limited harvesting is allowed in some of them. These areas are likely effective at conserving the species they contain, and are most representative of "natural" conditions, however they are relatively small areas and not necessarily near enough to managed sites for spore dispersal. In addition, it is not certain whether they represent the full suite of bryophyte species found in the province, and some contain different species from the target upland forests. If the new Crown Lands Forest Management Strategy increases harvesting in these areas, it will reduce the source populations of upland forest species, and could put other groups of species at risk.

- *Steep slopes* occasionally support mature, relatively undisturbed forests that have been left unharvested because they are too dangerous for harvesting equipment. These make up a tiny proportion of the province's forest.
- *Plantations* have been shown to have lower bryophyte diversity, particularly of liverworts, and experience the shortest rotations because they are managed for maximum wood production. As a result, they are not reliable sources of the bryophytes that are most vulnerable to harvesting operations, and are unlikely to acquire them before the end of their rotation. We are conducting experiments to determine whether alternative management practices that protect large pieces of rotting wood will allow source populations to persist, and contribute to biodiversity in the silviculture plantations and elsewhere.
- *Second-growth forest* (either managed or unmanaged) – makes up the greatest proportion of our remaining forest, and our most extensive source for bryophyte regeneration. The habitat conditions of second growth forests are likely to be more similar to natural forests than silviculture plantations or wetland buffers, however they differ widely in their habitat features, history of disturbance, and resulting bryophyte flora. As a result, the bryophyte species composition, and therefore their value as a source of bryophytes, also varies.

What do we need to know to conserve forest bryophytes?

Currently, there are enormous gaps in our general knowledge of bryophyte biology and ecology. Bryophyte species

Mossy log
Photo by B. Brown

differ in their responses and ecological requirements, suggesting that they do not operate, nor should they be managed, as a single ecological unit. Basic conservation efforts await answers to several critical puzzle pieces.

- *Basic biology.* What is the natural diversity of mosses and liverworts in specific components of the Acadian forest (e.g. stand age, canopy composition)? Which bryophytes are truly rare/threatened/endangered?
- *Recovery after disturbance*. What are the relative recovery times of bryophyte communities that have experienced specific suites of management operations (Figure 1), e.g. clear-cut with dispersed vs. aggregated retention, site preparation, herbicide treatment? (Our longest study is only 20 yrs.) What are the ecological bottlenecks to recovery: availability of spores or other reproductive units, or availability of suitable habitat conditions, including specific substrates and microclimates?
- *Dispersal and source populations.* What is the species composition of the "spore rain", how far and in what patterns does it travel? How does the probability of recolonization relate to distance to a source population?

The new Strategy increases silviculture plantations (which have markedly reduced bryophyte diversity) while decreasing the area of designated Conservation Forest (the small proportion of forested areas that can be expected to maintain bryophyte diversity, and act as source populations for the rest). In order to maintain natural diversity of bryophytes, we must ensure that we maintain enough mature forest (even if it is second-growth) across the landscape to account for the wide range of habitat conditions and to supply populations of the large number of inherently infrequent species. We do not yet know how much mature forest across the landscape is enough to conserve bryophytes. Invoking the precautionary principle, changes to management policies that further reduce the amount of mature forest in New Brunswick risk long-term, irreversible, impacts on bryophyte diversity.

For More Information

Sollows, M.C., K.A. Frego, and C. Norfolk. 2001. Recovery of *Bazzania trilobata* following desiccation. *Bryologist* 104: 421-429.

Ross, A.L. and K.A. Frego. 2002. Comparison of three managed forest types in the Acadian forest: diversity of forest floor bryophyte community and habitat features. *Canadian Journal of Botany* 80: 21-23.

Fenton, N.J., K.A. Frego, and M.R. Sims. 2003. Changes in forest floor bryophyte (moss and liverwort) communities four years after forest harvest. *Can. J. Bot*. 81(7): 714-731.

Ross-Davis, A.L. and K.A. Frego. 2004. Propagule sources of forest floor bryophytes: Spatiotemporal compositional patterns. *Bryologist* 107(1): 88-97.

Fenton, N.J. and K.A. Frego. 2005. Bryophyte (moss and liverwort) conservation under remnant canopy in managed forests. *Biodiversity and Conservation* 122: 417-430.

Roberts, M.R., Frego, K.A., and A.L. Ross-Davis. 2005. Plantations and high impact forestry practices. Pages 79-84 in *Forest Management Guidelines to Protect Native Biodiversity in the Greater Fundy Ecosystem,* Betts, M. and Forbes, G. (Eds.). University of New Brunswick Cooperative Fish and Wildlife Research Unit, Fredericton.

Frego, K.A., N.J. Fenton and M. Betts. 2005. Coarse woody debris. In *Forest Management Guidelines to Protect Native Biodiversity in the Greater Fundy Ecosystem*, Betts, M. and Forbes, G. (Eds.). University of New Brunswick Cooperative Fish and Wildlife Research Unit, Fredericton.

Frego, K.A. 2007. Bryophytes as potential indicators of forest integrity. *Forest Ecology and Management* (Special Issue) 242(1): 65–75.

Schmalholz, M., K. Hylander and K. Frego. 2011. Bryophyte species richness and composition in young forests regenerated after clearcut logging versus after wildfire and spruce budworm outbreak. *Biodiversity and Conservation* 20: 2575-2596.