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Quantifying the influence of residual-tree responses on stand development after partial harvests

Highlights

- We documented a 13% mortality rate of residual trees over the first decade after partial harvest in the black spruce boreal forest of northeastern Ontario.
- Mortality peaked in the first year after harvest at over twelve times the background rate.
- The most important predictor of mortality risk was proximity to skid trails.
- Residual trees also displayed large positive growth responses to harvest.
- Simulation model results indicated that stand-level 10-year basal area growth rates are likely to be overestimated by 55% if post-harvest mortality is not included.
- Across simulated harvest treatments in which the distance between skid trails ranged from 3 to 15 m, differences in collateral damage (destruction of unmerchantable trees during harvest and elevated mortality of residual trees after harvest) led to a projected 45-year difference in basal area return intervals.

The impact of partial harvest on stand development

In forest regions across Canada, partial or "structural retention" harvests are being implemented where clearcutting practices formerly dominated. These alternative silvicultural treatments generally aim to maintain habitats such as denning and nesting sites, provide microclimate conditions necessary for seedling establishment, and supply woody debris essential for terrestrial and adjacent aquatic systems. Despite the increasing popularity of alternative silviculture, little is known about how treated stands will develop over long time scales. This represents a critical knowledge gap, since understanding how current forest practices will impact long-term stand development and regeneration is essential for sustainable forest management.

Accurate predictions of stand development following partial harvests require information on growth and mortality responses of residual trees. For example, post-harvest stand development is expected to proceed rapidly when residual trees respond well, displaying large growth responses and low mortality rates. In contrast, treatments associated with high residual-tree mortality rates and minimal growth responses are likely to develop slowly, and may not be justifiable from either an ecological or an economic perspective.

We quantified residual-tree growth and mortality responses to partial harvests in the black spruce boreal forest in northeastern Ontario. Using a simulation model, we explored how variations in the harvest prescription influence stand development over short and long time scales.

Partial harvest treatment

Harvest with Advance Regeneration Protection (HARP) is a partial harvest treatment that was developed for uneven-aged lowland black spruce stands in the clay belt region of northern Ontario and Québec. The HARP treatment was initially designed to reduce harvest return intervals and regeneration costs by protecting large unmerchantable stems and existing regeneration. Within the current ecosystem management paradigm, HARP is often described as a more ecologically-based harvest method that mimics moderate-severity disturbances such as windstorms.

Figure 1. Harvest with Advance Regeneration Protection (HARP) in the black spruce boreal forest of northeastern Ontario. Photo courtesy of AbitibiBowater.

HARP-treated stands are characterized by alternating clearcut strips, 5-7 m wide, in which harvest machinery travels, and partial harvest strips, 5-9 m wide, in which 10-12 cm diameter-limit cutting takes place (Figure 1). In Ontario, at least 6 large trees per hectare are also retained to meet provincial wildlife standards.

Quantifying residual-tree responses to harvest

We quantified post-harvest mortality and growth over the first decade after HARP in the Iroquois Falls Forest, a 1.1 million hectare area in northeastern Ontario. We mapped and measured all stems (stumps and live and dead trees) larger than 5 cm diameter in fifty-four 20 m radius circular plots. We took disc samples from over 600 dead trees and used dendrochronological methods to identify year of death. We took core samples from 900 live trees to quantify growth responses to harvest. Spatial information gained from stem mapping was used to estimate the influence of neighbourhood factors, including local competition, exposure, crowding and skid trail proximity, on residual-tree growth and mortality responses.

Rates and causes of post-harvest mortality

An average of 13.3% of retained trees died over the first decade after HARP. Background mortality accounted for 2.8% of this mortality, while the remaining 10.5% was attributed to elevated harvest-related mortality. Annual mortality peaked in the first year after harvest, at ~4% of residual trees, and declined thereafter, falling below the average background rate by the tenth year after harvest (Figure 2).

Residual-tree mortality in the first decade after harvest was split nearly equally between standing dead and windthrown trees, including snapped and uprooted trees. Most windthrow occurred in the first two years after harvest, while the standing death rate declined more slowly over the study period. For both windthrow and standing death, proximity to skid trails was the most important factor affecting mortality risk. Where skidding impacts were highest, over 35% of residual trees died in the first decade after harvest. In contrast, mortality rates were comparable to background levels where skidding impacts were low. Exposed residual trees were also at increased risk of windthrow, while crowded trees experienced higher standing death risk.

We assume that the strong influence of skid trails on mortality risk is a result of root damage that occurs through soil compaction. Bark damage, which can compromise tree defenses and increase vulnerability to insect and pathogen invasion, may also play a role in increasing risk of mortality.

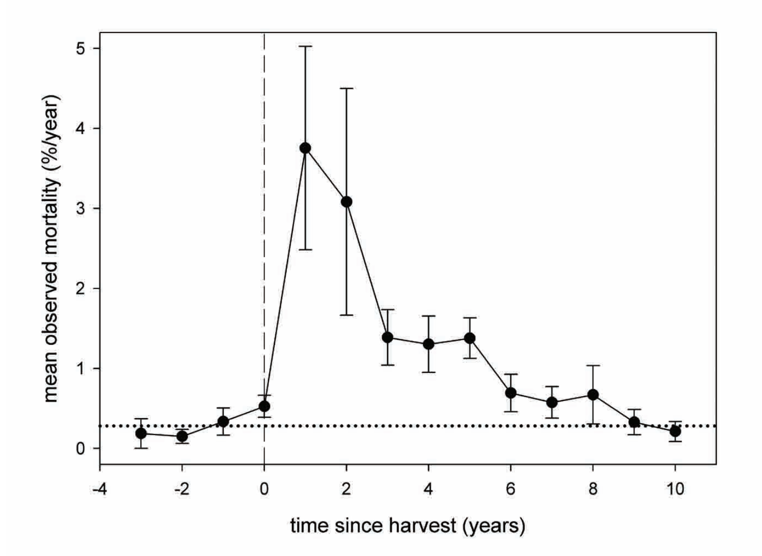

Figure 2. Mean observed annual mortality (± standard error) following Harvest with Advance Regeneration Protection (HARP) in the black spruce boreal forest. The dashed vertical line indicates the harvest event and the dotted horizontal line indicates pre-harvest background mortality (0.28% per year). Figure from Thorpe et al. 2008.

Positive growth responses to harvest

Residual trees also showed increased radial growth rates following HARP. The pattern was characterized by a 2-year lag period of no response followed by a steep increase in growth (Figure 3). By the eighth year after harvest, trees were growing at twice their pre-harvest rate. On an individual-tree basis, radial growth rates decreased with increasing neighbourhood competition. Smaller trees grew faster in the absence of competition but their growth rates declined more steeply with increasing levels of competition.

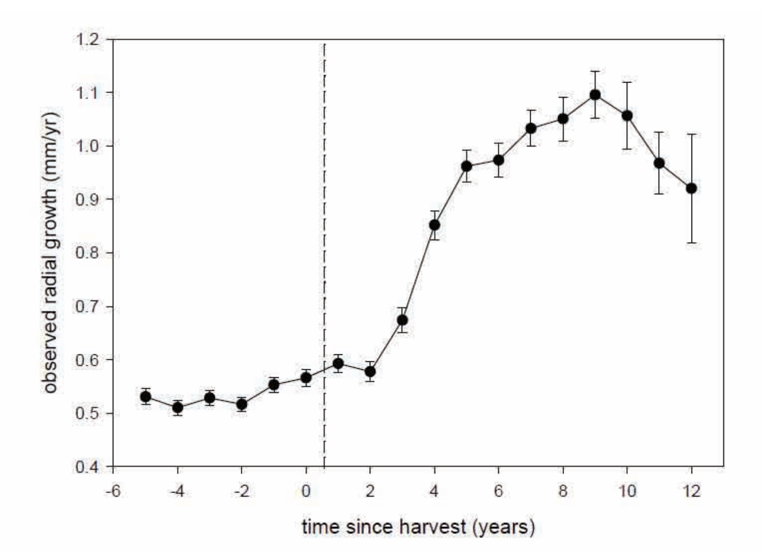

Figure 3. Mean observed radial growth response of residual black spruce trees (n=944) to partial harvest (± standard error). Dashed vertical line indicates harvest event. Figure from Thorpe et al. 2007.

A model to predict post-harvest stand development

We used the empirical results from our field studies to develop spatially-explicit, individual-based neighbourhood sub-models of black spruce growth and mortality. Predictors of mortality risk included tree size, proximity to skid trails, and neighbourhood basal area (a proxy for exposure and crowding). Growth rates were predicted by tree size and neighbourhood basal area (a proxy for competition).

To explore alternative partial harvest treatments, we developed a harvest sub-model based on three parameters: skid trail width, leave strip width, and diameter limit. All stems are harvested from the skid trails, while only stems larger than the diameter limit are removed from the leave strips. Although in practice the HARP treatment varies, results from our field data indicated that the average prescription entailed 6-m-wide skid trails, 8-m-wide leave strips, and a 12-cm diameter limit. We explored the effect of the harvest parameters by varying one of the following paramers: skid trail width (from 3 to 15 m); leave strip width (from 3 to 15 m); or diameter limit (from 10 to 20 cm); while holding the other two constant.

We used SORTIE-ND, a spatially explicit, individual-based stand simulation model, as a platform to implement our harvest and residual-tree growth and mortality submodels. In our simulations, we quantified stand development over short (10-year) and long (120-year) time scales following a range of partial harvest treatments. In the 120-year simulations, recruitment was initiated as a single cohort. Recruitment was not included in the short-term simulations.

Projected stand development after partial harvests

Model results indicated that stand development proceeded most rapidly in treatments in which retention levels remained relatively high and residual-tree mortality rates were low. Retention levels were increased by narrowing the skid trails, widening the leave strips, and/or employing a larger diameter limit. Wider leave strip treatments were also associated with reduced rates of post-harvest mortality, since higher proportions of residual trees were located away from skid trails and their related mortality risk.

Our simulation results highlight the strong influence of residual-tree responses on post-harvest stand development. For example, stand-level basal area growth rates over the first decade after simulated HARP were overestimated by 55% if observed rates of post-harvest mortality were not included in the model. These decadal-scale differences in basal area development continued over longer time periods as well. For the HARP treatment, the projected basal area return interval was 85 years; excluding post-harvest mortality reduced this estimated return interval to 65 years. Similarly, across leave strip widths from 3 to 15 metres, projected basal area return intervals ranged from 115 to 70 years respectively (Figure 4).

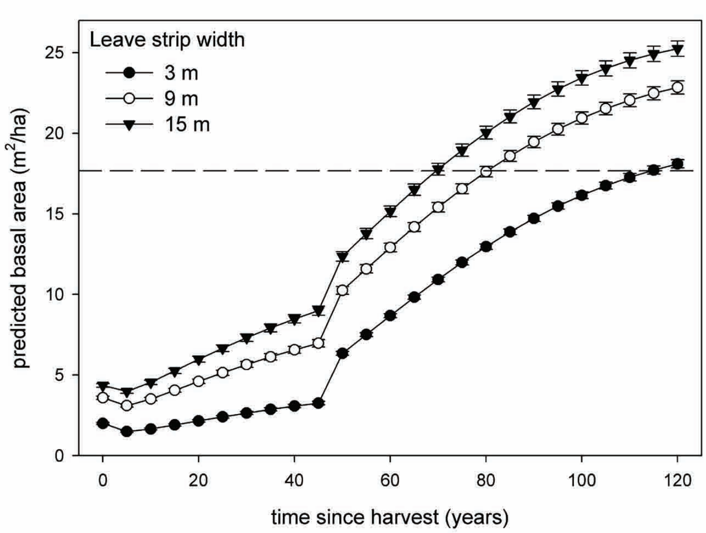

Figure 4. Mean projected basal area development (stems > 5 cm diameter) in the first 120-years after partial harvest. In all treatments, every stem larger than 12-cm diameter was harvested and skid trails were 6-m wide. Basal area increases in year 50 are a result of the cohort of recruiting trees reaching the adult (> 5 cm) size class. The dashed horizontal line indicates pre-harvest basal area. The first timestep in which basal area exceeds this line is the estimated basal area return interval.

Implications for management

Various forms of partial harvests are being implemented in forest regions worldwide. Although some level of residual-tree mortality is expected and perhaps even desirable, partial harvests are likely to succeed only if tree mortality rates remain low. Our results indicate that treatments in which the distance between skid trails is maximized are likely to display lower tree mortality and faster stand development rates.

Although increasing retention levels are often associated with reduced harvest volumes, this is not necessarily the case. In the treatments depicted in Figure 4, for example, every merchantable stem (>12 cm dbh) is harvested, and thus differences in basal area immediately after harvest are solely a result of collateral damage—trees harvested in the skid trails that are too small to be merchantable. In each of these treatments, the same volume of wood would be taken to the mill, but differences in collateral damage, both during and after harvest, led to a projected 45-year difference in basal area return intervals (Figure 4).

In summary, results from this study highlight the strong influence of residual-tree responses on long-term stand development, and suggest that minor modifications to harvest prescriptions are likely to accelerate stand development after partial harvests.

Management Implications

- *Consider residual-tree responses when planning partial harvests.* Residual-tree responses to partial harvests strongly influence the structure of treated stands, and may reduce the ability of partial harvests to provide the ecological functions for which they were designed. Forest managers must consider residual-tree responses when designing prescriptions. In particular, minimizing post-harvest tree mortality will help to ensure success of novel treatments.
- *Maximize distance between skid trails.* Increasing the distance between skid trails is expected to reduce post-harvest mortality rates and thus increase rates of post-harvest stand development.
- *Maintain high levels of retention.* A clear trade-off exists between per-hectare harvest volumes and retention levels. However, high-retention partial harvests are associated with faster stand development and lower windthrow rates. Thus, retention levels should remain as high as possible in partial harvests. This may require modifications to harvest scheduling; for example, using shorter return intervals and removing lower volumes at each stand entry.

Further reading

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SORTIE-ND: http://www.sortie-nd.org

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