Approximating natural landscape pattern using aggregated harvest

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Abstract: Successful implementation of the natural disturbance model for timber harvest is hindered by the lack of strategies to approximate landscape fire pattern. In the forests of Alberta, Canada, the fire regime is dominated by large fires that create large regions of same-aged forest. Current forestry practices disperse harvest blocks across the landscape, causing increased fragmentation as compared with fire. Aggregating harvest blocks is one potential strategy to improve approximation of natural landscape pattern. We used a simulation approach to compare landscape pattern created by aggregated harvest strategies, the current dispersed harvest approach, and the natural disturbance regime for a 270 000 ha forest landscape in northeastern Alberta. Compared with dispersed harvest, aggregated strategies increased compatibility with natural landscape pattern by reducing fragmentation. Capacity to aggregate harvest declined when the constraint of maintaining a constant proportion of deciduous to coniferous harvest was included. We conclude that aggregated harvest can improve implementation of the natural disturbance model by bringing several landscape metrics closer to the conditions that fall within the natural range of variability. Aggregated harvest alone, however, performed poorly at maintaining interior old forest, emphasizing that an explicit old-forest strategy is also required.

Résumé : Étant donné l'absence de stratégies pour modéliser le comportement du feu à l'échelle du paysage, il est difficile d'appliquer avec succès un modèle de récolte du bois qui imite les perturbations naturelles. Dans les forêts albertaine, au Canada, le régime des feux est dominé par de grands incendies qui engendrent de vastes étendues de forêt équienne. Les pratiques forestières actuelles dispersent les blocs de coupe à travers le paysage, ce qui augmente la fragmentation comparativement à l'action du feu. Le regroupement des blocs de coupe est une des stratégies potentielles pour reproduire plus fidèlement le paysage naturel. Nous avons eu recours à la simulation pour comparer les modèles de paysage engendrés par des stratégies de regroupement des coupes, l'approche actuelle de coupes dispersées et le régime de perturbations naturelles pour un paysage forestier de 270 000 ha dans le sud-est de l'Alberta. Comparativement aux coupes dispersées, les stratégies de regroupement augmentent la compatibilité avec le paysage naturel en réduisant la fragmentation. La capacité de regrouper les coupes diminuait lorsqu'on incluait comme contrainte la récolte d'une proportion constante de feuillus et de résineux. Nous tirons comme conclusion que le regroupement des coupes peut améliorer l'application d'un modèle qui imite les perturbations naturelles en rapprochant plusieurs mesures du paysage des conditions qui se retrouvent à l'intérieur de la gamme naturelle de variation. Cependant, le regroupement des blocs de coupe seul n'était pas très efficace pour conserver les vieilles forêts intérieures faisant ressortir le fait qu'il faut aussi adopter une stratégie explicite pour les vieilles forêts.

[Traduit par la Rédaction]

Introduction

The natural disturbance model (Hunter 1993) has been embraced as a strategy to transition forestry from sustained-yield to ecological forest management. The premise is that biodiversity will persist if anthropogenic disturbance approximates the natural disturbance regime to which native biota are adapted (Bunnell 1995). In the province of Alberta, located in western Canada, the natural disturbance model is supported by provincial policy (AFCSSC 1997) and has been adopted as a guiding principle by forestry companies (e.g., Alberta Pacific Forest Industries 1999). Implementation of the approach is incomplete, however, limited in part by insufficient understanding of how to approximate natural landscape patterns (Schneider 2002).

The dominant natural disturbance agent in Canada's boreal forest is fire (Johnson et al. 1998). According to the natural disturbance model, forestry should therefore be managed such that the rate of harvest equals the rate of fire and such that pattern imposed by harvest resembles pattern imposed by fire at both the stand and landscape scale (Hunter 1993). Relevant strategies have been developed to set harvest rates (Armstrong et al. 2003) and emulate stand-level fire patterns through harvest (Song 2002). In comparison, how to emulate landscape fire pattern is poorly understood. A prevailing characteristic of fire at the landscape scale is the dominant influence of large fires, with an estimated maximum fire size of 650 000 ha (Cumming 2001). Large fires are responsible for the majority of area affected by fire in Alberta, with just 5% of the fires between 1961 and 2000 being responsible for 98% of the area burned (Schneider

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2002). As a result, large regions of same-aged forest are created (Johnson et al. 1998) that differentiate postfire into smaller stands of various forest types, depending on site characteristics and seed availability (Lieffers et al. 1996).

Compared with the aggregated tendency of fire, timber harvest in Alberta is dispersed. For example, in the Alberta Pacific Forest Management Agreement Area in northeastern Alberta, harvest scheduling attempts to disperse harvest across the managed region to achieve stable delivered log costs and dispersion of remnant older forest (Alberta Pacific Forest Industries 1999). While effective at achieving these goals, dispersed harvest is likely incompatible with the natural disturbance model because of exaggerated landscape fragmentation. Spatially aggregating harvest or increasing the size of harvest units has been suggested as a strategy to reduce fragmentation, thus better approximating natural landscape pattern (Delong and Tanner 1996; Hunter 1993). Simulation studies using theoretical landscapes have lent support to the strategy by indicating that aggregated harvest should reduce edge and increase interior habitat as compared with dispersed harvest (Franklin and Forman 1987; Li et al. 1993).

Shifting the scheduling of harvest blocks from dispersed to aggregated represents a dramatic change in landscape forest planning, and while potential benefits of aggregated harvest have been identified, additional information is required to justify and guide the transition. Compared with previous analyses, large landscapes must be considered and forest characteristics such as succession and variable initial age-class and species composition more fully incorporated. Operational strategies for aggregating harvest must be developed. Finally, the effects of aggregated harvest on landscape pattern must be compared with those expected from fire. Here we use a spatially explicit simulation approach to evaluate a range of strategies for applying aggregated harvest to a 270 000 ha landscape in northeastern Alberta and compare the strategies with both dispersed harvest and the natural fire regime. Focus is on implementation of the natural disturbance model at the landscape scale and on the changes over time of several spatial landscape metrics.

Methods

Study area

The study area was the L1 Forest Management Unit (FMU), a 278 125 ha boreal mixedwood landscape within the Alberta Pacific Forest Management Agreement Area in northeastern Alberta. Approximately half of the FMU (136 426 ha) is timber productive forest (i.e., capable of producing merchantable forest), consisting of aspen (*Populus* L.) and white spruce (*Picea glauca* (Moench) Voss) pure and mixed stands, jack pine (*Pinus banksiana* Lamb.) stands, and a lesser amount of black spruce (*Picea mariana* (P. Mill.) B.S.P.) stands. The remaining area within the FMU exists as stands with insufficient volume, peatland complexes, aquatic features, watercourse buffers, and other operational deletions. Coniferous harvest in the FMU began between 1915 and 1920, although clear-cutting did not begin until the early 1970s (G. Dribnenki, personal communication, 2006). Deciduous harvest began in the early 1990s when a hardwood pulp mill was built.

TELSA

The baseline scenarios establishing the natural range of variability resulting from historical fire regimes and the harvest strategies were simulated using the Tool for Exploratory Landscape Scenario Analyses (TELSA) (Kurz et al. 2000), version 1.5. TELSA is a polygon-based, spatially explicit model designed to evaluate the implications of succession, natural disturbance, and forest management on indicators relevant to forestry and ecological integrity. To prepare input data for TELSA simulations, 71 767 polygons were assigned cover types (aspen, aspen leading mixedwood, white spruce, white spruce leading mixedwood, jack pine, aspen – jack pine mixedwood, black spruce, and a variety of nonmerchantable cover types), age classes (0–20, 21–40, . . ., 181–200, >200 years), and merchantability (i.e., capable of producing merchantable timber) as specified for each polygon in the Alberta Vegetation Inventory database for the study area provided by Alberta Pacific Forest Industries (Al-Pac). Fire and clear-cut harvest were assumed to reduce a polygon's age to zero. Although TELSA is designed to simulate complex successional pathway diagrams, for this simulation experiment, stand-replacing disturbances were assumed to not alter the successional pathways, and each polygon will over time return to its predisturbance cover type. Deciduous and coniferous timber volume of each polygon changed through time according to cover-type specific growth and yield tables provided by Al-Pac. Simulations were 150 years in length, with annual time steps. Management regimes varied across simulations, as described below.

Natural range of variation

The fundamental goal of the natural disturbance model is to maintain or return landscape conditions within the natural range of variation. Several landscape metrics (explained below) were used to describe the natural range of variation. Natural range of variation equaled the interval defined by the minimum and maximum value of a fragmentation metric between years 100 and 300 from three independent simulations of the same fire regime (i.e., same return interval but different time series of the area burned per year) in the absence of fire suppression and harvest. The initial 100 years were not considered to ensure the legacy of existing timber harvest did not bias the natural range of variation estimates. In each simulation year, the total area burned was drawn from a lognormal distribution (Armstrong 1999) and then divided into individual fires that were applied to the landscape. Mean fire rates were equal to Cumming's (1997) fire rate estimates (deciduous = 0.271, white spruce = 0.671, black spruce = 0.597, pine = 0.738, and mixed = 0.315) calculated from 1940–1993 fire data for the Alberta Pacific Forest Management Agreement Area and corrected to remove the effect of fire suppression. Annual fire rate variance was equal to the variance calculated from fire records for Alberta north of 55° latitude from 1961 to 1996 (coefficient of variation = 2.2). When simulating individual fires, fire location was random, and fire sizes were based on a fire size distribution for the region provided by Al-Pac: 0–1 ha (63.4% of fire events), 1–10 ha (22.9%), 10–100 ha (9.6%), 100–1000 ha (2.7%), 1000 – 10 000 ha (1%), and 10 000 – 100 000 ha (0.4%). Fire shapes were irregular,

Table 1. Management scenarios differed with respect to spatial aggregation, temporal aggregation, and whether there was a single annual allowable cut (AAC) target across forest types or separate AACs for softwood (SW) and hardwood (HW).

Scenario	Spatial aggregation	Temporal aggregation	AAC target
Dispersed harvest	No	No	Single
Spatially aggregated	Yes	No	Single
Temporally aggregated	Yes	Yes	Single
Spatially aggregated with separate AACs	Yes	No	Separate SW and HW target

with fire spreading to adjacent polygons based on the probability of burning the polygon's vegetation type until the target size for the specific fire was reached.

Management strategies

We simulated four management scenarios to compare dispersed harvest with a suite of aggregated harvest strategies that varied in spatial and temporal aggregation and in the rules specifying the annual allowable cut for softwood and hardwood as either combined or separate (Table 1). Minimum harvest age was 70 years, and annual harvest was set at 261 000 m^3, the region's combined annual allowable cut across species (D. Cheyne, Al-Pac, personal communication, 2003). Harvest scenarios were simulated without fire to facilitate meaningful comparison, but this does not imply that we assume that 100% fire suppression success will be achievable in the future.

To implement aggregated harvest scenarios, we partitioned the 278 125 ha landscape into 15 000 ha aggregation units (AUs). (Fig. 1). Dispersed harvest was simulated by sequencing stands using an oldest first rule applied across the FMU. Spatially aggregated harvest strategies restricted harvest to a single AU. Upon exhaustion of an AU's merchantable timber, harvest proceeded to an adjacent AU, moving south to north. An additional simulation of the 15 000 ha AU scenario evaluated the implications of having separate deciduous (157 500 m^3) and coniferous (103 500 m^3) harvest targets, as is currently the situation in the region (D. Cheyne, Al-Pac, personal communication, 2003).

In addition to spatial aggregation, wildfire in Alberta exhibits temporal aggregation due to infrequent but severe fire years (Armstrong 1999). Temporal aggregated harvest was simulated by harvesting at four times the usual rate (1 000 044 m^3) for 20 years, followed by 60 years of no harvest. During the 20-year harvest period, harvest proceeded south to north using 30 000 ha AUs.

Indicators

The primary landscape difference expected among simulations was fragmentation of similar-aged timber productive forest. Following Li et al. (1993), we defined fragmentation as increased number of landscape patches (as measured by mean patch size, given that the study area is fixed), decreased old interior habitat area (as measured by interior old, i.e., >100 years, forest area at least 50 m from the edge of forest with another age), increased edge density (measured as metres of edge per hectare), and increased isolation of similar patches (as measured by contagion). Old forest was evaluated when calculating the interior habitat metric owing to the importance of old forest to boreal biodiversity (Schieck et al. 1995) and its sensitivity to harvest (Schneider et al. 2003). Edge buffer width was assumed to be 50 m when calculating interior habitat, based on a 20–60 m distance of edge influence found by Harper and Macdonald (2002) for the mixedwood boreal forest. The contagion metric is inversely related to dispersion and interspersion, ranging from 0 (every patch is a different type) to 100 (every patch is the same type).

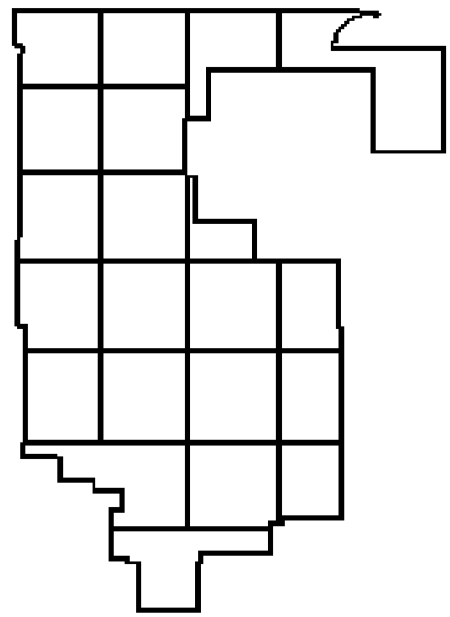


Fig. 1. The study area divided into 15 000 ha aggregation units. Under the aggregated harvest scenarios, harvest is restricted to a single aggregation unit until a subsequent aggregation unit must be entered to satisfy harvest targets.

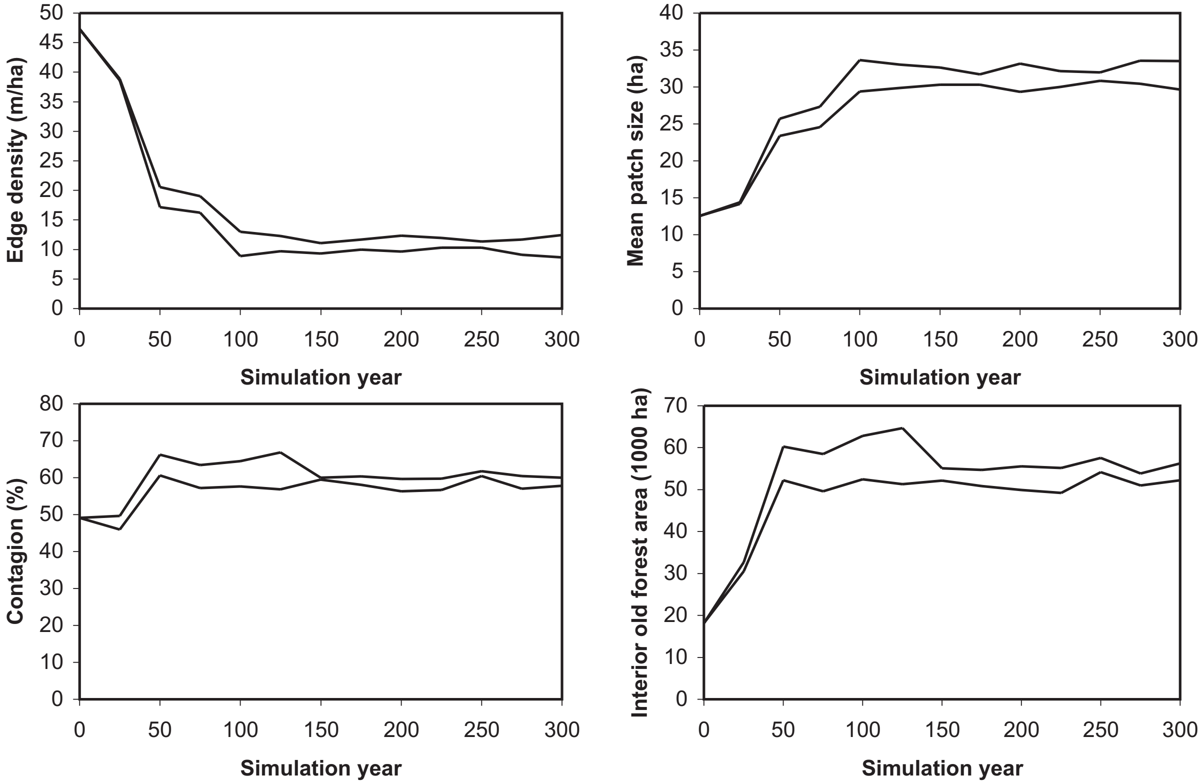
Fragmentation analysis was isolated to the timber productive portion of the landscape, with patch definitions based on four age classes: 0–20 years (early successional), 21–60 years (young), 61–100 years (mature), and >100 years (old). Fragmentation metrics were calculated using FRAGSTATS (McGarigal et al. 2002) to analyse maps produced by TELSA at 25-year intervals showing forest cover and age of all polygons.

Total harvest volume and distribution of volume between deciduous and coniferous components were calculated to compare economic implications of the scenarios.

Results

Results from the fire regime simulations indicated that eliminating the first 100 years was sufficient to ensure that

Fig. 2. Minimum and maximum edge density, mean patch size, contagion, and interior old forest area over the course of three simulations of the natural fire regime. Patches were defined as contiguous timber productive forest belonging to the same age class (0–20, 20–60, 60–100, or >100 years) when calculating landscape metrics. Interior old forest area refers to forest >100 years and separated from other age classes by at least 50 m.



the natural range of variation estimate was unaffected by the landscape legacy of timber harvest (Fig. 2). Based on the final 200 years of the fire regime simulations, the estimated natural ranges of variation for landscape metrics were 8.7–13.0 m/ha edge density, 29.3–33.6 ha mean patch size, 56.3%–66.8% contagion, and 49 227 – 64 645 ha interior old forest area. All landscape metrics were outside of the simulated natural range of variation at year 0 of the simulation. Under dispersed harvest, patch size was smaller, edge density higher, contagion lower, and old interior forest habitat lower than the simulated natural range of variation (Fig. 3). Through time, the spatially aggregated harvest scenarios improved approximation of natural spatial patterns, except amount of interior old forest, which was nearly eliminated from the study area (Fig. 3). In comparison with spatially aggregated harvest, temporally aggregated harvest increased the rate at which mean patch size approached the natural range of variation and resulted in contagion and edge density that exceeded the natural range of variation (Fig. 3). Interior old forest initially declined rapidly under temporally aggregated harvest but increased moderately towards the end of the simulation, albeit to a level lower than both the initial level and the natural range of variation.

Each of the scenarios achieved the harvest goal, with the periodic strategy exhibiting phases of high harvest and no harvest (Fig. 4). Although this would violate even-flow constraints for an individual management unit, the L1 FMU represents only 6% of the Alberta Pacific Forest Management Agreement Area (Alberta Pacific Forest Industries 1999). In scenarios with a single AAC, the deciduous harvest proportion was highly variable from year to year, as illustrated by the spatially aggregated scenario (Fig. 5). Separate deciduous and coniferous harvest targets reduced the variability in the deciduous harvest proportion (Fig. 5). However, separate harvest targets also reduced capacity to aggregate harvest. At the end of a spatially aggregated simulation that included coniferous and deciduous harvest targets, mean patch size was only half (14 ha) that achieved by the simulation with a single harvest target (Fig. 6).

Discussion

Our results show that the common forestry practices of dispersing cut blocks and sequencing stands on an oldest first basis fail to approximate natural landscape patterns. In the western boreal forest of Alberta, the natural fire regime is characterized by large fires that create large regions of similar-aged forest. In comparison, simulated dispersed harvest fragmented the forest. Spatially aggregated harvest improved approximation of natural forest landscape pattern, in some cases adjusting spatial metrics to within the simulated natural range of variation. The effectiveness of spatially aggregated harvest may be at least in part due to the simulated strategy of sequencing adjacent AUs. Subsequent analysis should evaluate the effect of sequencing dispersed rather than adjacent AUs. Temporally aggregated harvest excessively simplified the forest, as indicated by a contagion value that exceeded the natural range of variation. This find-

Fig. 3. Simulated edge density, mean patch size, contagion, and interior old forest area over time for the dispersed, spatially aggregated, and temporally aggregated harvest scenarios. The natural range of variation (NRV) for each metric represents the minimum and maximum value of the metric across all years of three simulations of the natural fire regime in the absence of suppression and timber harvest. Patches were defined as contiguous timber productive forest belonging to the same age class (0–20, 20–60, 60–100, or >100 years) when calculating landscape metrics. Interior old forest area refers to forest >100 years and separated from other age classes by at least 50 m.

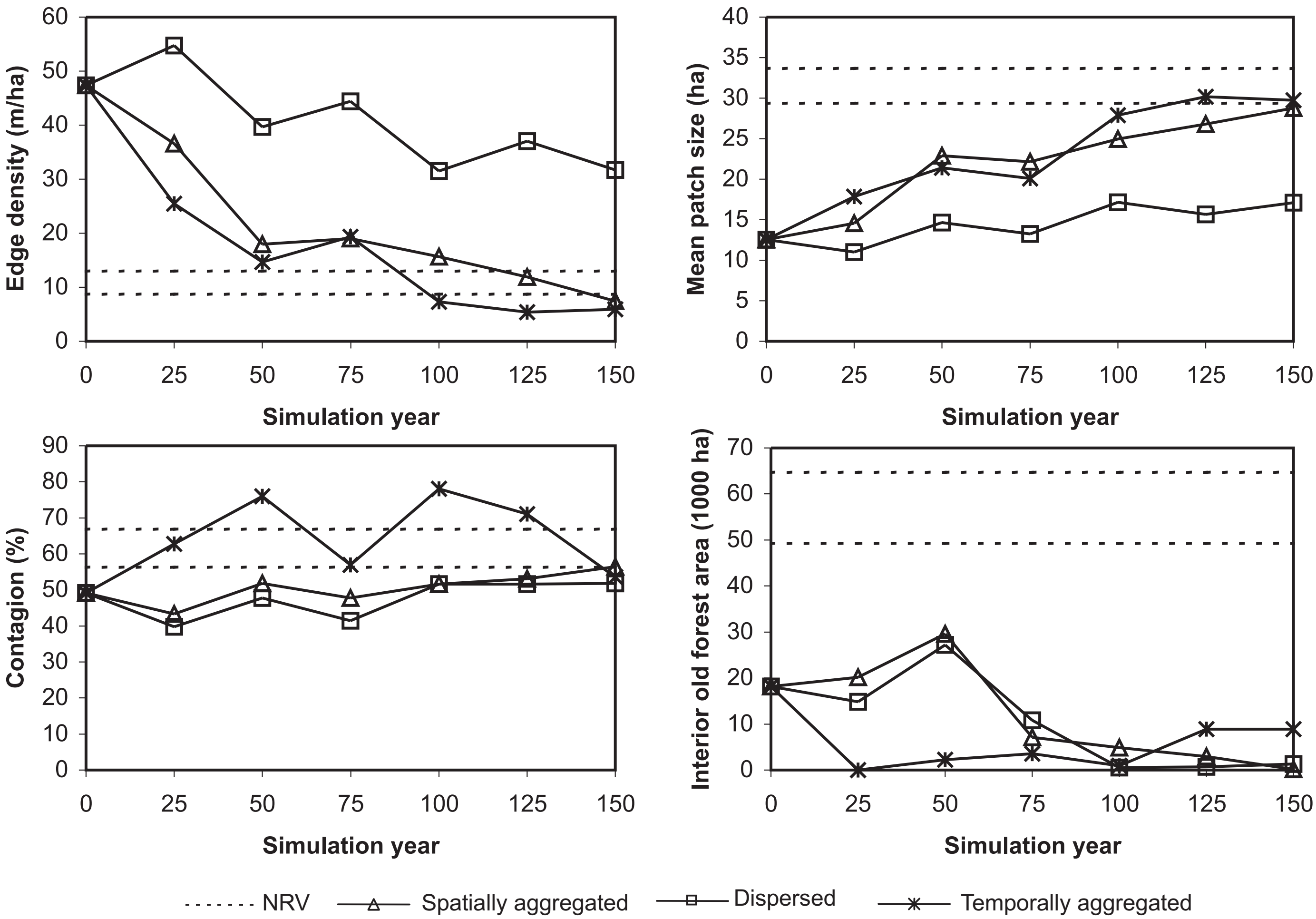


Fig. 4. Simulated annual timber harvest (m^3) for the spatially aggregated and temporally aggregated harvest scenarios.

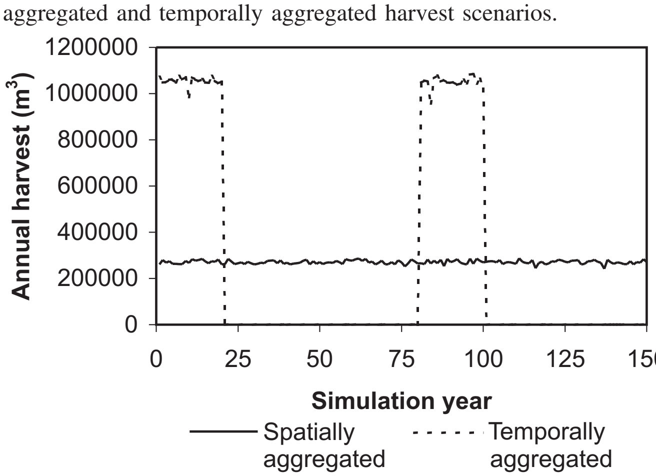


Fig. 5. Proportion of simulated annual timber harvest belonging to deciduous species for the spatially aggregated harvest scenario with a single annual allowable cut (AAC) and with two AACs (deciduous and coniferous).

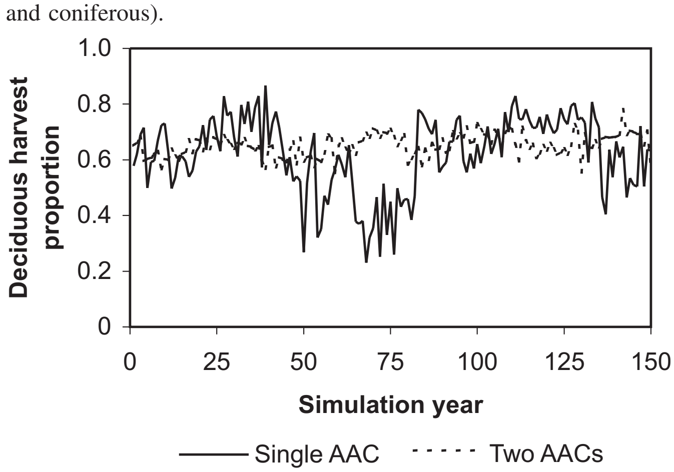
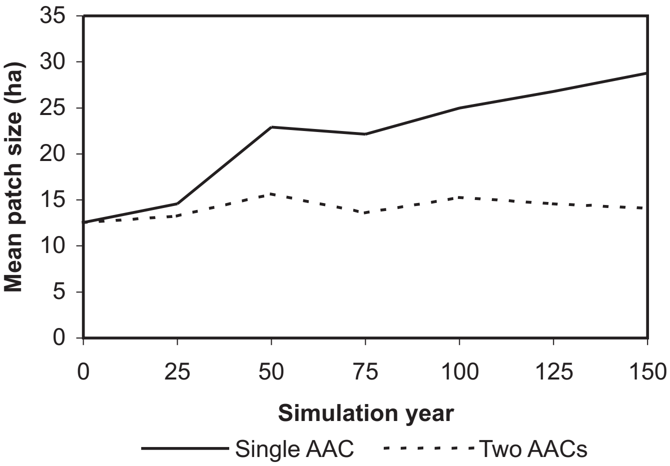


Fig. 6. Simulated mean patch size for the spatially aggregated harvest scenario with a single annual allowable cut (AAC) and with two AACs (deciduous and coniferous).



ing and our expectation that intense harvest intervals resulting from temporally aggregated harvest would be unacceptable to society suggest that spatial aggregation may be the better choice as harvest strategy.

The accuracy of the landscape metrics' natural range of variation estimated from fire simulations is difficult to determine. The current configuration of the landscape is outside the natural range of variation estimates, but this is to be expected given the history of land use in the region. Timber harvest, which has occurred for approximately 90 years, will result in a more fragmented and younger forest (Schneider 2002; Klenner et al. 2000; Bergeron et al. 1999; Delong and Tanner 1996). We attempted to compare the natural range of variation estimates with those made by previous studies, but we were not able to identify such studies, except for interior old forest area. By applying the average annual rate of burning observed in Alberta from 1960 to 2000 (0.4%), Schneider (2002) estimated that 67% of the landscape should be older than 100 years in the absence of land use. In comparison, we estimated that 36%–47% of the timber productive forest should be interior old forest in the absence of land use. Our lower estimate is to be expected, because interior old forest area does not include all old forest on the landscape, but rather is restricted to old forest that is at least 50 m from younger forest. If all old forest area is considered, the natural range of variation estimated by our simulations is 58%–74%, which compares well with Schneider's (2002) estimate. In addition, the use of empirically derived fire size and rate estimates in simulations lends support to the relevancy of the estimated natural range of variation for the other metrics. However, the extent to which the current landscape configuration differs from the estimated natural range of variation is perhaps surprising, and the accuracy of natural range of variation remains uncertain. The difficulty of estimating the natural range of variation in managed landscapes emphasizes the importance of studying areas that are relatively unaffected by human activities to increase understanding of natural conditions (Wiersma 2005).

Old forest must be maintained if the full spectrum of native fauna is to be sustained (Niemela 1999). Our results indicate that aggregated harvest is an inadequate old forest management strategy. Interior old forest was reduced from covering over 13% to less than 1% of the merchantable forest area in the spatially aggregated harvest. Temporally aggregated harvest performed better in this regard, maintaining 6.6% of the merchantable forest as interior old forest by the end of the simulation. Temporally aggregated harvest was able to maintain more old forest because not all of the productive forest was harvested in the second harvest period, effectively allowing a portion of the forest to escape a harvest rotation. This result is artificial, however, and is the outcome of under-representing disturbance to the merchantable forest. Our simulations assumed harvest to be the sole disturbance to the merchantable forest. Another simulation study for the same region that considered the more realistic scenario of timber harvest acting in concert with fire and oil and gas development found that there was insufficient timber volume to satisfy annual allowable harvest requirements (Schneider et al. 2003). Such effects would eliminate the ability of temporally aggregated harvest to maintain old forest. If old forest is to be maintained, aggregated harvest must be combined with an old forest strategy, such as protection of some portion of the merchantable land base (Klenner et al. 2000) or selection cutting to retain old forest structural characteristics in harvested stands (Bergeron et al. 1999). Even if the area annually disturbed by wildfire (in the historical simulations) and harvest (in the future simulations) were the same, fire affects stands of all ages, while harvest targets only stands that are of merchantable age. Fire-dominated landscapes thus typically contain more old forest than do managed landscapes, unless old forest is specifically protected against harvest using reserves or extended rotations (Burton et al. 1999). Increased reserves or extended rotations will have negative implications for the annual allowable cut (Armstrong et al. 1999), although the timber supply shortfall can be at least partially offset by allocating part of the landscape to intensive forest management (Krcmar et al. 2003). For example, Al-Pac is developing poplar farms on leased private agricultural land to supply part of the mill's fibre requirements (Alberta Pacific Forest Industries (no date)).

The boreal fire regime creates patterns at multiple spatial scales. We evaluated the ability of harvest strategies to emulate the coarse-scale pattern of large regions of same-aged forest arising from a wildfire-only regime. At a finer scale, fire skips leave patches of older forest within a fire's boundary (Johnson et al. 1998). Lee et al. (2002) found the amount of residuals within Alberta fires to vary from 5.6% to 10.8% of the timber productive landscape, with larger burns exhibiting the greatest level of retention. The size of the residual forest patches varied from under 0.1 ha to larger than 80 ha. Residual patches can be important in maintaining habitat diversity necessary to support biodiversity (e.g., Merrill et al. 1998). Successful implementation of the natural disturbance model requires retention of merchantable forest within aggregated harvest blocks. The amount and spatial distribution of residuals should be guided by analyses of residual patterns within burned areas, such as presented by Lee et al. (2002).

Division of harvest between deciduous and coniferous components was erratic when a single harvest target was simulated because of the variable spatial distribution of deciduous and coniferous forest across the study area. This is problematic because regulations require constant flows of each of the four merchantable species. However, when a single harvest target was replaced with targets specific to deciduous and coniferous components, capacity to aggregate harvest and approximate natural landscape pattern decreased. Relaxation of the requirement to maintain constant proportions of species in timber harvest may therefore be required if the full benefits of aggregated harvest are to be realized in the mixedwood region. This can be tolerated because a single FMU represents only a small fraction of the timber supply landbase, and shortfalls of one species within the FMU can be compensated from other FMUs.

Our simulations, using actual forest data and more realistic harvest strategies, agree with the conclusion from previous theoretical simulation studies (e.g., Li et al. 1993; Franklin and Forman 1987; Wallin et al. 1994) that aggregation of harvest units decreases landscape fragmentation. One discrepancy between our results and those of Wallin et al. (1994) is worthy of mention, however. Wallin et al. (1994) found that existing landscape patterns imposed by dispersed harvest are difficult if not impossible to eliminate using aggregated harvest rules, even over three centuries. In contrast, we observed steady reduction in landscape fragmentation, sometimes to within the natural range of variation within 150 years. Reasons for the conflicting result are difficult to identify, but likely stem from differences in aggregation strategy. To aggregate harvest, Wallin et al. (1994) used an algorithm called the dispersion index (Clark and Evans 1954). Our strategy of using aggregation units, in addition to being simpler and more amenable to real-world implementation, appears more efficient at reducing landscape fragmentation.

Timber harvest was simulated in the absence of other disturbances, namely fire and oil and gas development, to simplify comparisons across management strategies. Including these disturbances in all simulations will not affect relative effects of the strategies to fragmentation and therefore not affect the conclusions of this paper. Three implications are worth noting, however. As discussed previously, including these disturbances may cause timber harvest to become unsustainable. In addition, fire and oil and gas development will affect landscape configuration. Inclusion of fire will decrease old forest area, but it is hard to predict how the combined impacts of fire and timber harvest will affect the other fragmentation metrics. Oil and gas development, on the other hand, will cause increased fragmentation across scenarios. Each year in the region, the energy sector disturbs an area approximately two-thirds the size of that disturbed by forestry activities (Schneider et al. 2003). Energy sector disturbances, including seismic lines, well sites, roads, and pipelines, are potentially more disruptive to natural forest pattern because they persist much longer. Aggregating energy exploration to synchronize with forestry activity is an interesting option and should be explored in future research. However, application of the strategy will be difficult because of government policies that discourage long-term planning of energy development (MacKendrick et al. 2001). Finally, harvest areas are ecologically different than burned areas. Forest harvesting can degrade sites through processes such as depletion of nutrients and deadwood resources (Lee 1999); forest structure differs between stands recently disturbed by fire and harvest; and early fire communities that provide habitat for wildlife (Hoyt and Hannon 2002) cannot be replicated by harvest (Lee 1999). Maintenance of fire, and the habitat it creates, is therefore a necessary component of any attempt to implement the natural disturbance model.

The realism of the dispersed harvest simulation must be considered given that it was used as a benchmark to interpret landscape-planning options. Dispersed harvest was meant to approximate the current forest landscape-planning strategy. The dispersed harvest scenario may actually underestimate landscape fragmentation associated with the current approach, because it did not include green-up delay, the practice of not harvesting next to recently harvested blocks. The moderate decrease in fragmentation over the course of the dispersed harvest simulation supports this possibility. Should this be the case, we have underestimated the relative benefits of aggregated harvest.

Management implications

Spatially aggregated harvest returned several landscape metrics closer to the natural range of variability while not affecting the AAC for the area. While the strategy performed much better than the current practice of dispersed harvest, neither is sufficient to maintain interior old forest patches in the management area, suggesting that an explicit old forest strategy will be required. Effectiveness of aggregated harvest was compromised when harvest attempted to achieve separate deciduous and coniferous harvest targets.

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