Natural Disturbance Regimes as Templates for Boreal Forest Harvest

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ABSTRACT

The importance of natural disturbance events (e.g., fires, floods, blowdowns, insect outbreaks) to forest structure and function is generally accepted by ecologists. Accordingly, forest harvest strategies that reasonably approximate the variability in stand structure created by natural disturbances may offer a preferred risk management strategy for maintaining forest integrity. A critical task confronting managers who adopt a coarse-filter (e.g., disturbance regime) approach to forest management is the identification and measurement of variables that most meaningfully define disturbances. In Alberta and elsewhere in North America, variance in stand size, age, and structure created by wildfires is presently being considered by the forest sector, academia, and government as a general model for logging. Alberta-Pacific Forest Industries (AlPac), a large (~6 million ha) Forest Management Area (FMA) holder in northeast Alberta, is evaluating a forest harvest strategy based on a natural disturbance model. Specifically, variation in harvest rotation ages, cutblock sizes, and cutblock residuals (green trees, snags, downed woody material) would approximate fire return intervals, fire sizes, and post-fire residuals, respectively. Justification for this shift in forest harvest planning is the potential for traditional two-pass, 20–30 ha, short-rotation, clearcut harvest in boreal mixedwood forests to alter stand- and landscape-level heterogeneity and thus impair ecological function and wildlife habitat. To evaluate this potential change in landscape pattern, a series of stand metrics (patch size, shape, and interspersion) were used to compare pre-harvest landscapes to those created by a conventional two-pass harvest and modified type-cut harvest regime proposed by Alberta-Pacific Forest Industries. Relative to pre-harvest forest landscapes, traditional two-pass, clear-cut logging resulted in a landscape comprised of stands that had increased edge density, decreased shape complexity (double-log fractal dimension), decreased core area, and increased interspersion of patch types. Relative to the traditional two-pass logging strategy, the modified type-cut logging strategy created a forest mosaic more similar to the pre-harvested landscape. The analyses indicated that changes to landscape patterns caused by different forest harvest strategies were strongly influenced by existing patch configurations (e.g., variances between townships) that occur prior to logging. These preliminary results suggest that modified "type-cut"

logging may maintain pre-harvest forest landscape patterns better than a conventional two-pass logging strategy where cutblocks are spatially constrained to 40–60 ha.

INTRODUCTION

As societal expectations concerning North American forests broaden, so does the need to identify and implement a broader set of objectives that direct management policy (Maser 1994). Past management frequently focused on few forest attributes, primarily tree-fiber production, creating forest landscapes with altered structure and function, which were less able to provide non-fiber benefits to society. Recently, due to large hardwood-fiber allocations, the boreal mixedwood forests of North America have become a focus of national and international controversy involving the forestry sector and environmental groups (Nikiforuk and Struzik 1989). Relative to Alberta's total available Annual Allowable Cut (AAC) for trembling aspen (*Populus tremuloides*), harvest has increased from 2% (1971) to 15% (1988) to ~80% (1990) according to Karaim et al. (1990) and Peterson and Peterson (1992). Current harvest strategies for Alberta's aspen mixedwood forests are dominated by short-rotation (70-year) clear-cut (20–30 ha) logging involving two or three passes. Cutblocks are spatially constrained in that average size should not exceed 40 ha and cutblock width cannot exceed 400 m. The ecological issues concerning forest age, forest structure, landscape fragmentation, and sustainable harvest levels that dominated the Pacific Northwest conflict in recent decades have become topical and relevant to the boreal mixedwood forest sector.

Boreal mixedwood forests are a mosaic landscape comprised of countless stands that vary in age, size, shape, and dispersion (Peterson and Peterson 1992). Additional variation is apparent at the stand level for species composition of canopy trees, understorey structure, and levels of snags and downed woody material (Lee et al. 1995). Although much of the variability found in forest communities can be explained by soil type, elevation, and topography (Rowe 1972; Corns 1983; Swanson and Franklin 1992), natural disturbances occurring since the retreat of continental glaciers have contributed significantly to boreal forest heterogeneity (Pickett and White 1985; Attiwill 1994). Boreal forests have experienced a number of natural perturbations (e.g., floods, insect outbreaks, windstorms) during the Holocene epoch (past 10,000 years); however, fire is considered to have been the primary disturbance that shaped these communities (Rowe and Scotter 1973; Kelsall et al. 1977; Barney and Stocks 1983; Johnson 1992). The vegetative patterns created by fire on boreal landscapes are both complex and dynamic, as fire cycles vary both in space (Payette et al. 1989) and time (Bradshaw and Zackrisson 1990; Clark 1990; Bergeron 1991).

Variability created by natural disturbances in forest systems may be essential to plants and animals since biota are adapted to biophysical structures created by disturbances. In Alberta, boreal mixedwood forests support a diverse assemblage of organisms, including 40 fish species (Nelson and Paetz 1992), five amphibians (Russell and Bauer 1993), one reptile (Russell and Bauer 1993), 236 birds (Francis and Lumbis 1979; Semenchuk 1992), 45 mammals (Pattie and Hoffmann 1992; Smith 1993), and thousands of arthropods (Danks and Foottit 1989). Based on distribution maps in Moss (1983) and Vitt et al. (1988), conservative estimates indicate a rich diversity of plants in Alberta's boreal mixedwood forests, including 600 vascular species, 17 ferns, 104 mosses, 13 liverworts, and 118 lichens. Conservation of these organisms, and the communities to which they belong, may be constrained by the capacity for land-uses to maintain adequate variability in stand and landscape structure.

Current knowledge of the autecology of boreal forest biota is decidedly sparse and directed primarily at species of privileged recreational, conservational, or commercial status. From the better-known vertebrates, forest companies commonly select "feature" or "umbrella" species as models to guide harvest strategies for habitat purposes. Given our information vacuum, it remains uncertain whether forest management strategies built on habitat requirements of selected "umbrella" vertebrate species will adequately conserve entire biotic assemblages and associated forest processes. Concerns about the "fine-filter" approach to forest management include biased selection of taxal groups to which feature species belong, and the uncertainty of this approach to maintaining ecological processes (e.g., soil decomposition, nutrient pathways, successional pathways).

During recent decades, the role of natural disturbances in boreal forest systems has arguably changed as human attitudes and actions towards flooding, fire, and insects have altered the intensity, recurrence, and geographic extent of natural perturbations. Flood-control measures, insect-abatement campaigns, and fire-suppression programs have likely influenced the nature and extent of natural disturbances. In Alberta's boreal forests, research by Murphy (1985) indicates that fire return intervals increased from 38 years in pre-settlement times to 90 years by the late 1960s. In sharp contrast, anthropogenic disturbances are now conspicuous and growing in prevalence in northern forests (Anonymous 1991). Some land-use disturbances, such as agriculture, seismic activity, urban expansion, and transportation corridors, permanently excise patches or corridors of forests from the mixedwood forest mosaic. Others, like commercial clear-cut logging, permit the forest to persist, although in a different form and subject to altered ecological processes.

Recently, forest ecologists have suggested that the impacts of forestry on wildlife and ecological processes could be reduced if logging strategies were devised that approximated natural disturbance regimes and maintained variability in ecosystem conditions (Franklin 1993; Hunter 1993; Maser 1994). Elements of natural disturbances that may serve as a stand-level template for "new forestry" include retention and dispersion of live trees, snags, and downed woody material. At the scale of the landscape, the size, shape, rotation age, and interspersion of cutblocks could approximate the frequency distribution of these attributes created by natural disturbances such as fire. If we accept that organisms are adapted to different forest structures and scales, then it is important to ask whether contemporary forest practices maintain adequate heterogeneity within the forest landscape. Such is the intention of this paper. It is a deserving question because guidelines that regulate forest harvest are arguably restrictive and may encourage forest companies to reduce environmental variability as they seek to create an "acceptable" forest directed by the regulatory process. Monotypic approaches to forest harvest and regeneration are unlikely to accommodate the variable and dynamic nature of the boreal mixedwood forest mosaic. They are, however, perceived to facilitate less costly and less complicated planning, harvest, and regeneration.

To date, there exist few studies examining spatial patterns of forest stands created by harvest within the boreal mixedwood forest. The advent of geographic information systems (GIS) and availability of remote photometric data permit exploration of spatial patterns (size, shape, interspersion) that are important to forest ecosystem management. Simulation models of forest structure and development allow forecasting of future forest attributes following defined forest successional trajectories and management practices. Together, these analytical techniques can be used to explore spatial and temporal patterns of forest communities subjected to commercial logging. In this paper we quantitatively examine the frequency distribution of stand size, stand age, and stand shape of pre-harvest forests, and forests of two different harvest strategies in the boreal mixedwood region of northeast Alberta. These analyses focus on eight selected townships within the FMA area of Alberta-Pacific Forest Industries Inc.

METHODS

Digital GIS data for this study were obtained from the Alberta Vegetation Inventory (AVI) through Timberline Forest Industry Consultants and AlPac. AVI is an ongoing initiative to develop a standardized vegetation inventory for forest-dominated areas of Alberta. This inventory is compiled from a combination of 1:20,000, black-and-white aerial photography and ground measurements. AVI data describe multiple-stand variables including canopy species composition, height, crown closure, site productivity rating, soil moisture, decade of stand origin, stand structure/understorey, stand condition, and modifiers describing non-vegetated and anthropogenically disturbed land. AVI organization and availability focused our study design on those areas within the FMA with available data. As AVI data were only available at the township level and not continuous across the FMA, the township (9.6 × 9.6 km) was chosen as the discrete unit of landscape analysis. Township units were chosen using two criteria: (1) digital AVI data were complete, and (2) digital traditional forest harvest plans (standard two-pass, 10–20-year green-up period, 70–80-year rotation) had been generated for the township and were readily available.

A SUN Sparc Station 10 and Arc/Info (1994) software were used to perform initial GIS manipulations of digital landscape coverages. In order to remove erroneous stand boundaries and to group the data to a relevant level, adjacent polygons were pooled by height class and cover type for each township. Stands were first classified into six height classes of five-metre increments (0–5 m, >5–10 m, >10–15 m, >15–20 m, >20–25 m, >25 m) and four cover types (coniferous, deciduous, mixedwood, other). Coniferous polygons were those composed of ≥80% coniferous composition, deciduous polygons were ≥80% deciduous composition, and mixedwood polygons were those in which neither deciduous nor coniferous composition was ≥80%. Polygons classed as "other" included aquatic areas (lakes, rivers, streams, ponds, flooded areas), clearings vegetated by herbs, grasses, forbs, and/or shrubs less than six metres, pasture, roads, industrial areas (well sites, microwave towers, transmission lines, gravel pits, farm areas, rail lines, gas and oil development), and urban development and recreation areas. Based on identical species/height classification, boundaries between adjacent polygons of the same type were removed. The resultant coverage of pooled AVI polygons was the base coverage for all other coverages generated, and was labelled as the pre-harvested coverage.

To create traditional harvest coverages, operational harvest plans generated by Timberline were used. First-pass harvest blocks were overlaid on the pre-harvested coverage and those areas scheduled to be cut were reclassified to the lowest height class (0–5 m). Forest cover height data were then projected 10 years using a growth/yield model (data provided by Timberline). Second-pass harvest blocks were overlaid on this new coverage and scheduled polygons reclassified to the lowest height class (0–5 m). Coverages with both first and second pass were again dissolved based on species/height classification to remove old polygon boundaries from within new harvest-block polygons. Because first- and second-pass harvest blocks were not designed to follow pre-harvest stand boundaries, this process created many new polygons, a proportion of which had a high length-to-width ratio (sliver polygons). Because it was determined likely that harvesting would remove many of these sliver polygons rather than leaving them, those smaller that 200 m^2 and of the same species/height class as the adjacent scheduled stand were joined with the cutblock polygon.

Coverages for modified type-cut harvest were created using Foreman+1 harvest scheduling software (data provided by Timberline). Foreman+1 schedules stands to be harvested based on site productivity, stand age, volume, and species composition, but does not consider operational economics or logistics. It was decided to schedule those remote stands where logging costs would be high because criteria now used to determine feasibility may not be relevant with modified type-cut harvest. It is possible that the range of harvest blocks scheduled in a modified type-cut harvest plan may include much larger blocks than are presently harvested. This may result in economic flexibility to pursue smaller, more isolated blocks. All polygons were evaluated for fiber and site attributes by Foreman+1 for a 20-year window. For purposes of analyses, all scheduled stands were considered to be harvested during a single, short (one-year) entry. All harvested polygons were then reclassified to the lowest height class (0–5 m), and boundaries removed from between adjacent polygons with the same species/height class.

Each of three landscape coverages (pre-harvested, traditional, and modified type-cut) for each of eight townships was examined using FRAGSTATS (McGarigal and Marks 1994) software. FRAGSTATS generates a number of metrics based on the pattern of polygons composing the landscape, a subset of which were used for these analyses (Table 1). To generate metrics relating to core area, an edge width or edge buffer was defined at 30 metres. This approximated 1–1.5 the height of mature aspen trees.

TABLE 1 *Subset of spatial pattern metrics generated by FRAGSTATS used in these analyses*

	Metrics generated by FRAGSTATS
Number of patches	Number of polygons on the landscape coverage.
Patch density	Number of polygons per unit area.
Perimeter	Total length of polygon boundaries.
Edge density	Length of edge per unit area.
Total core area	Sum of area of all polygons after eliminating the area of a previously defined buffer (30 m for these analyses).
Shape complexity	Double-log fractal dimension calculated using perimeter and area; varies between one and two with one being a simple Euclidean shape and two the theoretical maximum shape complexity.
Interspersion Index	Index describing the extent to which patch types are distributed in relation to other patch types. A high interspersion index defines a patch mosaic whereby each patch is uniformly distributed among other patch types.

From the landscape metrics generated by FRAGSTATS comparisons at the landscape scale were made using area, perimeter, number of patches, total core area, edge density, shape complexity, and interspersion index. Because there was great variation in overall pattern between different townships, comparisons were limited to within-township changes. Percentage change from pre-harvest to traditional harvest, and from pre-harvest to modified type-cut harvest were calculated for each of the landscape metrics, with the exception of area, perimeter, and number of patches. Frequency distributions were generated for polygon area and perimeter, while the number of patches was presented as a mean of the eight townships.

RESULTS

Frequency distributions of polygon area and perimeter describe a similar negative-exponential pattern for all landscapes examined (Figures 1 and 2), with many polygons of small areas or short perimeters, and a few polygons with large areas or long perimeters. In both area and perimeter, the traditional harvest landscapes had more polygons with small areas or short perimeters than did pre-harvest or modified type-cut landscapes. This is due to an increase in the number of polygons in the traditional harvest townships as compared to the pre-harvest and modified type-cut harvest (Figure 3). With traditional harvest, constrained by operating ground rules, many small polygons are created around the edges of cutblocks and, therefore, the number of polygons with small areas and short perimeters is greater in traditionally harvested landscapes.

Relative to pre-harvest landscape, total core area decreased in traditional harvest landscapes for all eight townships (Figures 4 and 5), indicating an increase in polygon fragmentation. The modified type-cut

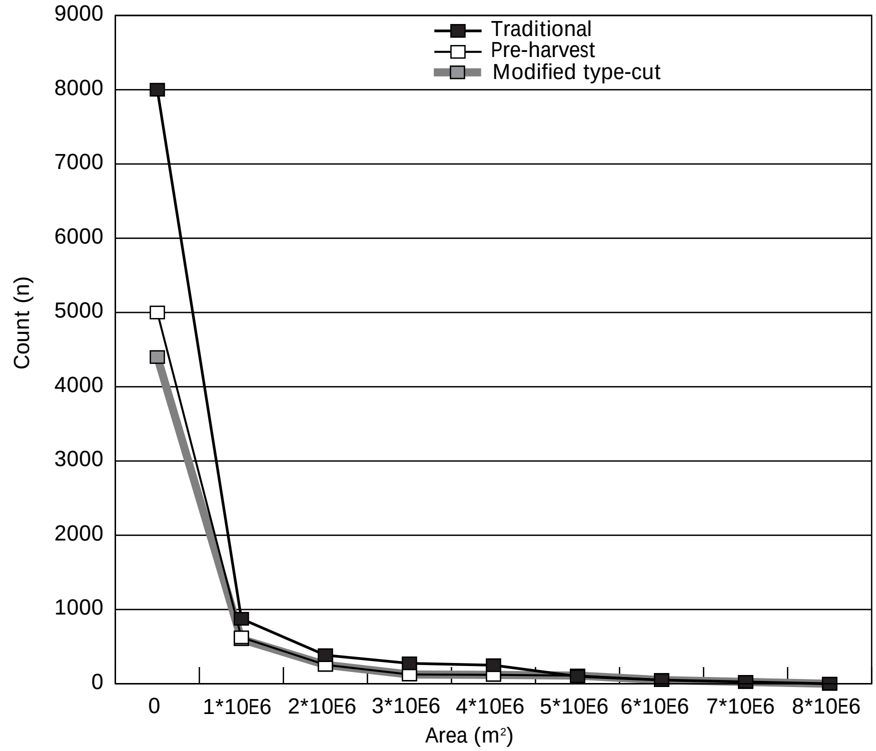

FIGURE 1 *Frequency distribution of patch size in pre-harvest, traditional, and modified type-cut forest landscapes.*

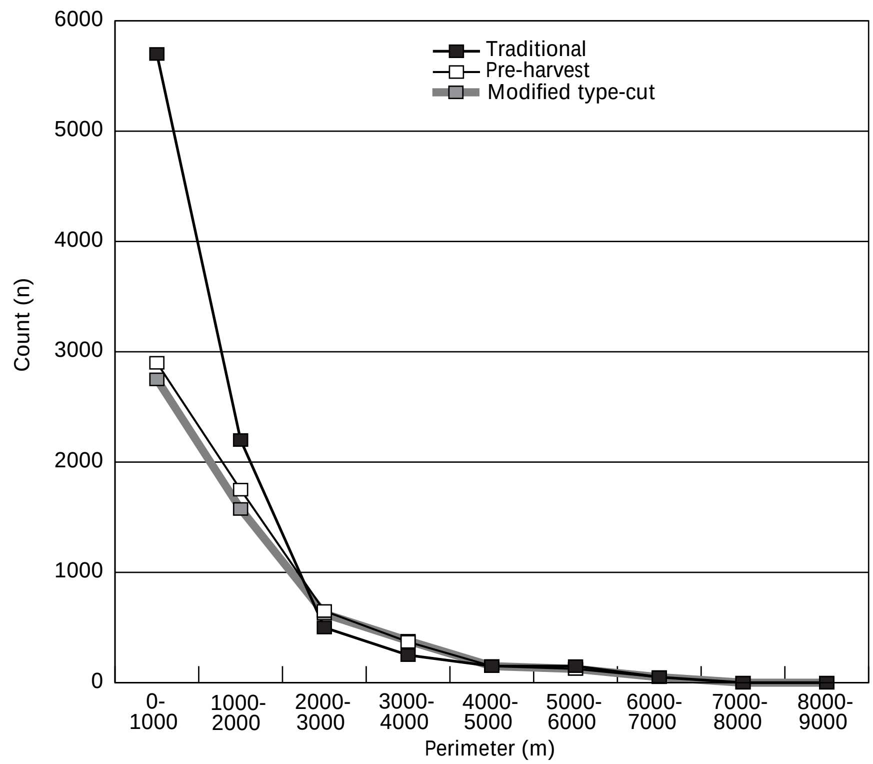

FIGURE 2 *Frequency distribution of patch perimeter in pre-harvest, traditional, and modified type-cut forest landscapes.*

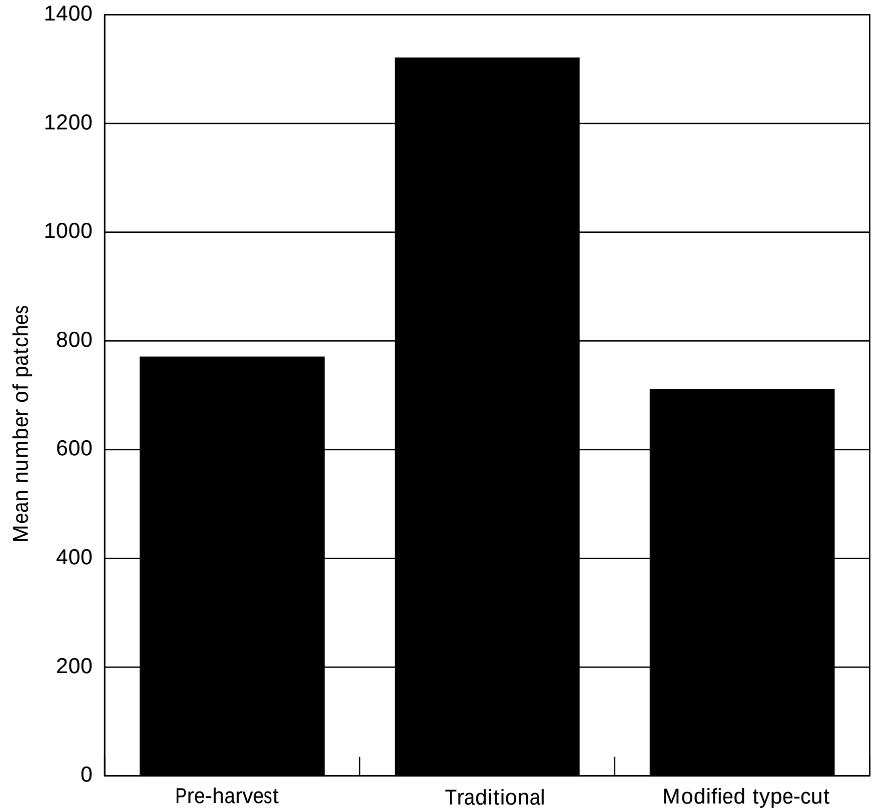

FIGURE 3 *Mean number of forest patches in pre-harvest, traditional, and modified type-cut landscapes.*

landscapes demonstrated an overall increase in core area as a result of the aggregation of polygons ready for harvest in the 20-year window. There were two townships in which the modified type-cut landscapes demonstrated a decrease in total core area (Townships 1 and 6). This is likely due to site productivity differences detected by Foreman+1 within species/height defined polygons. This site productivity difference resulted in the partitioning of these polygons based on differences in growth/yield projections, resulting in more edge and, therefore, less core area.

Shape complexity decreased in all eight traditional harvest landscapes relative to the pre-harvest landscapes (Figures 6 and 7). This indicates a change towards simpler, more Euclidean shapes. Relative to pre-harvest landscapes, the modified type-cut harvest exhibited little change in shape complexity (<1% versus >22% for modified type-cut and traditional harvest, respectively).

Edge density increased in all traditional landscapes when compared with the pre-harvest landscapes (Figures 8 and 9), due to an increase in the number of polygons and fragmentation of the landscapes with traditional two-pass logging. There was a decrease in edge density for six of the eight modified type-cut townships, reflecting the aggregation of polygons due to scheduling of 20 years of merchantable harvest in one year. The two townships that had increases in edge density (1 and 6) likely reflect the same patch configurations causing the decrease in core area for these townships (Figures 4 and 5).

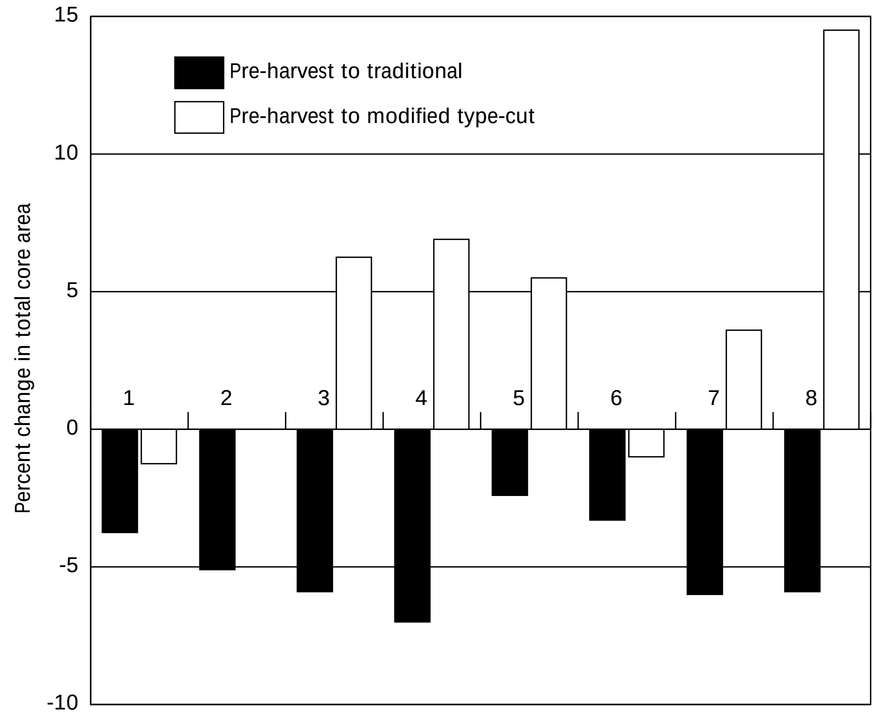

FIGURE 4 *Changes in total core area, relative to pre-harvest landscape, caused by traditional and modified type-cut harvest.*

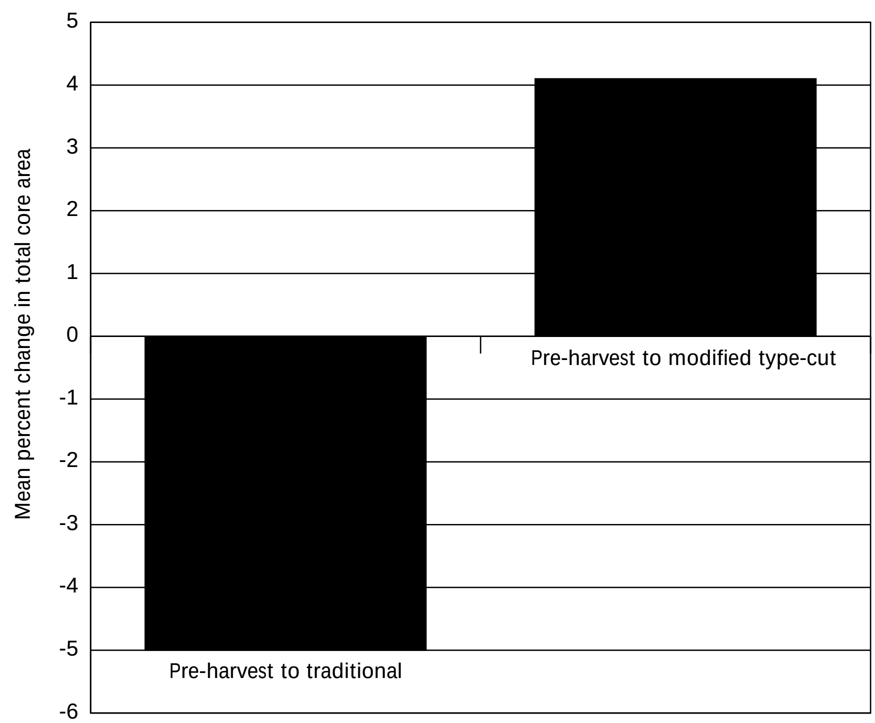

FIGURE 5 *Mean percentage change in total core area comparing three landscapes: (a) pre-harvest to traditional, and (b) pre-harvest to modified type-cut. Positive change indicates an increase in core area and negative change indicates a decrease in core area.*

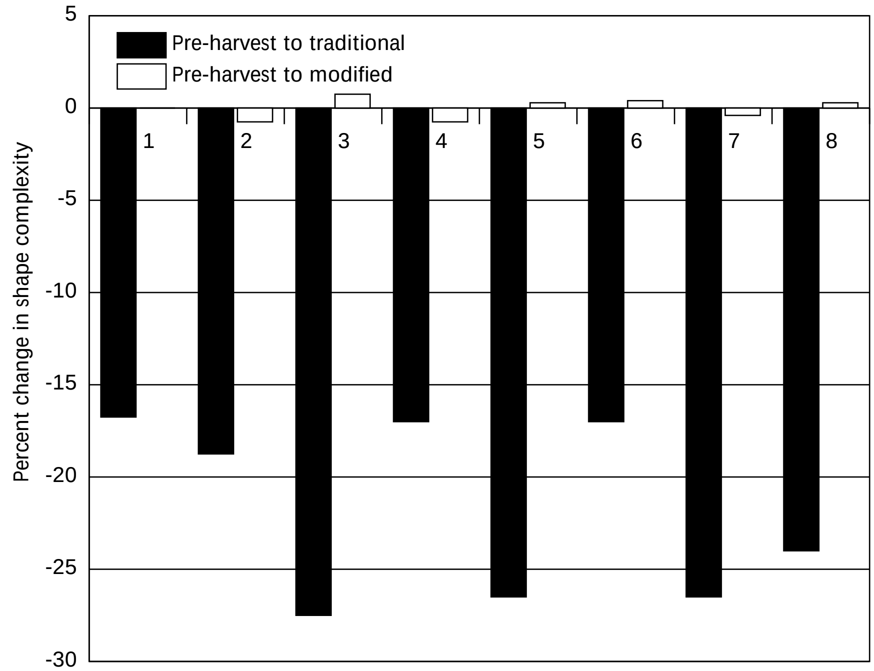

FIGURE 6 *Percentage change in shape complexity (double-log fractal dimension) comparing three landscapes: (a) pre-harvest to traditional, and (b) pre-harvest to modified type-cut. Positive change indicates an increase in shape complexity and negative change indicates shape simplification.*

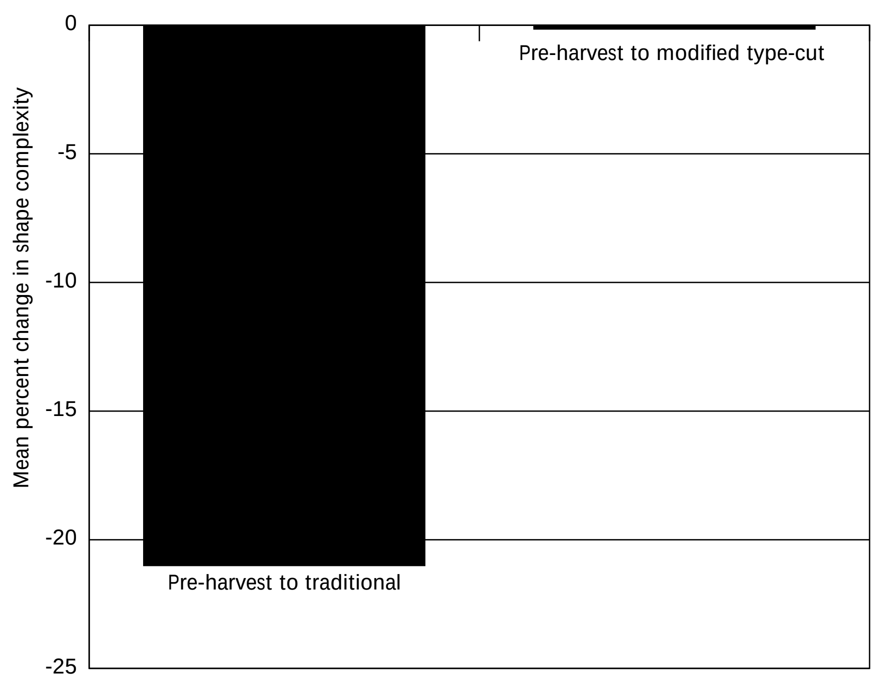

FIGURE 7 *Mean percentage change in stand complexity (double-log fractal dimension) comparing three landscapes: (a) pre-harvest to traditional, and (b) pre-harvest to modified type-cut. Positive change indicates an increase in shape complexity and negative change indicates shape simplification.*

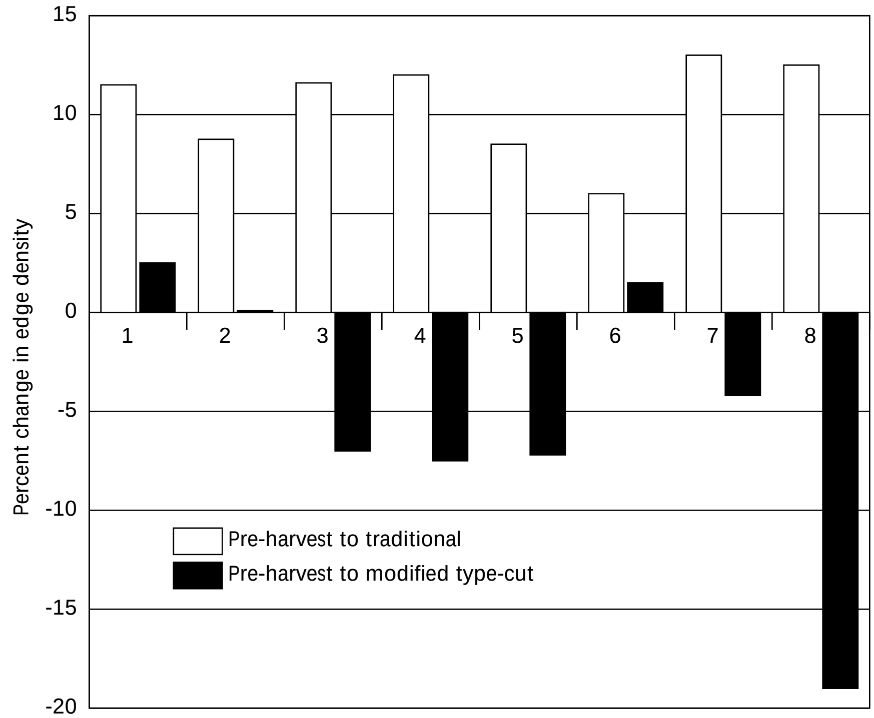

FIGURE 8 *Percentage change in edge density comparing three landscapes: (a) pre-harvest to traditional, and (b) pre-harvest to modified type-cut.*

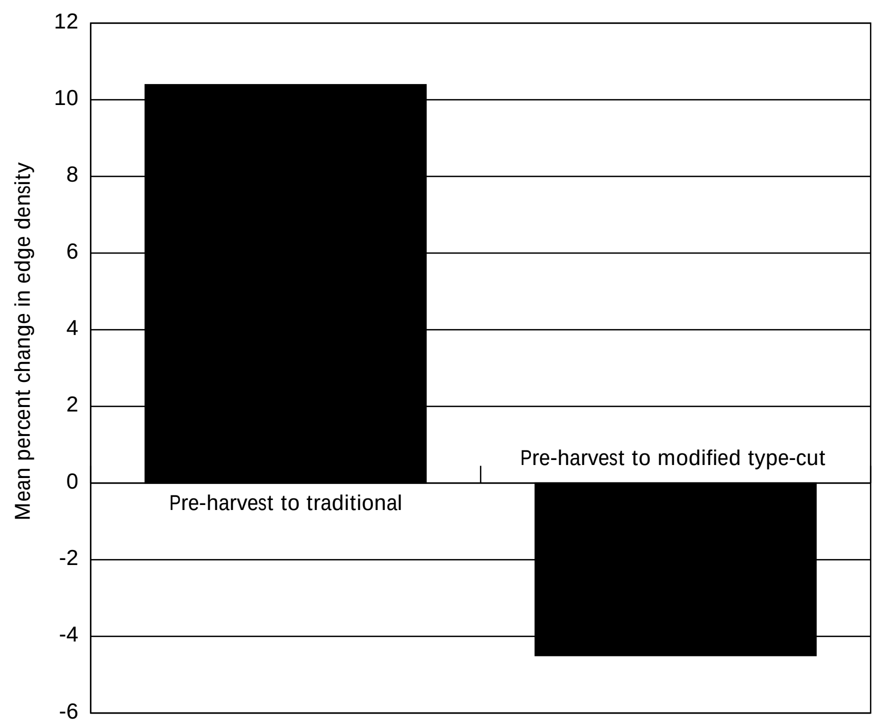

FIGURE 9 *Percentage change in edge density comparing three landscapes: (a) pre-harvest to traditional, and (b) pre-harvest to modified type-cut. Positive change indicates an increase in edge per unit area and negative change indicates the opposite.*

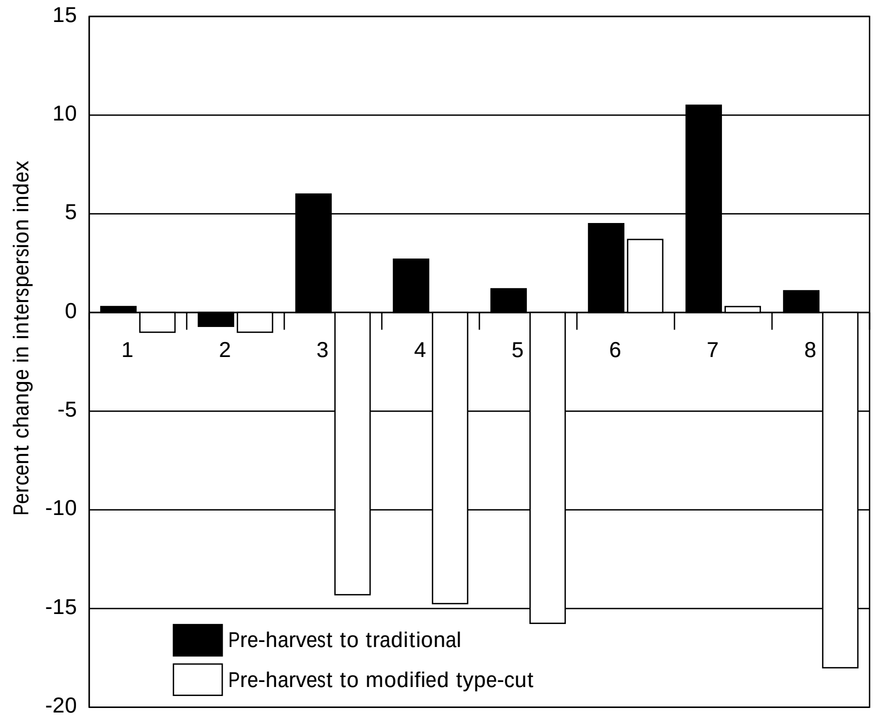

FIGURE 10 *Percentage change in interspersion comparing three landscapes: (a) pre-harvest to traditional, and (b) pre-harvest to modified type-cut.*

FIGURE 11 *Mean percentage change in the interspersion index comparing three landscapes: (a) pre-harvest to traditional, and (b) pre-harvest to modified type-cut. Positive change indicates an increase in interspersion and negative change indicates the opposite.*

Relative to pre-harvest landscapes, there was an overall increase in the interspersion index in traditional landscapes reflecting the "checkerboard" pattern created by traditional two-pass harvest (Figures 10 and 11). There was a decrease in the interspersion index for the modified type-cut landscape, a result of the aggregation of polygons of different cover/height types.

DISCUSSION

Results of these spatial analyses of landscape pattern in the boreal mixedwood forests of northeast Alberta support the contention that the preharvested landscape is highly variable in patch size, shape, and interspersion. Considerable township-to-township variance indicates that landscape patterns are not uniform at the spatial scale of the township. A comparison of traditional (two-pass, 20–30-ha cutblocks) and progressive (modified type-cut) forest harvest strategies reveal that cutblocks constrained in size and shape by regulations frequently create a landscape dissimilar to the pre-harvest landscape. In contrast, the type-cut approach to forest harvest maintained heterogeneity in stand size, shape, and interspersion found in the pre-harvest townships.

The implicit assumption of this paper is that biota are capable of detecting and responding differently to patches of different composition, canopy height, size, and shape. However, the 5-m canopy height intervals and canopy composition of greater than or less than 80% coverage are arbitrary break-points that may or may not have biological relevance. In contrast, some species may detect and respond differently to patches whose canopy heights differ by less than 5 m. Detecting levels of sensitivity by biota to stand shape, canopy height, stand area, and composition is an important area of evaluation by ecologists if future landscape analyses are to be completed with meaningful biological criteria.

Maintaining a range of natural variability (RNV) (Swanson et al. 1993) in commercial forest landscapes is a recognized goal of the Alberta Forest Conservation Strategy (1995). Rationale for maintaining RNV is based on the assumption that biota are adapted to environmental variation created by disturbances. As such, these findings suggest that government regulatory agencies should consider revisions to timber harvest rules that currently constrain patch size, patch shape, and patch interspersion.

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