



Should riparian buffers be part of forest management based on emulation of natural disturbance?

Ellen Macdonald^{a,*}, Carl J. Burgess^{b,1}, Garry J. Scrimgeour^{c,2},
Stan Boutin^b, Sharon Reedyk^{c,3}, Brian Kotak^{d,4}

^aDepartment of Renewable Resources, University of Alberta, Edmonton, Alta., Canada T6G 2H1

^bDepartment of Biological Sciences, University of Alberta, Edmonton, Alta., Canada T6G 2E9

^cConor Pacific Environmental Technologies Inc., Edmonton, Alta., Canada T6E 6A8

^dAlberta Pacific Forest Industries, Boyle, Alta., Canada T0A 0M0

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Abstract

Riparian communities (those near open water) have often been shown to display high structural and compositional diversity and they have been identified as potentially serving a keystone role in the landscape. Thus, they are the focus of specific management guidelines that attempt to protect terrestrial and aquatic ecosystems. We used a digital forest inventory database for a portion of the boreal mixed-wood forest in Alberta, Canada, to examine whether proximity to a lake affects forest composition, age, or configuration. Two analyses were employed: (1) forest composition (dominant canopy species, proportional composition of different species) and age (decade-of-origin) in bands of 50 m width and varying distance from small lakes were compared to forest in a similar spatial configuration but away from open water and (2) forest composition, dominant canopy species, age, and stand shape metrics were examined along transects emanating out from lakes in two regions, which varied in topography and dominant forest cover. We found no effect of distance from lake on forest age. The proportion of the landscape covered by forest of the predominant canopy species increased with distance from lake, but this was largely due to a corresponding decline in cover of non-forest vegetation rather than a change in forest canopy composition. At the spatial resolution of forest management planning, riparian forests in this region are of similar age and composition as those away from lakes. Since there is no natural analogue for riparian buffer strips around lakes, they may not be justified in the context of ecosystem management following the natural disturbance paradigm. Management of riparian forests should focus on meeting defined management and conservation objectives through, for example, protection of finer scale features of riparian zones and landscape-level planning for allocation of uncut forest.

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* Corresponding author. Tel.: +1-780-492-3070; fax: +1-780-492-4323.

E-mail address: ellen.macdonald@ualberta.ca (E. Macdonald).

¹ Present address: Department of Energy, Mines and Resources, Yukon Government, Box 2703, Whitehorse, Yukon, Canada Y1A 2C6.

² Present address: Alberta Conservation Association, P.O. Bag 40027, Edmonton, Alta., Canada T5K 2M4.

³ Present address: Prairie Farm Rehabilitation Association, Agriculture and Agri-Food Canada, Edmonton, Alta., Canada T5J 4C3.

⁴ Present address: Tembec Forest Resource Management-Pine Falls Operation, P.O. Box 268, Pine Falls, Man., Canada R0E 1M0.

1. Introduction

The emulation of natural disturbance as a key component of ecosystem-based forest management has gained wide acceptance in western North America and the boreal forest in particular. This approach requires an understanding of landscape patterns of forest structure, composition and age as determined by the interaction between climate, landform, and disturbance (Franklin and Forman, 1987; Hunter, 1992; Franklin, 1993; Larsen et al., 1997; Scrimgeour et al., 2000). Natural resource managers attempt to emulate these patterns and their inherent variation by varying structure left on blocks, cutblock sizes and shapes, and rotation lengths (Bergeron, 2000). Communities adjacent to open water (riparian communities) have long received special management consideration because of the desire to protect aquatic systems from upland disturbance and to actively manage direct disturbance within the water body (e.g. log removal). Virtually in all cases, the practice is one of leaving uncut forest strips (buffers) adjacent to open water. To date there has been no thorough consideration of how the creation of buffer strips fits with the paradigm of emulation of natural disturbance.

Although different processes likely influence riparian plant communities next to lakes versus streams the composition and structure of both are a reflection of an unusually complex array of edaphic influences and natural disturbances including: complexity of soils, topography, and microclimate; high productivity stemming from accumulation of water and nutrients; edaphic gradients; frequent disturbances associated with the water body itself; and the effect of the water body on disturbance by external agents (e.g., fire, wind, herbivory) (Swanson et al., 1988; Baker, 1990; Naiman et al., 1993; Naiman and Décamps, 1997; Scrimgeour et al., 1994; Pollock et al., 1998; Denneler et al., 1999). The combination of these factors could lead to unique patterns of stand composition, age, and structure within and among forested regions. However, management of riparian areas by the creation of static buffers fails to consider this inherent variability and will ultimately lead to relatively narrow bands of old forest adjacent to water bodies. We were interested in how the landscape pattern arising from riparian buffers compared to that created by natural disturbance.

The mixed-wood boreal forest of western Canada is a mosaic of deciduous and coniferous forest stands and wetlands on gently undulating terrain shaped by relatively frequent and intense fires (Rowe and Scotter, 1973; Johnson, 1992). Forest succession in upland mixed-wood sites is described as a transition from deciduous-dominated to mixed-wood to conifer-dominated stands (Cumming et al., 2000). Shallow open water bodies in the form of lakes and wetlands are a common feature in the mixed-wood forests and current forest practices involve leaving 100 m forest buffers around fish-bearing lakes. Theory and empirical evidence suggest that fire may be less frequent and/or intense in riparian areas (Suffling et al., 1982) due to higher surface soil and forest floor moisture (Rowe and Scotter, 1973; Chandler et al., 1983; Swanson et al., 1988; Andison, 1997), the effect of open water acting as a fire break, or the fact that on-shore winds keep fire from reaching the riparian zone (Bergeron and Dubuc, 1989; Bergeron, 1991; Denneler et al., 1999). Flooding, disturbance by beavers, and their hydrological effects on soil nutrient and water dynamics also likely influence structure and composition of boreal riparian forests (Donkor and Fryxell, 1999; Devito et al., 2000).

Given that riparian areas might experience different disturbance regimes or edaphic conditions compared to upland areas, we conducted this study to determine whether forests near lakes were significantly different than forests elsewhere on the landscape in terms of canopy composition, age and configuration. We predicted that forests adjacent to lakes would be older, and consequently also have greater conifer cover, than the upland forest landscape. If our prediction is correct, riparian management guidelines developed within the context of the natural disturbance paradigm would need to incorporate such effects by prescribing protection or extended rotations for riparian forests. Conversely, the lack of “natural” buffers would suggest that leaving strips of forest around water bodies is contrary to forest management models designed to emulate natural disturbance.

2. Materials and methods

2.1. Study area

The study area fell within the mid-Boreal mixed-wood ecoregion in central Alberta, Canada (Strong

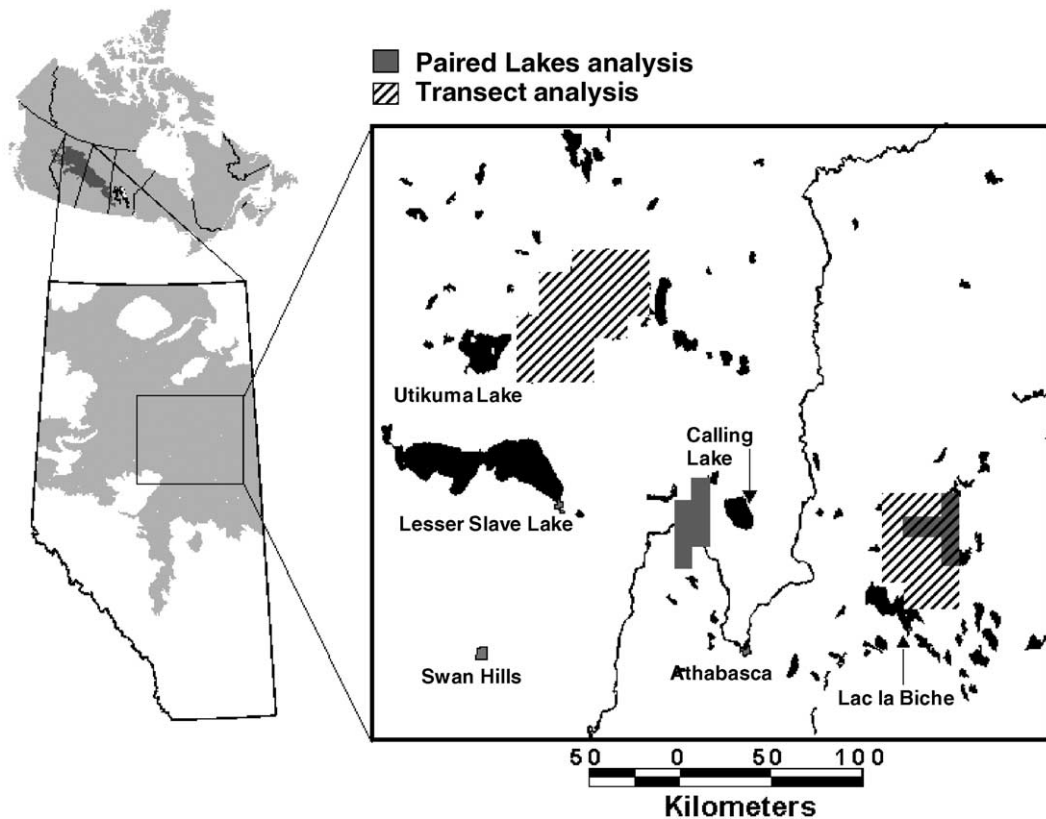


Fig. 1. Location of the mixed-wood boreal forest in Canada and in Alberta and locations of study regions for the different analyses. Large lakes (not included in analysis) and towns are marked. See text for details of “paired buffer analysis” and “transect analysis”.

and Legatt, 1992), which lies within the boreal mixed-wood forest region (Rowe, 1972) (Fig. 1). The landscape is dominated by a mosaic of pure and mixed-wood forest stands including seven major tree species: trembling aspen (*Populus tremuloides*), balsam poplar (*Populus balsamifera*), white spruce (*Picea glauca*), black spruce (*Picea mariana*), tamarack (*Larix laricina*), paper birch (*Betula papyrifera*), jack pine (*Pinus banksiana*) and balsam fir (*Abies balsamea*). The area is characterized by a mean summer temperature of 13.5 °C, a mean winter temperature of −13.2 °C, and annual precipitation of ~400 mm, of which most falls in the summer (Strong and Legatt, 1992). Undulating morainal plains are overlain by Gray Luvisol soils with some Eutric Brunisols on more xeric sites (Rowe, 1972; Strong and Legatt, 1992).

Data for the study were derived from a digital forest inventory database [Alberta Vegetation Inventory

(AVI; Anonymous, 1991)]. The inventory was developed using 1:15,000–1:20,000 aerial photographs of forested landscapes combined with extensive ground-truthing (Anonymous, 1991). For each identifiable stand (= polygon) on the forested land-base, including forested peatlands, numerous attributes were estimated including: crown closure, canopy height, tree species composition (% based on canopy closure) and age (decade-of-origin). The minimum mapping unit has been estimated at ~0.4 ha (Joy, 1996). Age classifications are based on height versus age regressions for each species within the inventoried region. Extensive ground-truthing confirmed that ages were generally (overall 75%) accurate to within 10 years, with poorer accuracy for the oldest and youngest age classes (Burgess, 1997). The entire study area was largely unaffected by commercial logging at the time this database was developed. Digital elevation models (DEMs, 20 m resolution) for the sampled regions were

purchased from the Data Resources Office of Alberta Environmental Protection.

Our analysis was designed to address the question: does proximity to a lake affect forest composition, age, or configuration? In order to address this question we examined the western boreal mixed-wood landscape at varying spatial extents (size of sampling area) in three different regions (Lac La Biche, Calling Lake, Muskwa). The dataset defined the spatial resolution of our analyses, which is the same as that employed in forest management planning in Alberta. We used two different analyses.

2.2. Data sets

2.2.1. Paired buffer analysis

The study area for this analysis consisted of two regions including a total of 11 townships (total area ca. 1023 km²) within which ca. 82,000 ha was forested, south of Calling Lake, Alberta (55°N, 114°W, approximately 640 m.a.s.l.), and near Lac La Biche, Alberta (55°N, 113°W, approximately 670 m.a.s.l.) (Fig. 1). Within these areas 12 lakes (5–100 ha in size) were chosen. These lakes were the only small to mid-sized lakes in the study area for which digital vegetation inventory data were available at the time. Wetlands with open water were not considered to be lakes. The GRASS Geographic Information System (GIS) was used to manipulate data and produce summaries for statistical analysis (Baker, 1994).

For comparison to the forest cover around the sample lakes, control areas were created and placed in the surrounding landscape, away from open water, as follows. GIS software was used to create an exact duplicate (shape, size, orientation) of each of the 12 study lakes and artificially re-locate it within the same township to the nearest local “upland” with a minimum of 2 km distance between this control area and the “original” lake, other lakes, extensive peatlands or wetlands, and other open bodies of water. These locations were identified using 1:50,000 NTS data independent of the digital forest inventory.

For each lake and control, a series of concentric bands, 50 m wide, were placed at distances from 0 to 600 m from the edge of the real lake or the control area. Forest composition for each polygon (i.e., forest stand) was classified based on the most abundant species (as given by canopy cover in the AVI

database). For each band the proportional area covered by white spruce- or aspen-dominated forest was determined. In addition, the proportional area covered by forest in age classes of 60–70 years (mature) and 120–140 years (old) was calculated. We focused on these two species and age classes because they were, by far, the predominant in these two study regions; older and younger forests were very rare. Paired *t*-tests (on arc-transformed proportions) were used to compare these four canopy attributes between real lakes and the control areas for the concentric bands each of the distances (Zar, 1984).

The Paired Buffer analysis allowed for specific pairing of areas close to and away from open water within the same region, but was restricted to areas for which we could find sufficiently large control areas away from any open water. We subsequently undertook a second analysis (transect analysis) so as to increase the spatial extent and the sample size of lakes.

2.3. Transect analysis

Using ArcView GIS software we tested for differences in vegetation attributes with increasing distance from small lakes (10–200 ha in surface area) by sampling in two different regions of east-central Alberta: an area north of Lac La Biche (55°N, 112°W, ca. 630 m.a.s.l., similar location but greater spatial extent and different sampling approach than in the Paired Buffer analysis) and in the Muskwa region (56°N, 115°W, ca. 580 m.a.s.l.) (Fig. 1). An initial distribution analysis of lakes in the region showed that 50% were ≤35 ha in size whereas the average lake area was about 100 ha. The total area examined was 1800 km² in the Lac La Biche region and 3000 km² in the Muskwa region. The two regions differed in terms of slope (average 1.0° in Lac La Biche versus 0.3° in Muskwa) and dominant forest cover. Aspen most commonly forms the dominant canopy in the Lac La Biche region (44% by area compared to 25% for Muskwa). Conversely, black spruce-dominated forest is most common in the Muskwa area (41% by area compared to 19% in Lac La Biche). Small lakes and wetlands account for over 75% of all standing water bodies in both regions. When combined, the two study regions are thought to be representative of a large proportion of Alberta's boreal mixed-wood.

We sampled polygons at 50 m intervals out to 300 m along eight transects emanating from the midpoint of each lake and extending out in eight cardinal directions (22.5°, 67.5°, 112.5°, 157.5°, 202.5°, 247.5°, 292.5°, and 337.5°). The resolution of the DEMs was not sufficient to delineate small watersheds thus transects were truncated at their highest elevation or 300 m, whichever came first. In a preliminary analysis very few transects ran beyond 300 m using the elevation criterion. The abundance of small lakes within each study area resulted in instances where transects originating from one lake extended to the sampling area of an adjacent lake; in these instances transects were cut-off at the midpoint between the two lakes. At each sample point, the following polygon attributes were recorded: area (ha), perimeter (m), shape $[(\text{perimeter}/(2 \times \sqrt{\pi \times \text{area}}))/(10,000)]$ and linearity (perimeter/area) metrics, age (decade-of-origin, for forested polygons only), dominant canopy species (aspen, black spruce, white spruce, shrubs or grasses), and percent cover for each of four vegetation types (aspen, black spruce, white spruce, and shrubs/grasses). Increased values of the shape metric indicate increased polygon complexity whereas the linearity metric increases with departure from roundness. Analyses were confined to polygons that appeared unaffected by anthropogenic factors and to lakes for which there were at least four usable transects (overall average = 6 transects). These criteria resulted in comparisons of stand attributes for 62 and 64 lakes in the Lac La Biche and Muskwa regions, respectively.

The effects of distance from lake edge on polygon attributes were evaluated using a nested, mixed model ANOVA (SAS, 1996) in which transects were nested within sample sites (= lakes). For these analyses we treated distance as a fixed variable and transect (4–8 nested within each lake), lake and lake-distance interactions as random. We used the ‘Proc mixed’ procedure within SAS, which uses maximum likelihood estimations to fit models and Satterthwaite approximations to identify degrees of freedom (SAS, 1996). In addition to comparing mean stand age with distance from lake, we completed pairwise comparisons of age class distributions between distances using Kolmogorov–Smirnov goodness-of-fit tests. Prior to analyses data were either \log_{10} (area, perimeter, shape, linearity) or arcsine-square root transformed (% cover by

vegetation type, dominant canopy) to satisfy assumptions of normality and homogeneity of variances. When ANOVA models were significant ($P < 0.05$), we tested for differences among treatment means (i.e., distances) using least squares means tests.

Comparisons of the effects of distance from lake edge on dominant canopy species were analyzed differently from the other polygon attributes. For this analysis, we calculated the frequency of sample points dominated by each of the four main vegetation types (aspen, black spruce, white spruce, shrubs-grasses) for each distance across all transects around each individual lake. These data were then used to compare among distances across lakes using a nested, mixed-model ANOVA (same model as above but without the term transect).

3. Results

3.1. Paired buffer analyses

There were no significant differences (all paired t -tests, $P > 0.20$) in the percent area covered by white spruce or aspen-dominated forest between real lakes and control areas for 50 m wide buffers varying in distance from the lakeshore (Fig. 2A and B). The proportional area covered by aspen- or white spruce-dominated forest increased with distance from the real lakes (not significant), but not the control areas. There were no significant differences (all paired t -tests, $P > 0.10$) between the real lakes and control areas in area covered by ‘mature’ (60–70 years) or ‘old’ (120–140 years) forest (Fig. 2C and D).

3.2. Transect analysis

Stands (= polygons) were larger in the Muskwa region (mean = 103 ha) than in Lac La Biche (mean = 32 ha), but stand area was not affected by distance from lake edge in either region (Table 1). Similarly, neither polygon perimeter nor the shape metric were affected by distance from lake in either region (Table 1). In contrast, the linearity metric declined (i.e., stands became more round) with distance from lake in both regions (Table 1, Fig. 3A and B). Mean age of forested stands was not significantly affected by distance from lake in either region (Table 1,

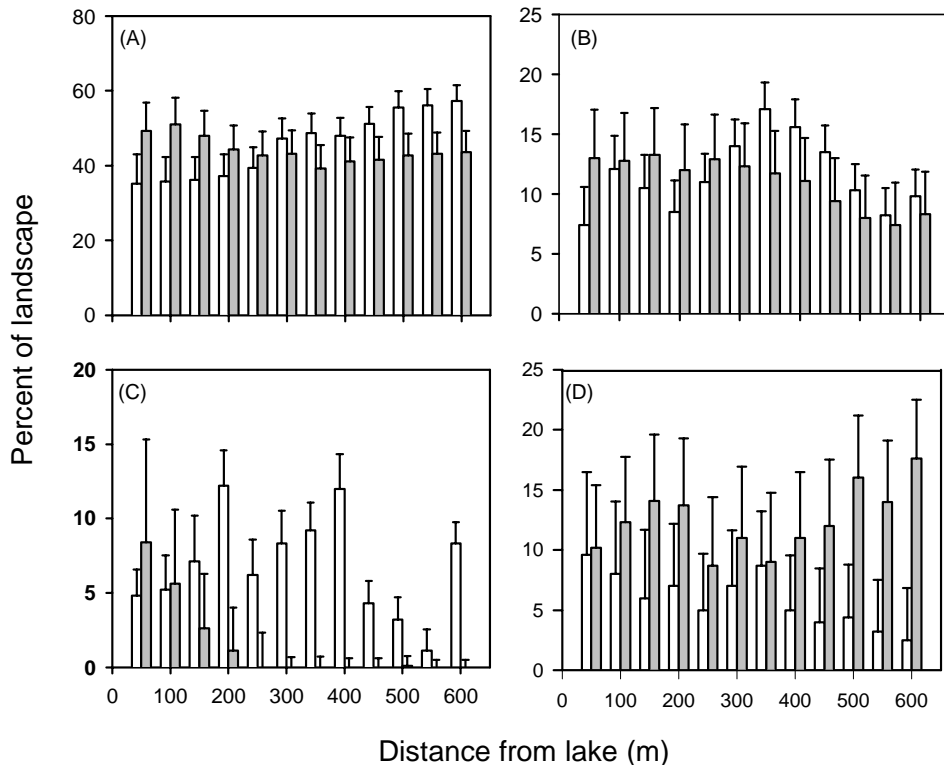


Fig. 2. Percent of landscape covered by forest of a given age or dominated by aspen or white spruce for bands of forest of 50 m width at varying distances from 12 lakes in the Calling Lake region as compared to bands of forest surrounding paired control areas of similar size and shape in the same township but away from any open water. (A) Aspen-dominated forest, (B) white spruce-dominated forest, (C) forest in the 60–70-year-old age class and (D) forest in the 120–140-year-old age class. Means \pm standard errors are given. Open bars = real lakes, closed bars = control areas.

Fig. 3C and D). Kolmogorov–Smirnov tests showed that age class distributions were not significantly affected by distance from lakes in the Lac La Biche or the Muskwa regions (not shown). The percent cover (within polygons) of the most abundant tree species and shrubs/grasses varied significantly with distance from lake and these effects differed between regions (Table 1). For instance, average aspen composition for polygons in the Lac La Biche region was 30–45% and was significantly greater for polygons 100–300 m from lakes compared with those located 50 m from lakes (Fig. 3E). In contrast, aspen composition for polygons in the Muskwa region was lower (20–25%) and did not vary with distance from lake (Table 1, Fig. 3F). Conversely, black spruce composition was greater for polygons in the Muskwa region (32–47%) and was significantly greater for polygons 100–300 m from lakes compared with those located 50 m from

lakes (Fig. 3G). This trend did not hold for the Lac La Biche region, where black spruce was less prevalent (20–24%) (Fig. 3H). Similarly, white spruce composition was significantly greater for polygons at 200–300 m, compared with those at 50–150 m, from lakes in Muskwa, but not in Lac La Biche (Table 1, Fig. 3I and J). The relative composition of shrubs and/or grasses declined significantly with increasing distance from lake in both regions (Table 1, Fig. 3K and L).

The proportion of polygons that were aspen-dominated increased significantly with distance from lake in Lac La Biche, but not Muskwa (Table 1, Fig. 4A and B). In the Lac La Biche region, aspen was the dominant species in about 50% of polygons at distances >100 m compared to 32% of polygons located 50 m from lakes (Fig. 4A). Conversely, the prevalence of black and white spruce as the dominant trees increased significantly with distance from lake in the

Table 1

Results of analysis of variance (P) for each of the two study regions testing for effect of distance from lake on polygon area, perimeter, shape, linearity, age, % cover (within stands) for each of the following: aspen, black spruce, white spruce, shrubs or grasses, and frequency of polygons dominated by: aspen, black spruce, white spruce or shrubs and grasses^a

Region	Lac La Biche				Muskwa			
	Distance	Lake	Transect (lake)	Lake × distance	Distance	Lake	Transect (lake)	Lake × distance
Stand attributes								
Area (ha)	0.07	<0.001	<0.001	<0.001	0.12	<0.001	<0.001	0.04
Perimeter (m)	0.78	<0.001	<0.001	<0.001	0.78	<0.001	<0.001	<0.001
Shape	0.56	<0.001	<0.001	<0.001	0.42	<0.001	<0.001	<0.05
Linearity	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Age	0.17	<0.001	<0.001	0.07	0.18	<0.001	<0.001	0.02
Stand composition								
Aspen	<0.001	<0.001	<0.001	<0.001	0.08	<0.001	<0.001	0.07
Black spruce	0.47	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
White spruce	0.18	<0.001	<0.001	0.54	<0.001	<0.001	<0.001	<0.005
Shrubs and grasses	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Proportion of stands dominated by								
Aspen	<0.001	<0.001	–	<0.001	0.28	<0.001	–	NC
Black spruce	0.27	<0.001	–	NC	<0.001	<0.001	–	NC
White spruce	0.07	<0.001	–	NC	<0.001	<0.001	–	NC
Shrubs and grasses	NC	NC	–	NC	NC	NC	–	NC

^a Probabilities for fixed effects of distance are based on F -tests whereas probabilities for the other (considered random) effects are based on Z tests. NS: not significant. Satterthwaite's numerator degrees of freedom approximations for the main effect of distance was 5 whereas denominator degrees of freedom ranged between 269 and 321. NC: could not be calculated due to small sample size, –: not included as a factor in analysis (see Section 2).

Muskwa, but not in Lac La Biche region (Table 1, Fig. 4C–F). The low occurrence of shrubs/grasses as the dominant vegetation type prevented statistical analysis for either region but the trend was for a decline in stands dominated by shrubs/grasses with increasing distance from a lake.

4. Discussion

4.1. Effect of distance from lake on stand composition, age and configuration

Our results show that forest age and canopy composition did not vary predictably with distance from lake, demonstrating that there is no natural analogue to riparian forest buffers. Overall our results suggested little influence of proximity to lakes on forest composition, successional development or time since disturbance. The proportion of the landscape under cover of the dominant canopy species did increase with distance from lake, but this was attributable to

decreasing cover of non-forest vegetation rather than a shift in forest canopy composition with distance from lake. Lakes in this area of relatively low relief are typically associated with a network of wetlands (Devito et al., 2000) and our data suggest that it is the extent of this non-forest cover that distinguishes the vegetation surrounding lakes from that found elsewhere in the landscape. Stand size, shape, and perimeter did not vary with distance from lake, but stands near lakes were elongated relative to those away from open water (linearity metric in transect analyses). This suggests that stands near lakes have a greater amount of natural lakeshore forest edge compared to similarly sized stands away from lakes. For both stand composition and age a notable finding was the very high degree of variability among transects and lakes.

Our results suggest that forest contained within riparian buffer strips around lakes in the boreal mixed-wood is not likely to be older, or younger, on average than that in the surrounding landscape. Although it has been suggested that areas near lakes burn less frequently (Bergeron and Dubuc, 1989;

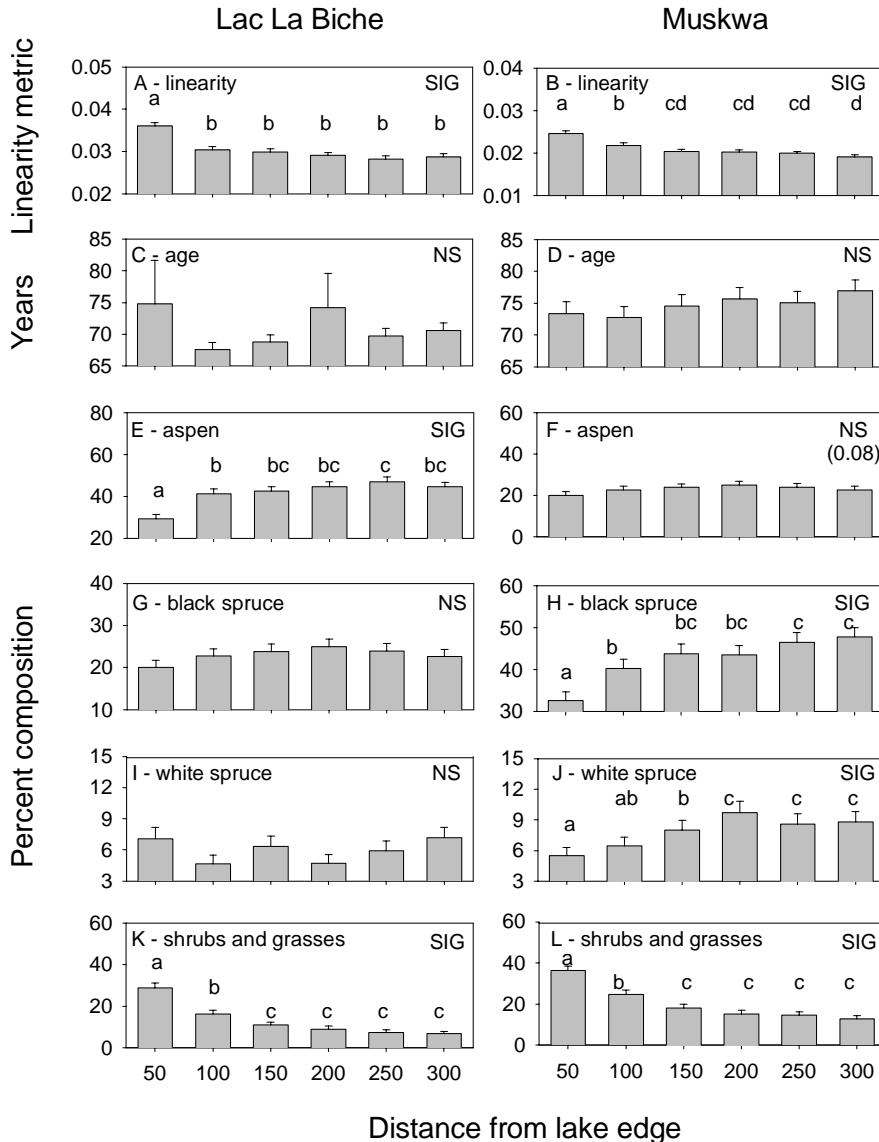


Fig. 3. Effects of distance from lake on mean (standard error) linearity metrics, polygon age and percent composition of the dominant cover types for the Lac La Biche and Muskwa regions of Alberta. SIG: significant effect of distance ($P < 0.05$), NS: not significant ($P > 0.05$). Different letters indicate distances that were significantly different from one another. Note differences in y-axis scales among plots.

Denneler et al., 1999), Bergeron (1991) found no effect of local lakeshore topography or forest composition on spread of fire from the adjacent mainland in the boreal forest of eastern Canada and concluded that under a regime of large, intense fires the effect of fire is homogenized among topographic units and fuel types. This seems to hold true for our study region as well,

and is logical given that lakes are small relative to the scale of fire. Cumming and Pelletier (1995) found no relationship between the incidence of wildfire and the proportion of the total landscape that was adjacent to rivers or lakes in a region for the boreal mixed-wood in eastern Alberta. Our results suggest that the influence of small bodies of open water on disturbance regime,

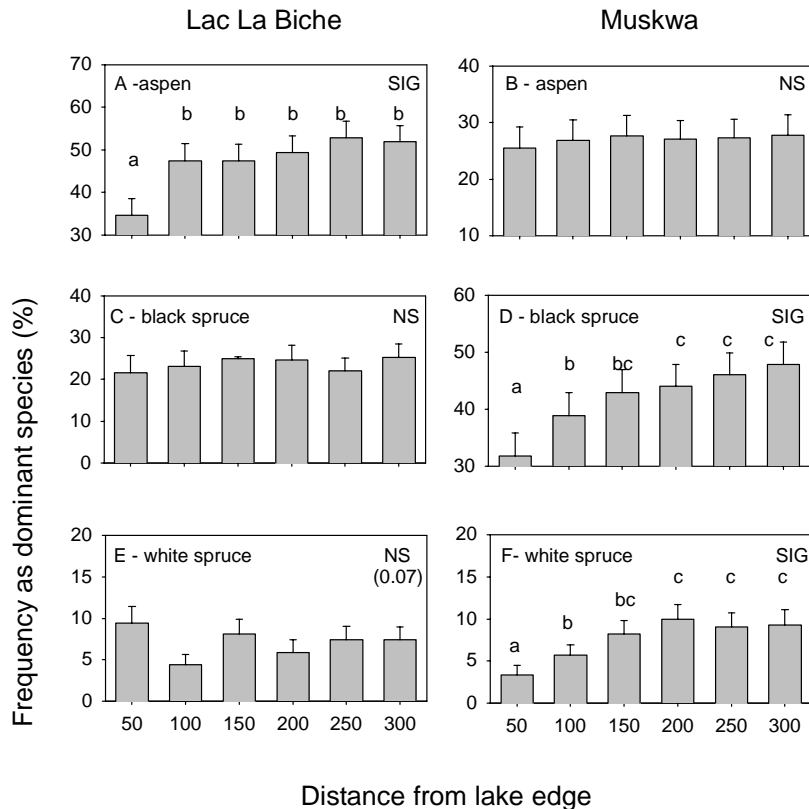


Fig. 4. Effects of distance from lake on mean (standard error) proportion of stands dominated by aspen, black spruce, and white spruce for the Lac La Biche and Muskwa regions of Alberta. SIG: significant effect of distance ($P < 0.05$), NS: not significant ($P > 0.05$). Different letters indicate distances that were significantly different from one another. Note differences in y-axis scales among plots.

and thus forest age structure, is minimal in the boreal mixed-wood landscape. It is possible that small fire skips or veteran trees are more common around water bodies and these have important ecological and habitat values (Bergeron, 1991) that would be worthy of consideration in riparian management, but at a finer scale than considered here. In a separate paper we will explore finer-scale effects of distance from lake on forest structure, composition and wildlife (Macdonald, Boutin, Paszkowski, Hannon, unpublished).

Our expectation that riparian forests should be older than that of upland regions assumed that: (1) fire, rather than blow-down, pest outbreaks, or flooding, is the primary disturbance type; (2) fire intensity and severity are affected by local factors including a reduced probability of burning in riparian areas and (3) that differences in fire prevalence and intensity between riparian and upland habitats are sufficiently

large to be detectable above natural variation. There are at least four explanations for our finding that forest composition and age did not vary predictably with distance from lake. First, the effects of fire around lakes may be more homogenous than initially contended. Second, the effects of fire are less important than initially contended; they are masked by moderately high variation in geomorphic factors between riparian and upland sites. Third, similar forest ages between upland and riparian areas arise because the effect of fire in upland areas produces an age class distribution that coincides with age classes produced from the interplay of fire combined with flooding of riparian habitats. In fact, our understanding of the relative importance of fire, wind-throw, pest outbreaks and flooding on forest age in the boreal mixed-wood is in its infancy. Models predicting forest age class distributions based on the interplay of several

disturbance types, within different physiographic settings, need to be developed and tested. Fourth, the absence of differences in forest age with increasing distance from lakeshore could arise from low statistical power or analyses based on an inappropriate spatial resolution. We largely dismiss the final alternative because our analyses were based on large sample sizes and we tested for differences in forest age using a diversity of inherently suitable approaches that were completed at a number of spatial extents and at the spatial resolution relevant to our intended application of these results (forest management planning).

4.2. Topographic effects on forest composition and age

Our results suggested that topographic effects around lakes may be important in determining adjacent forest composition, confirming prior studies on riparian forests next to streams (Pabst and Spies, 1998, 1999; Rot et al., 2000). In our study, however, these effects were generally weak as compared to topographic influences on forest vegetation in the broader landscape context. Boreal Plain lakes are situated within the context of complex hydrological patterns (Devito et al., 2000); their surrounding forest landscapes, it appears, are nested within broader landscape/landform influences. Adjacency of stands to a lake may not be correlated with landscape features that support structurally or compositionally unique forests. Random sampling of the entire Calling Lake region revealed a significant controlling influence of topographic position on both forest composition and age (Burgess, 1997). The vast majority of stands on sites with greater than 2% slope were aspen-dominated, irrespective of aspect. On flat topographic positions, however, there was a higher frequency of white spruce- and black spruce-dominated stands (Burgess, 1997); in addition, stands at higher elevations were younger. This was surprising given the very mild relief of this area and that the primary ignition source, lightning, was spatially random in this area (Burgess, 1997).

Several studies have indicated that riparian forests are a reflection of interacting processes, operating at different scales (Baker, 1989; Bendix, 1994; Pabst and Spies, 1999). While fine-scale processes may account for vegetation patterns very close to water, coarser-scale patterns must be understood in the context of

regional climatic and geologic differences (Pabst and Spies, 1999). For the scale of this study, and of forest management planning, the fine-scale patterns were not detectable and the coarser-scale influences appear to operate independently of proximity to lake.

4.3. Implications for riparian management

Our results suggest that there is not a strong natural analogue to riparian forest buffers around lakes in the mixed-wood boreal forest. This practice, therefore, does not seem to be justified within the context of forest ecosystem management which attempts to emulate natural disturbance. Such buffers will not contain a unique forest type, but may include more non-forest vegetation than is found in similarly sized areas away from lakes. These non-forested areas are largely low productivity wetlands for which no management is planned; thus, there is little need to protect them in riparian buffer strips.

Many studies conducted at a finer resolution than ours have demonstrated that riparian areas exhibit unique composition and high species richness for both flora and fauna and that they may be important as movement corridors for animals (Stauffer and Best, 1980; Doyle, 1990; Naiman et al., 1993; Machtans et al., 1995; Ericsson and Schimpf, 1986; Naiman and Décamps, 1990; Pabst and Spies, 1998; Pollock et al., 1998). Further, the natural lakeshore ecotone in the mixed-wood boreal forest is structurally and compositionally unique at a fine spatial scale (Machtans et al., 1995; Harper and Macdonald, 2001), and could contain a higher density of old trees (Suffling et al., 1982), as compared to upland forest. In addition non-forested riparian zones immediately adjacent to lakes in the boreal mixed-wood show a high diversity of plants and some types of wildlife and high compositional heterogeneity (Macdonald, Boutin, Paszkowski, Hannon, unpublished). Given this information riparian management in the western boreal mixed-wood would be appropriately focused on waterbody protection, designed within the context of local hydrologic conditions, protection of specific riparian habitat features, and creation of movement corridors.

A prescriptive approach to buffer management, i.e. 100 m buffers placed around most lakes, is likely not the best way to meet the diversity of objectives for riparian management. Buffers of this width may not

always be necessary to protect receiving waters, while in some cases much wider buffers may be required (Devito et al., 2000). Neither will such buffers protect a representative sample of forest types, which are associated with a variety of landforms and elevations of the overall landscape. Further, the combined influence of edge effects (windthrow, microclimate, forest structure) from two sides may severely impact the habitat value of narrow riparian buffers (Johnson and Brown, 1990; Gates and Giffen, 1991; LaRue et al., 1995; Hannon et al., 2002). We propose an adaptive approach to riparian forest management focused on meeting specific conservation and management objectives, and which incorporates variable buffer widths prescribed on the basis of lake-specific concerns, fine-scale management to retain specific habitat features, and landscape-level planning for fire suppression and placement of uncut forest.

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