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RESEARCH ARTICLE

Logging pattern and landscape changes over the last century at the boreal and deciduous forest transition in Eastern Canada

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Abstract Forestry practices associated with the industrial era (since ~1900) have altered the natural disturbance regimes and greatly impacted the world's forests. We quantified twentieth century logging patterns and regional scale consequences in three sub-boreal forest landscapes of Eastern Canada (117,000, 49,400 and 92,300 ha), comparing forestry maps depicting age and forest cover types for early industrial (1930) and present-day (2000) conditions. Results were similar for the three landscapes, indicating large-scale forest change during the twentieth century. In 1930, previous logging activities had been concentrated in the lowlands and along the main hydrographical network, as compared to a more even distribution over the landscapes in 2000, reflecting a decreasing influence of the environmental constraints on forest harvesting. In 1930, old-aged forests (>100 years) accounted for more than 75% of the unlogged areas of the three landscapes, as compared to less than 15% for the present-day conditions. Logging practices have thus inverted the stand age distribution of the landscapes that are currently dominated by young and regenerating stands. The 1930 forest cover types showed a clear relationship with elevation, with conifers located in the lowlands and mixed and deciduous stands restricted to the upper slopes. Between 1930 and 2000, 58–64% of the conifer areas transformed to mixed and deciduous forests, such that no clear altitudinal relationships remained in 2000. We conclude that twentieth century logging practices have strongly altered the preindustrial vegetation patterns in our study area, to the point that ecosystem-based management strategies should be developed to restore conifer dominance, altitudinal gradients, as well as the irregular structure inspired from old forest stands.

Keywords Balsam fir · Ecosystem-based management · Historical forestry maps · Land cover change · Logging constraint · Preindustrial forest · Physical environment · Timber floating · Reference conditions

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Introduction

Human-induced land cover changes have caused widespread transformation of the earth's terrestrial surface (Defries et al 2004; Crutzen and Steffen 2003). In particular, silvicultural practices associated with the industrial era (since ~1900), including large scale forest harvesting and plantations, have led to major changes in the structure and composition of forest landscapes in North America and Fennoscandia (Whitney 1994; Östlund et al. 1997; Foster et al. 1998; Kouki et al. 2001). Logging, which differs from natural disturbances in severity, frequency, and spatial extent, often resulted in younger, more fragmented forests, in addition to changing the composition of the landscape's tree species (Mladenoff et al. 1993; Whitney 1994; Friedman and Reich 2005; Schulte et al. 2007; Rhemtulla et al. 2007). Logging is also known to have altered the influence of several physical factors, such as elevational and climatic gradients and landform, on forest composition (Siccama 1971; Mladenoff et al. 1993; Foster et al. 1998; Whitney and DeCant 2003; Boucher et al. 2006a, b).

In eastern Canada, the Great Lakes-St. Lawrence forest region extends from the Great Lakes to the center of the Gaspé Peninsula along the St. Lawrence River valley in Quebec (Rowe 1972). This region, which is at the interface between the deciduous forest and coniferous boreal forest, is comprised of a mix of both coniferous (*Abies balsamea* (L.) Mill., *Tsuga canadensis* L., *Picea glauca* ((Moench.) Voss)) and deciduous (*Acer saccharum* Marsh., *Quercus rubra* L., *Betula alleghaniensis* Britt.) species. Before European influences, the forests of the Great Lakes-St. Lawrence forest region were affected primarily by small-scale secondary disturbances (windthrows, insect outbreaks and tree-fall gaps) (Lorimer 1977; Payette et al. 1990; Boulanger and Arseneault 2004). Severe disturbances, such as large windthrows and fires, were rare, with rotation periods estimated at 800 and >1,000 years, respectively (Lorimer 1977; Wein and Moore 1977).

For more than a century, this region has been under a regime of severe logging whose long-term impacts are far from being well understood. Yet, knowledge regarding the structure and composition of natural forested landscapes and their transformation under the influence of forestry practices is essential to develop benchmarks for ecosystem-based management (Landres et al. 1999; Harvey et al. 2002). For example, comparing the characteristics of virgin or almost virgin forests with adjacent stands that have been heavily exploited allows the impacts of logging to be evaluated and the planning of forestry practices that are compatible with natural forest dynamics (Mladenoff et al. 1993; Kuuluvainen 2002). Unfortunately, virgin stands are often located in areas that are not representative of the region (e.g., they are at high elevations or located on steep slopes) and thus are poor controls. In this context, historical maps and forest inventories can be used to compare the characteristics (structure and composition) of a given forest at different temporal periods and thus provide key information that would otherwise be unavailable (Axelsson and Ostlund 2002; Kuuluvainen 2002).

Although past studies have examined the long term, large-scale anthropogenic impacts on forest of the Great Lakes-St. Lawrence forest region from Central to Eastern North America (Foster et al. 1998; Jackson et al. 2000; Etheridge et al. 2005; Friedman and Reich 2005; Schulte et al. 2007), logging impacts are still undocumented for large sectors that have been heavily harvested, such as the Lower St. Lawrence region in Eastern Quebec. In this study, we used historical forestry maps to describe in a spatially explicit manner how the structure and composition of the landscapes have evolved between the early industrial period (1930) and the present-day (2000) in response to historical logging in three forested landscapes of the Lower St. Lawrence region. Specifically our objectives were: (1) to examine temporal changes in the patterns of logging across landscapes; (2) to examine changes in forest composition and age structure; (3) to examine changes in the influence of physical factors on forest composition. We also considered the implications of these changes in order to develop ecosystem-based management strategies.

Study region

The three studied landscapes are situated at the northeastern range limit of the Great Lakes-St. Lawrence forest region (Rowe 1972) and extend between 47°92′ N and 48°94′ N latitude and between 66°78′ W and 68°84′ W longitude (Fig. 1). This region is part of the Appalachian geological formation and is characterized by sedimentary rocks capped with in situ weathering and glacial till (Robitaille and Saucier 1998). The topography is variable and consists of low hills along the St. Lawrence River (25–150 m a.s.l.) and high hills (350–700 m a.s.l.) in the south-eastern section of the territory. The climate is characterized by a mean annual temperature of 3.1°C with a mean annual precipitation of 929 mm, of which 38% falls as snow

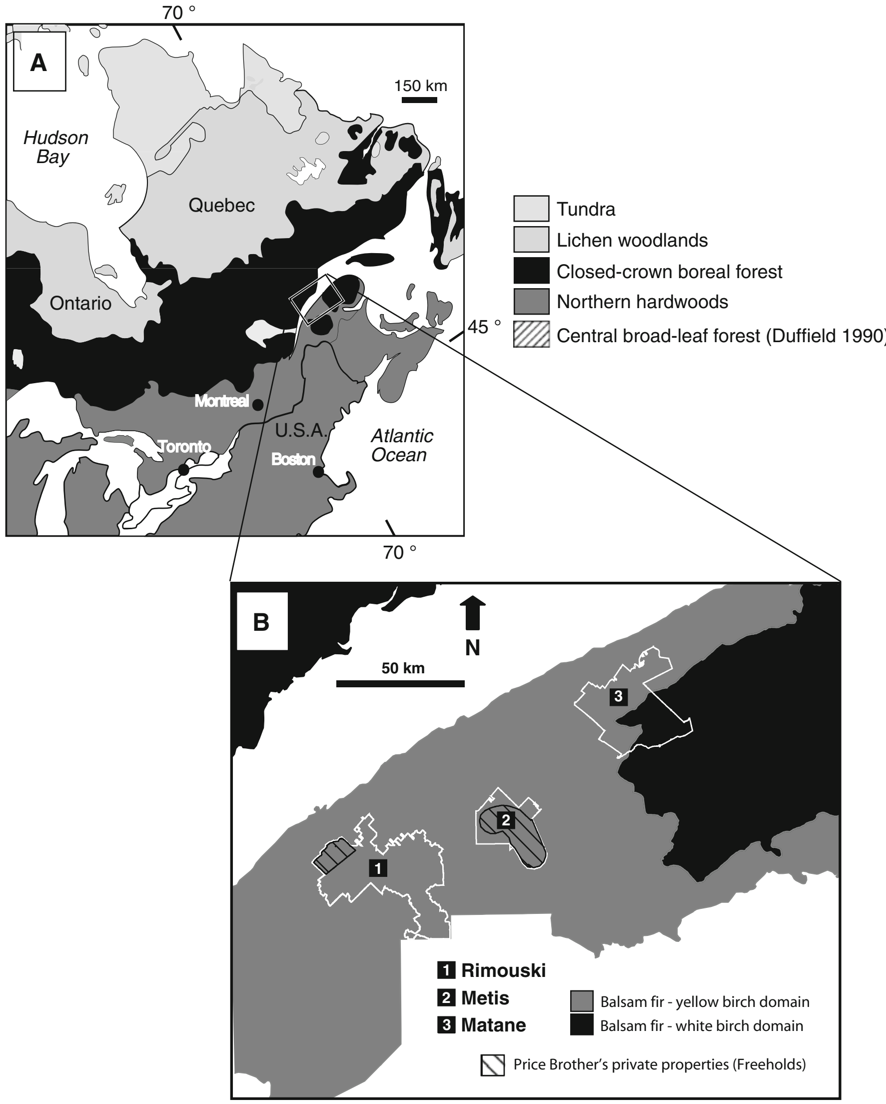

Fig. 1 Location of the study area in Eastern Québec, Canada (**a**); vegetation zones are delineated according to the classifications of Rowe (1972) and Duffied (1990). Location of the Rimouski, Metis and Matane landscapes and the private lands of the Price Brother's company (**b**); vegetation zones are delineated according to the Quebec ecological classification system (Robitaille and Saucier 1998)

(Robitaille and Saucier 1998; Environment Canada 2008).

Research conducted within the study region (Sorel 2004; Boulanger and Arseneault 2004; Boucher et al. 2006a), adjacent New England (Lorimer 1977; Seymour et al. 2002), and New Brunswick (Wein and Moore 1977; Taylor and MacLean 2005), indicates that the preindustrial disturbance regime was characterized by small gaps, windthrows, insect outbreaks, and rare fires. Native American communities did not seem to have an impact on the fire regime in the region unlike other areas of North America (Day 1953; Whitney 1994). On the other hand, land clearing fires lit during the colonization periods burned significant areas during the late nineteenth and first half of the twentieth centuries (Guay 1942, 1944; Fortin et al. 1993). Although Europeans began colonizing the area at the end of the seventeenth century, it wasn't until the start of the nineteenth century that the area truly began to be occupied. This occupation coincides with the selective cutting of pine (*Pinus resinosa* Ait. and *P. strobus* L.) for naval construction during the nineteenth century (Fortin et al. 1993). It was only at the beginning of the twentieth century, with the increasingly high demand for lumber and pulp and paper, that the industrial period of intense logging began (Whitney 1994).

The three studied landscapes, hereafter referred to as Rimouski (117,000 ha), Metis (49,400 ha), and Matane (92,300 ha), were logged during the nineteenth and twentieth century by the Price Brother's Company and their successors. The landscapes correspond to 72, 27, and 55% of the watersheds for the Rimouski, Mitis, and Matane rivers, respectively. The majority of the land within the three study areas is public land with the exception of two large private properties belonging to Price Brother's Company: the Lac-Métis seignory (33,900 ha) in the Metis landscape, and the Nicolas-Riou seignory (13,700 ha) in the Rimouski landscape (Fig. 1). These seignories had been privately held since 1693 (Metis) and 1751 (Nicolas-Riou) and were sold to the Price Company in 1876 and 1911, respectively (Fortin et al. 1993). According to the Québec ecological classification system, the three landscapes are located within the balsam fir-yellow birch bioclimatic domain except for the high plateaus of the Matane landscape (34,000 ha; >500 m a.s.l.), which are situated within the balsam fir-white birch domain of the boreal zone (Grondin et al. 1998). The forests are comprised of balsam fir, white and yellow birch (*B. papyrifera* Marsh. and *B. alleghaniensis* Britt.), sugar and red maple (*A. saccharum* Marsh. and *A. rubrum* L.), trembling aspen (*P. tremuloides* Michx.), white pine, eastern white cedar (*T. occidentalis* L.), white and black spruce (*P. glauca* ((Moench.) Voss)) and *P. mariana* (Mill.) BSP.). Monospecific plantations of spruce (*P. mariana*, *P. glauca*, and *P. abies* L.) occupy a significant area of the sectors cut after 1985. The three forested landscapes were never cleared for farming. Historical records indicate that no major natural disturbances have occurred in the forests since 1930 outside of a light spruce budworm outbreak from 1944 to 1955 and a severe outbreak between 1975 and 1990 (Boulanger and Arseneault 2004). Colonization fires only affected the northern margins of each study areas. Fires have not played a major role in the regional forests in recent history (1952–1998), the fire cycle being currently estimated at more than 2,700 years (Parisien et al. 2004).

Methods

Forestry maps of 1930 and 2000

Changes in the structure and composition of the forest landscapes were examined using forest inventory maps created from aerial photographs taken in 1930 and 2000 (Table 1). The 1930 maps, created by the Price Brother's company, were digitized in a vector format and georeferenced using ArcGis 8.3 (ESRI 2003). The 2000 maps were acquired directly in a digitized format and are part of the 3rd decennial forest inventory conducted by the ministère des Ressources naturelles du Québec (MRNQ 2000a). The 1930 maps included five forest age classes: 20–40, 40–60, 60–80, 80–100, and >100 years. To these five classes we added a 0–20 year class to those areas designated as "recently burned". Some stands belonging to the 20–40 year class had already been subjected to diameter limit logging at the turn of the century and were labeled as "cut-over" on the 1930 maps. Some older stands (60–80 years and >100 years) were also labeled "old cut-over". In addition to its age class, each of the 1930 polygon in the three landscapes was thus classified as logged or unlogged prior to 1930.

Table 1 Scale and type of aerial photographs used to elaborate the forest inventory maps

Map	Scale and type of aerial photographs	Minimal unit area (ha)	Source
1930	1: 32 000; BW	1	Québec national archives at Chicoutimi, Price funds, Maps and plans P666
2000	1: 15 000; IR	1	Ministère des Ressources naturelles du Québec. 3rd decennial inventory

BW Black and white, *IR* false color infrared

The 1930 map also contained information regarding the composition of the forest. Areas dominated by coniferous species (coniferous cover >75%) and originally designated as "softwood", "swamp softwood", or "black spruce" on the historical maps were merged into one class entitled "conifer". Mixed covers (>25% each of coniferous and deciduous) and deciduous (deciduous >75%) were also present on the 1930 map and were considered as such for this study.

Comparing old forest map with more recent inventory data is an important challenge as spatial resolution and classification criteria may have varied between time periods. In our study, cover types were based on the same classification criteria for the two maps (conifer or deciduous cover >75%; see above), thus allowing direct comparison. In addition, a previous study (Boucher et al. 2006a) demonstrated good agreement of these cover types between aerial photographs taken in 1930 and 1941, indicating robust cover delineation in 1930. As it is impossible to identify the composition of young forest covers on aerial photographs, the composition of the 0–20 age class was designated here as "regenerating" on all maps. In addition, areas classified as non-productive forest areas, including water bodies and naturally deforested terrestrial zones, were excluded from analysis. For the remainder of the article, the terms "conifer", "mixed", and "deciduous" refer to the forest stand cover type.

In contrast to cover type, criteria used to classify 1930 cover age were unknown. To allow valid age classes comparison between dates, we thus reclassified 1930 and 2000 data into three wide age classes labeled "young-aged" (0–40 years old), moderately-aged (40–100 years old) and old-aged (>100 years old) forests (Table 2). We assumed that such wide classes could be easily mapped from photographs of the two inventories.

Spatial analysis

The 1930 and 2000 maps were incorporated into a raster-based geographic information system using IDRISI I32.11 (Eastman 1999). Taking into consideration the minimal size of the cartographic units for each map (Petit and Lambin 2002), the landscape was divided into a grid with each pixel representing an area of 1 ha. Changes in the arborescent cover composition between 1930 and 2000 were determined using cross tabulation. A digital elevation model built from hypsometric maps provided by the ministère des Ressources naturelles du Québec (scale 1:20,000 with 10 m contours; MRNQ 2000b) was used to document the relationship between elevation, forest composition, and logging patterns, in 1930 and 2000. In order to determine the constraints related to timber floating on the transformation of the landscape, the cut-over areas during each period were also compiled as a function of the minimal distance to a principal watercourse i.e., a 3rd order or more watercourse following the classification of Strahler (1952). Based on 1-ha pixels, one factor ANOVA were performed to compare mean elevation and distance to a watercourse between logged and unlogged pixels for each landscape in 1930 and 2000. Because of non-normal data, we used a gamma distribution with logarithm as link function (McCulloch and Searle 2001). Spatial autocorrelation of elevation and distance to watercourse was controlled by an analog process described by Stroup et al. (1994). These analysis were performed with the GLIMMIX procedure of the SAS software. The NLIN procedure was used to estimate the spatial variogram model (Littell et al. 2006). The goodness-of-fit of models to data was evaluated with the scaled Pearson Chi-square statistic divided by appropriate degrees of freedom. Values between 0.77 and 0.93 showed very good fit.

Table 2 Correspondence between age classes used in this study and classifications on the 1930 and 2000 maps

Age-class in the present study (years)	1930 map	2000 map
0–40	Recently burned	Clear-cut, plantation, 10
0–40	20–40	30, 30–50[a], 30–70[a], young uneven aged
40–100	40–60	50, 50–90[a]
40–100	60–80	70, 70–30[a], 70–50[a]
40–100	80–100	90, 90–30[a], 90–50[a]
>100	>100	120, old uneven aged

[a] Two-storied stand

Results

Evolution of logging patterns in the twentieth century

The distribution of logged areas changed considerably between 1930 and 2000, as a function of constraints related to physical landscape conditions. In 1930, 35 and 33% of the respective Matane and Rimouski landscapes were logged, as compared to 6% for the much less exploited Metis landscape (Fig. 2). The proportion of the area harvested during this period generally diminished as a function of distance to a watercourse. For example, in the Rimouski and Matane landscapes, from 46 to 58% of areas located within 500 m of a watercourse had already been logged in 1930, compared to less than 10% for area situated between 5,500 and 6,000 m of distance (Figs. 2, 3a). At the same time, elevation was also

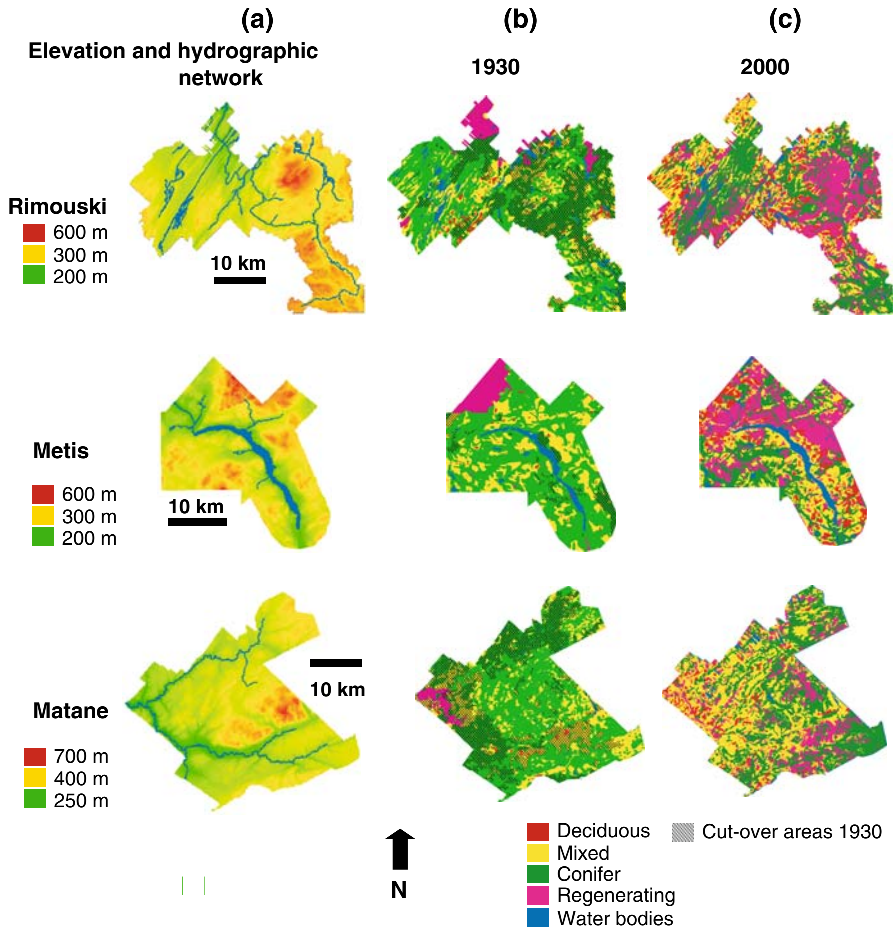

Fig. 2 Rimouski, Metis and Matane landscapes depicting elevation variation and main hydrographical network (**a**), forest cover type in 1930 (**b**), and forest cover type in 2000 (**c**). Regenerating stands correspond to stands 0–20 years old whose composition cannot be determined while cut-over areas refer to stands logged prior to 1930

an important factor in determining the location of cut-over areas before 1930. For the three landscapes, the percentage of area cut in 1930 was maximal in the lowlands (Figs. 2, 3b). In contrast, areas classified as recently logged in 2000 tended to be distributed at greater elevation or distance to the principal watercourse (Figs. 2, 3a). In 1930, mean elevation was significantly lower for logged than unlogged pixels for the three landscapes, while the reverse situation occurred in 2000 (One factor ANOVA, $P < 0.001$; Table 3). Similarly, mean distance to a watercourse was significantly lower for logged than unlogged pixels for the three landscape in 1930. This pattern was reversed in 2000, except at Metis.

Evolution of landscape age structure in the twentieth century

Between 1930 and 2000, the age structures of the forested landscapes changed to reflect their transformation from being dominated by old-aged (>100 years old) to young-aged (0–40 years; Rimouski and Metis) and moderately-aged (40–100 years; Matane) forest stands (Fig. 4a). In 1930, at least 75% of the unlogged territories were occupied by old-aged stands. Collectively, young-aged and moderately-aged stands never made up more than 18% of the unlogged lands. Areas already cut in 1930 were mainly represented by young-aged stands which comprised 4% of the Metis landscape and 29 and 23% of the Rimouski and Matane landscapes, respectively (Fig. 4a). The rest of the logged areas were distributed in older forests in sectors where historical diameter limit harvesting had previously been practiced (Gérin et al. 1944). Between 1930 and 2000, the average stand age of the three landscapes diminished considerably (Fig. 4a). In 2000, the old-aged age class was only a minor landscape component making up between 4 and 14% of the total area; a strong decline in comparison to 1930. In contrast, in 2000 young-aged forests made up

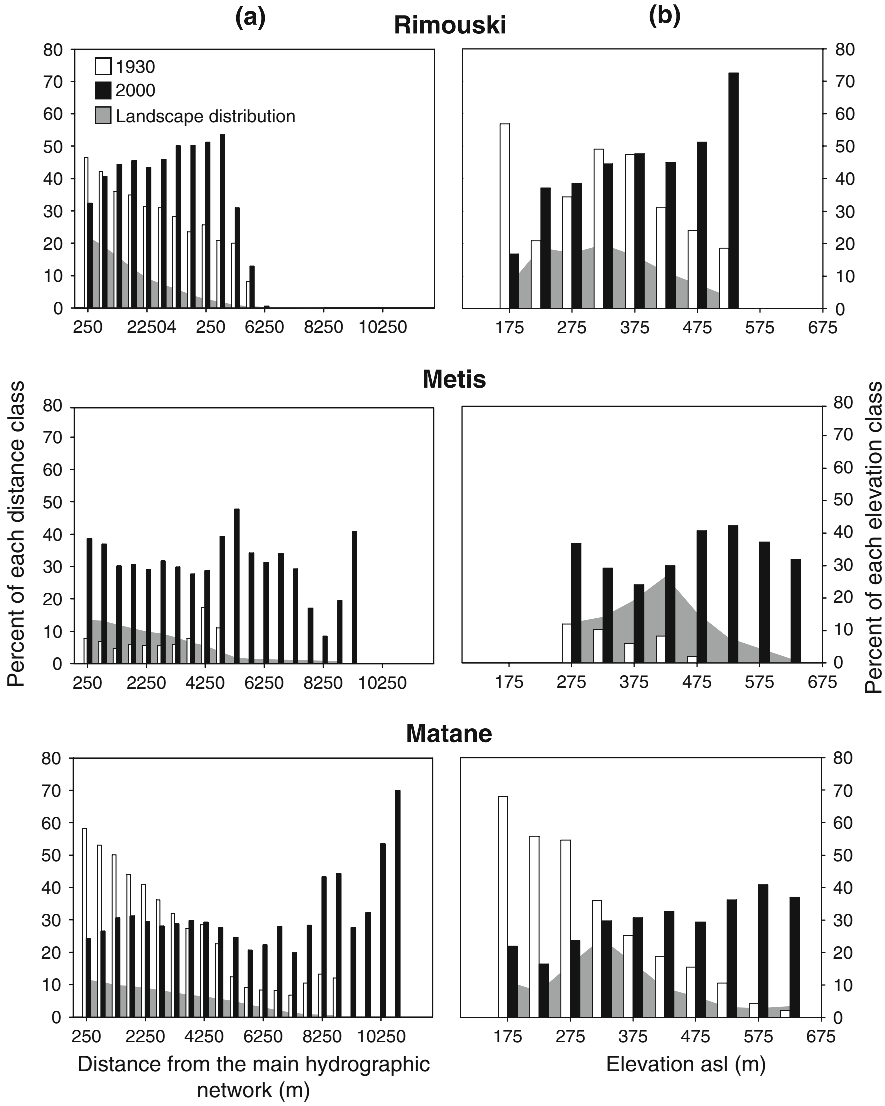

Fig. 3 Percent of cut-over lands according to distance from the main hydrographical network (**a**) and elevation (**b**). Each bar refers to the proportion of a given class that had been logged prior to 1930 or 2000. For each landscape the shaded area in the background show how the total landscape is distributed among distances or elevation classes

57, 62, and 40% of the Rimouski, Metis, and Matane landscapes, respectively.

Evolution of twentieth century landscape composition

In 1930, the uncut landscape matrix was dominated by conifer forests (55–60%), with mixed (29–32%) and deciduous (1–5%) forests being less abundant Fig. 4b). Overall, regenerating areas made up 2–8% of the landscape (Fig. 4b) and generally coincided with recent burns of anthropic origin at the edge of the mapped sectors. In 1930, the recently cut areas were regenerating primarily with coniferous (65–87%) or mixed species (13–35%; Fig. 4b). Without taking into consideration whether or not the forests were logged in 1930, the composition of the 1930s forests were controlled by elevation. Conifer abundance progressively diminished from lowlands to summits up to 500 m in altitude, while mixed forests displayed an inverse trend. An inverse relationship prevailed at altitudes above 500 m, with conifer cover increasing to the detriment of mixed (Fig. 5a).

The relative abundances of the cover types changed considerably after 1930. In 2000, conifer constituted only 25–28% of the landscape, as compared to 42–45% in 1930. The abundance of the mixed cover class remained relatively stable with

Table 3 Least square means of 1-ha pixels for elevation and distance to a watercourse by landscape and year

Landscape	Elevation (m)		Distance to a watercourse (m)	
	1930	2000	1930	2000
Rimouski				
Logged	318.16	337.62	1363.36	1626.22
Unlogged	323.67	310.22	1685.35	1542.78
Metis				
Logged	357.80	406.61	2196.16	2226.58
Unlogged	404.24	399.79	2399.89	2454.73
Matane				
Logged	280.33	361.13	2022.95	2870.80
Unlogged	373.58	332.48	3325.82	2857.88

Least square means are means that are adjusted for the spatial autocorrelation of elevation and distance to a watercourse. Differences between logged and unlogged areas for the two dates and the three landscapes are all highly significant ($P < 0.001$) because of high degrees of freedom of the error terms (104523, 42936 and 87705 for Rimouski, Metis and Matane, respectively)

variations ranging ±29% in comparison to the 1930 abundance, while the deciduous area (6–12%) increased by a factor of 2.3–12.4 compared to the values in 1930 (Fig. 4b). The changes in relative abundance of the cover types as a function of elevation show a general reduction in conifers to the advantage of mixed forests that is particularly evident at lower elevations (Fig. 5c). No clear altitudinal relationships were observed and the three cover types were distributed more or less equally across the altitudinal sections (Fig. 5b). The regenerating areas of indeterminate composition were considerably widespread in 2000 in comparison to 1930 and comprised 33 to 42% of the area of the landscapes (Fig. 4b).

The changes in cover types between 1930 and 2000 depict a highly dynamic episode with only 28–34% of the pixels remaining in the same cover class (sum of diagonals in Table 4). The most important change overall resulted in 17–28% of the landscapes transforming from conifer to regeneration cover. In addition 12–25% of the landscape transformed from conifer to mixed. In total, 37–42% of the landscapes changed from conifer to either mixed or regeneration types, i.e., 58–64% of their relative abundance in 1930. The 1930s mixed forests evolved primarily towards regeneration covers whereas the deciduous forests of 2000 were principally conifer or mixed in 1930.

Discussion

The preindustrial forest

This study shows that the introduction of industrial logging in the twentieth century has strongly modified the abundance and spatial distribution of forest cover types in the eastern part of the Great Lakes-St. Lawrence forest region. The preindustrial forest mosaic was dominated primarily by old-aged conifer forests in the lowlands and by old mixed forests on the hills and summits. The marked influence of elevation on landscape composition is a phenomenon that has been well documented in other regions of eastern North America (Barrett et al. 1995). Indeed, the distribution of conifers at the base of the hills is explained by cold air drainage combined with increased soil humidity, while intermediate summits, which are warmer and better drained, favour the development of deciduous stands (Loucks 1962; Barras and Kellman 1998). The dominance of conifers on high summits greater than 500 m in elevation is probably explained by conifers being better adapted to rigorous climates (Sprugel 1976).

The specific composition of the forests in 1930 can be partially inferred using forest inventories conducted by the Government of Québec in 1938 (Guay 1942, 1944) in order to document the volume, growth, and states of the regional forests. Inventories of stands >100 years in the Rimouski, Mitis, and Matane river watersheds indicate that balsam fir was the dominant species (33–36% of the total volume of stems with a diameter >20 cm), with white and black spruce (*P. glauca*, and *P. mariana*; 23–40%) and eastern white cedar (1–7%) comprising the rest of the abundant coniferous species. Paper birch (12–27%), yellow birch (9–13%), and sugar maple (≈1%) were the principal deciduous species in the regional forests.

Information concerning the structure and composition of the unharvested landscapes in 1930 allowed the disturbance dynamics that prevailed before the industrial cuts to be inferred. Firstly, the high abundance of old-aged forests (>100 years) suggests the predominance of secondary disturbances of relatively low spatial extent or low severity (Turner

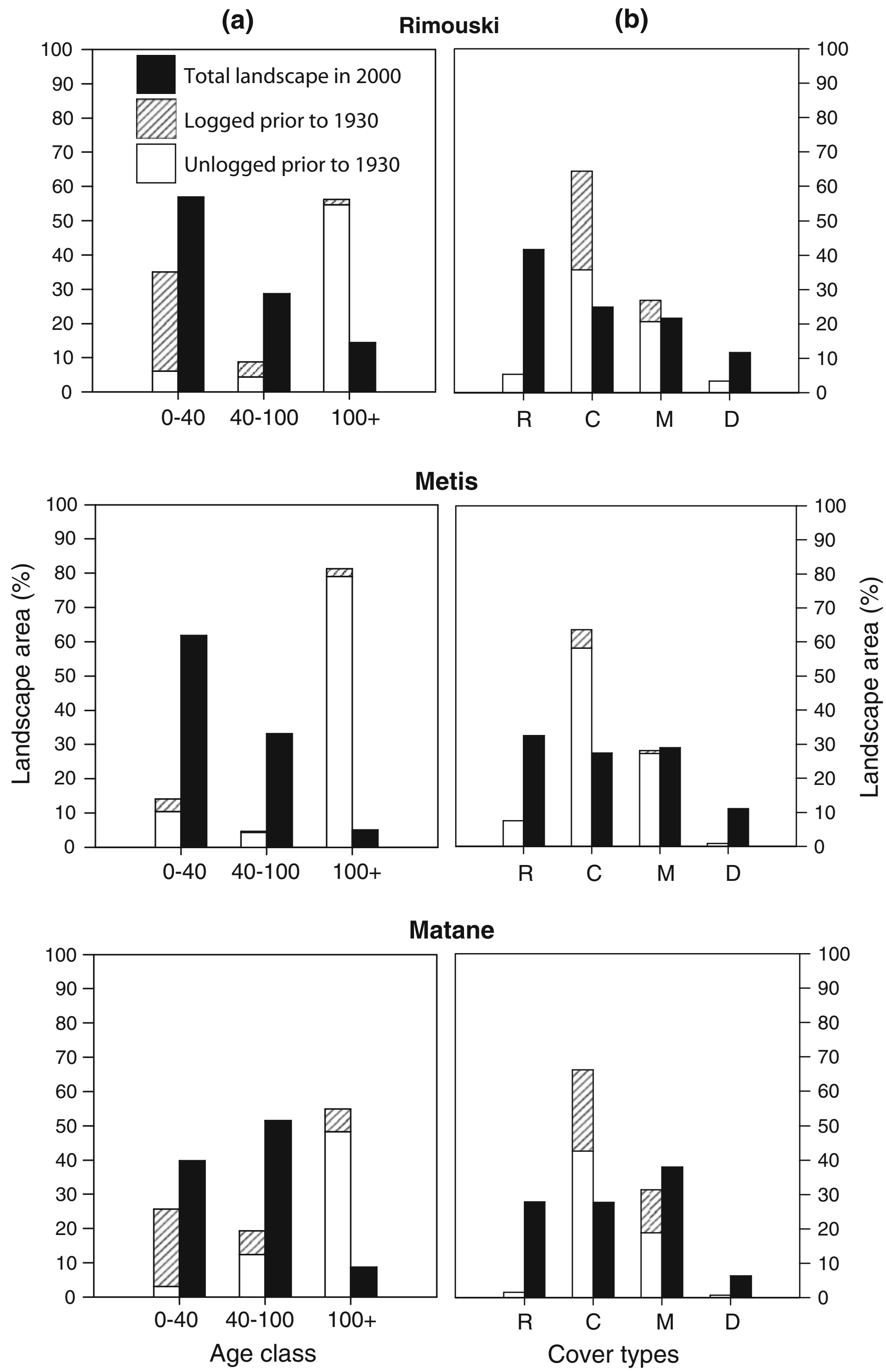

Fig. 4 Relative abundances of age-class (**a**) and cover types (**b**) for the Rimouski, Metis and Matane landscape in 1930 and 2000. R: regenerating stands (0–20 years) of indeterminate composition due to young age; C: conifer; M: mixed; D: deciduous

et al. 1993), including windthrows and insect outbreaks (Boulanger and Arseneault 2004; Sorel 2004). Secondly, the presence of species vulnerable to fire, such as balsam fir and eastern white cedar, combined with the rarity of fire adapted species, including jack pine and trembling aspen, indicates that fire was not common in the region (Frelich and Reich 1995; Park et al. 2005). Thirdly, the 1938 inventory mentions that, within the three landscape, the majority of uncut stands possessed either irregular or multi-cohorts structures generated by windthrows (Guay 1939). In the neighboring forest region north of St.-Lawrence,

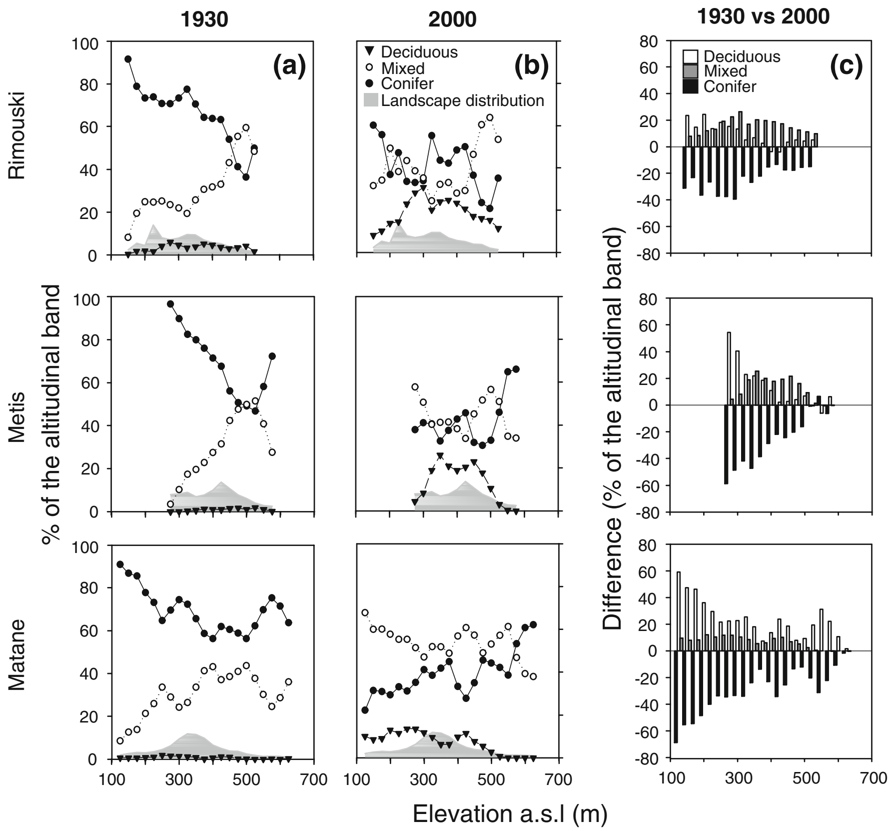

Fig. 5 Cover type abundance according to elevation for the Rimouski, Metis, and Matane landscapes in 1930 (**a**) and 2000 (**b**), excluding regenerating areas. Data outside the 2.5 and 97.5‰ of elevation were excluded to eliminate outliers. Difference of cover type abundance between 1930 and 2000 according to elevation at the three landscapes (**c**)

where the fire cycle extended up to 600 years (Bouchard et al. 2008), the same irregular structure was observed in the virgin forest (Pham et al. 2004; Boucher et al. 2006b). In addition, research concerning the dynamics of preindustrial forests in eastern Québec (Sorel 2004; Boucher et al. 2006a), New Brunswick (Wein and Moore 1977), and Maine (Lorimer 1977; Seymour et al. 2002) suggests a similar disturbance regime dominated by gaps with fires and large windthrows being rare events.

Forest dynamics since the introduction of logging in the twentieth century

By 1930, vast areas in the Rimouski and Matane landscapes had already been exploited in the early twentieth century (Fig. 2). The areas logged in 1930 were determined largely by their physical constraints. Harvesting sites were influenced in a large part by their proximity to water courses and by their elevation. Low elevations sites, which are generally associated with gentle slopes, allowed the transport of logs using horses while the presence of water courses close to the cut-over areas allowed logs to be floated to the sawmills. These same methods of exploitation were used elsewhere in the United States and in northern Europe (Judd 1989; Törnlund and Östlund 2002), which suggests that the early spatial distribution pattern of their cuts may be similar. In 2000, the distribution of logged areas was very different, with recently cut areas being less concentrated along watercourses at low elevation. The physical conditions, which formerly acted as exploitation constraints in 1930, were considerably less due to mechanical harvesting and the development of a modern network of forestry roads. The greater abundance of conifers in the lowlands as compared to the uplands is an additional factor that may have influenced the location of the logging sites prior to 1930, as these species were preferentially logged by the early forest industry (Fortin et al. 1993).

Curiously, the properties belonging to the Price Brothers' Company (the Lac-Métis seignory and the Nicolas-Riou seignory; see Figs. 1–2) were only slightly logged in 1930 despite possessing few exploitation constraints. To this effect, an analysis

Table 4 Correspondence (percentage of the total landscape area) between forest cover composition in 1930 and 2000

1930	2000 C	M	D	R	Total
Rimouski					
C	19.6	11.9	4.4	27.7	63.6
M	3.8	6.8	5.1	11.9	27.6
D	0.3	0.6	1.2	1.4	3.4
R	0.9	2.4	1.2	0.9	5.4
Total	24.6	21.8	11.8	41.9	100
Metis					
C	22.0	17.3	4.4	19.8	63.5
M	3.9	10.1	4.3	10.4	28.7
D	0	0.3	0.2	0.3	0.9
R	1.3	1.3	2.3	2.1	7.52
Total	27.2	28.9	11.2	32.7	100
Matane					
C	20.8	24.8	3.0	17.4	66
M	6.9	12.4	2.5	9.8	31.6
D	0	0.4	0.2	0.2	0.8
R	0	0.7	0.5	0.4	1.6
Total	27.7	38.2	6.2	27.9	100

C Conifer, *M* mixed, *D* deciduous, *R* regenerating (0–20 years). Each cell corresponds to the percentage of the landscape which transformed from one class to another between 1930 and 2000

of the historical documents indicates that at the start of the twentieth century, the company concentrated its logging activities on public lands susceptible to future colonization rather than on its private property (Fortin et al. 1993). The objective of this strategy was likely to exploit the public forests before they were deforested or burned during colonization. The Price Brother's private lands were thus reserved for future logging following exhaustion of the public forests. Indeed, the 1938 governmental forest survey reported that the Nicolas-Riou seignory contained the last virgin forests in the Rimouski Landscape (Guay 1942). These forests have been heavily exploited subsequently (Boucher et al. 2006a).

Logging in the twentieth century profoundly modified the structure of the regional forests. The age structures of the three landscapes reversed from being dominated by old stands in 1930 towards a dominance of young stands in 2000. A study conducted within the eastern balsam fir-yellow birch bioclimatic subdomain, showed that stands older than 100 years already formed less than 10% of the area in 1970 (Crete and Marzell 2006). Several other studies have shown that forest management, by targeting older stands, has reduced the abundance of old seral stages at the landscape scale (Mladenoff et al. 1993; Axelsson and Ostlund 2002; Etheridge et al. 2005). Beside clearcutting, salvage cutting of stands affected by the last spruce budworm outbreak is an additional explanation for the transition of conifer stands towards regeneration areas. Between 1984 and 1990, more than 40,000 ha of balsam fir forest were subjected to salvage cuts in our study region, the equivalent of 10 years of harvesting (Côté 2001).

In addition to having strongly modified the age structure of the landscapes, twentieth century logging also modified their composition, such that no clear altitudinal relationships remained in 2000. For the three landscapes, we observed a significant reduction in conifers and a subsequent increase in deciduous species in the twentieth century. In the first-half of the twentieth century, logging in the regional forests targeted primarily conifers with diameter limit harvesting being practiced in order to supply the regional sawmill industry (Guay 1939). A government of Québec inventory specifically covering the three landscapes reported that before 1930 the minimum exploitation diameter was 25 cm and that around 350 conifer stems/ha were retained in logged areas (Gérin et al. 1944). The minimal diameter was lowered to 15–20 cm between 1930 and 1944 (Gérin et al. 1944). These practices, along with winter cuts, which protect advance regeneration, may explain why stands cut at the beginning of the century were still dominated by conifers in 1930.

In the second half of the twentieth century, the large scale practice of clearcutting had a decisive impact that favoured the increase of deciduous species to the detriment of conifers. Firstly, by targeting conifers, the clearcuts removed seed-bearing trees and diminished the potential for conifer regeneration (Whitney 1994; Galipeau et al. 1997). Secondly, since around 1960, clearcutting was practiced year-round and the heavy machine movement often destroyed the coniferous regeneration (Harvey and Bergeron 1989). Formerly, this situation was avoided, as logging was conducted in winter. Thirdly, the newly created harvested areas constituted rich sites ideal for the rapid colonization of shade-intolerant deciduous species, which possess a competitive advantage over conifers (Carleton and MacLellan 1994; Archambault et al. 2006). For example, detailed studies conducted in the Metis landscape indicate that intolerant (white and yellow birch) and shade tolerant (mountain maple (*Acer spicatum* L.) and sugar maple) deciduous species heavily colonize logged areas for up to 20 years following a cut, thus delaying the recruitment of balsam fir and white spruce (Archambault et al. 1998, 2006; De Grandpre et al. 2000). The same phenomena of conifer forests transforming to deciduous caused by clearcutting has been observed in several other regions of eastern North America (Whitney 1994; Jackson et al. 2000; Friedman and Reich 2005).

In Québec, as in New Brunswick (Etheridge et al. 2005), the reforesting of salvaged areas during the last spruce budworm outbreak was conducted by establishing widespread plantations of the previously uncommon black spruce in order to reduce their vulnerability to future outbreaks. Although future development of these conifer plantations will undoubtedly attenuate the cover type difference with 1930 conditions, the resulting forests will remain outside the recent range of natural variability, as pure black spruce forests on well-drained soils generally occur in regions that are much more fire-prone than our studied landscapes (Robitaille and Saucier 1998).

Management implications

Our results have important implications for the management of forests in the eastern Great Lakes-St. Lawrence forest regions. Following an independent enquiry on forest management in Québec (Arsenault et al. 2004), the provincial government is currently shifting is forest policy from conventional management, where timber production was the main forest objective, to ecosystem-based management, where all relevant ecosystems concerns (e.g. biodiversity, ecosystems services) should be considered (MRNFQ 2008). Within this context aiming to maintain forests within their limits of natural variability (Landres et al. 1999), management strategies should be developed to restore conifer dominance, altitudinal gradients, as well as the irregular structure inspired from old forest stands in our studied landscapes. Adopting more diverse silvicultural practices, such as partial cuts, may be one approach to restore the irregular structure of the preindustrial forests (Seymour et al. 2002; Fortin et al. 2003). In addition, forest managers should allow for the reintroduction of conifer species, particularly white spruce, eastern white cedar, and pines, which were represented in the preindustrial forests of the nineteenth and early twentieth centuries (Guay 1942; Sorel 2004). They should also avoid the excessive planting of black spruce to the detriment of the preindustrial species pool.

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