Are the old-growth forests of the Clay Belt part of a fire-regulated mosaic?

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Abstract: Old-growth forests make up a substantial proportion of the forest mosaic in the Clay Belt region of Ontario and Quebec, Canada, despite fire cycles that are presumed to be relatively short. Two hypotheses have been suggested as explanations for this phenomenon: (1) the old-growth forests in question are located on sites that are protected from fire or (2) the fire hazard is just as great there as elsewhere, and that part of the mosaic is simply the tail of the distribution, having been spared from fire merely by chance. The tree-ring method has proven inadequate as a means of determining the date of the most recent fire in these old-growth forests, as the time that has elapsed since that date probably exceeds the age of the oldest trees. Accordingly, a paleoecological study was conducted with a view to determining the date of the last fire in these forests. Charcoal horizons were located and radiocarbon dated in six old-growth forests. The possibility that these forests have never burned at all is ruled out by the fact that macroscopic charcoal fragments were found at all sites. The proximity of potential firebreaks has a significant influence in the survival model, suggesting fire-cycle heterogeneity throughout the landscape. However, the proportion of old-growth forests observed is in agreement with what would be expected assuming that fire hazard is independent of stand age. Old-growth stands could thus be incorporated into natural disturbance based management, although the great variability of the intervals between catastrophic disturbances should be carefully considered.

Résumé : Les forêts anciennes constituent une proportion importante de la mosaïque forestière de la ceinture d’argile (Ontario et Québec, Canada) en dépit de cycles de feu que l’on présume relativement courts. Deux hypothèses ont été avancées pour expliquer ce phénomène : (1) Les forêts anciennes sont localisées sur des sites protégés des feux ou (2) le risque d’incendie y est équivalent et cette portion de la mosaïque ne constitue que la queue de la distribution, épargnée par le feu simplement par hasard. La dendrochronologie s’est avérée inadéquate pour dater le dernier feu dans ces forêts anciennes puisque le temps écoulé depuis le dernier feu est probablement supérieur à l’âge des plus vieux arbres. Une étude paléoécologique a donc été effectuée dans le but de dater le dernier feu dans ces forêts. Les horizons contenant du charbon de bois ont été localisés et datés au carbone 14 dans six forêts anciennes. Le fait que des fragments de charbon macroscopiques aient été retrouvés dans tous les sites indique que ces forêts ont bel et bien été affectées par les feux dans le passé. La proximité de coupe-feu potentiels accroît la durée du cycle des feux. Toutefois, la proportion de forêts anciennes observée indique que le risque d’incendie est indépendant du temps écoulé depuis le dernier feu. Les forêts anciennes pourraient donc être intégrées à des aménagements forestiers inspirés par la dynamique des perturbations naturelles. Toutefois, la grande variabilité de l’intervalle entre deux perturbations catastrophiques devrait être soigneusement considérée.

Introduction

The short fire cycles common in the North American boreal forest are generally thought to limit the abundance of old-growth forests in this biome (Heinselman 1981; Johnson 1992). However, relatively long fire cycles have been observed in eastern Canada (Foster 1984; Bergeron et al. 2001, 2004), where old-growth forests are prominent in the forest landscape.

Although old-growth forests have not yet been shown to contribute to regional biodiversity in the coniferous boreal forest of the Clay Belt, they possess distinctive structural attributes that suggest their potential role as key ecosystems (Harper et al. 2002, 2003). The Clay Belt is a region that

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Fig. 1. Study area in the Clay Belt forest region of Quebec.

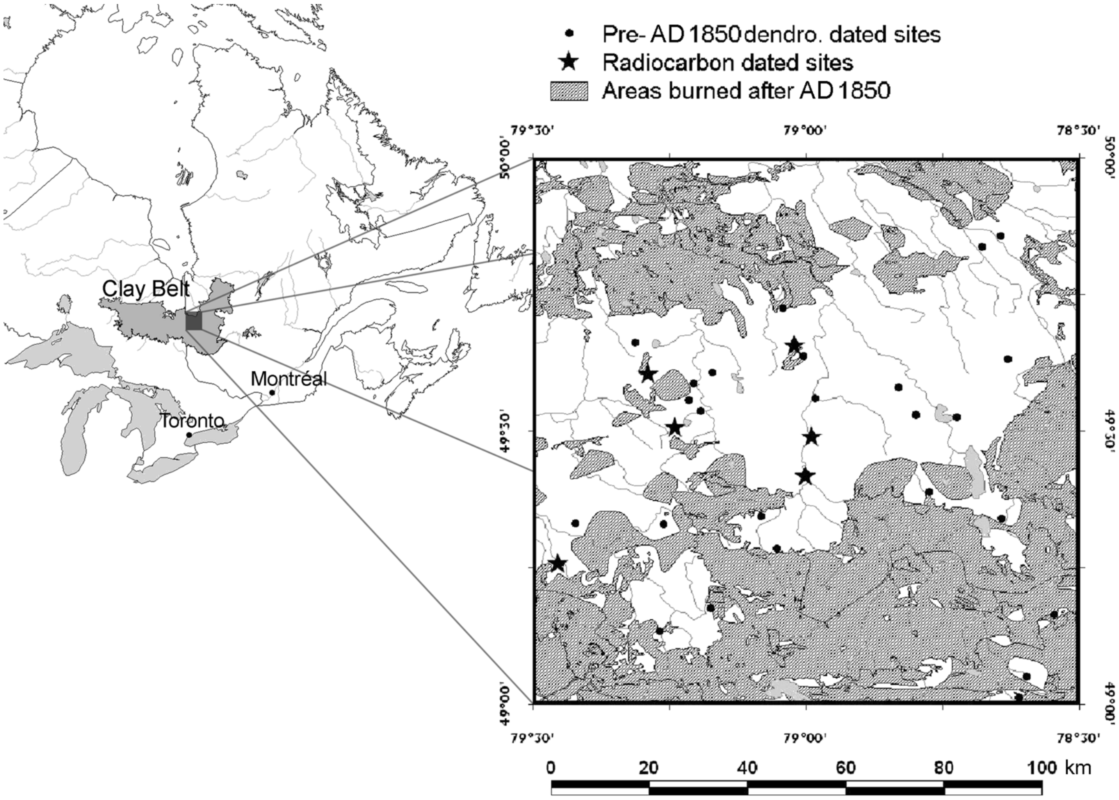


Table 1. Results of charcoal analyses.

Site	No. of profiles analyzed	Mean depth to charcoal horizon (cm)	Standard error (cm)
12	3	14.3	1.39
419	2[a]	25.5	4.60
416	3	38.0	3.71
9722	2[a]	34.0	0.71
9950	2[a]	36.5	1.06
417	2[a]	34.5	8.84

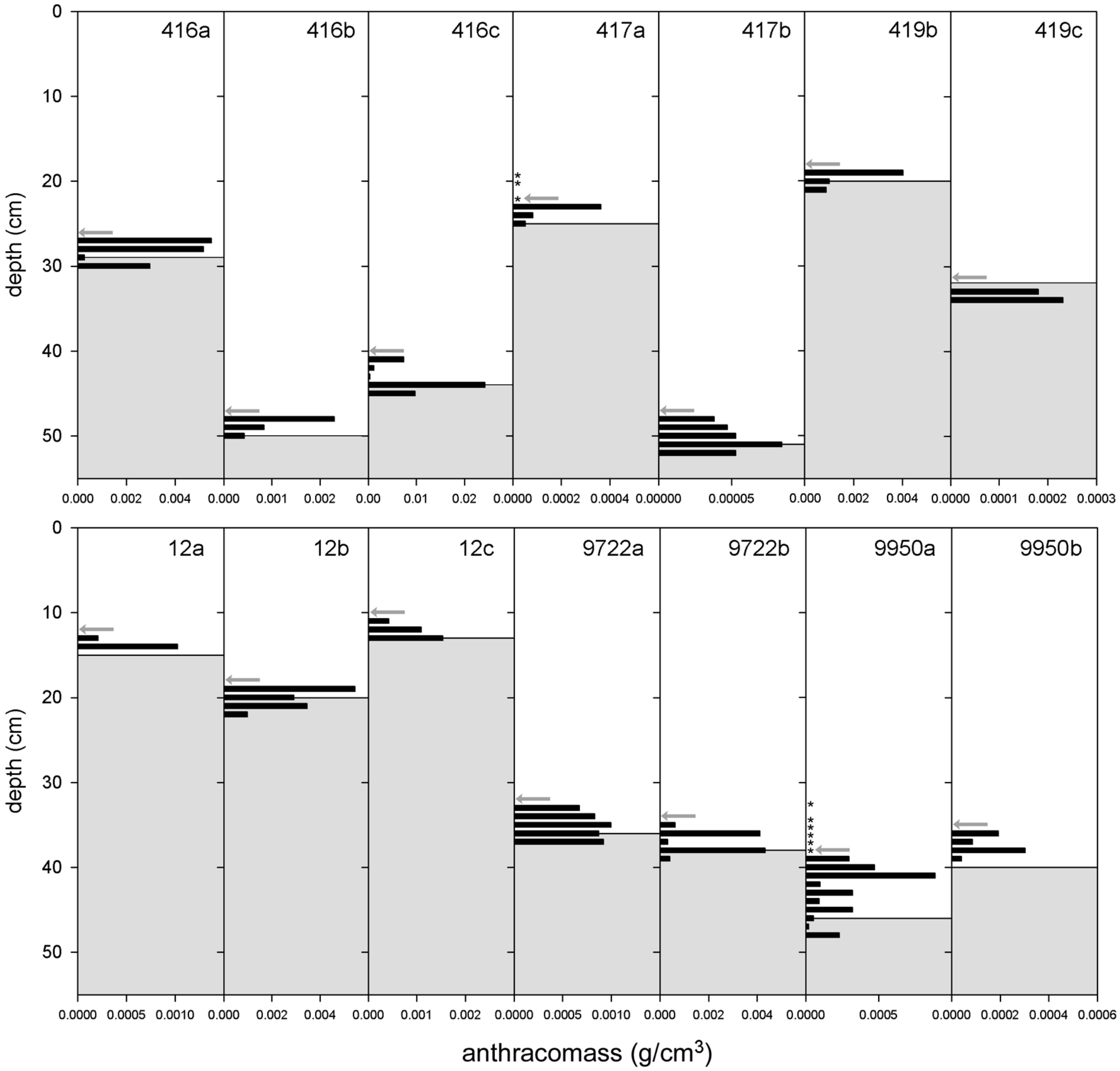
[a] For one profile in each of these sites, neither a charcoal horizon nor the mineral horizon was reached. The conclusion that charcoal was totally absent would be unwarranted.

straddles the border between Ontario and Quebec (Fig. 1) and is located mainly in the black spruce – feathermoss bioclimatic domain.

Forest fires are the main disturbance shaping the Clay Belt forest. In this type of forest, fires are characterized by extreme intensity, causing extensive mortality in the tree stratum as well as among understorey plants (Cayford and McRae 1983; Viereck 1983; Johnson 1992). As a result, these fires usually trigger a secondary succession. Black spruce (*Picea mariana* (Mill.) B.S.P.) and jack pine (*Pinus banksiana* Lamb.), which are two of the main tree species in the part of the Clay Belt under study, can establish themselves shortly after a fire, forming a dominant even-aged cohort (Sirois and Payette 1989; Sirois 1995). The time since the most recent fire event can, therefore, be derived from the age of the dominant cohort. However, when there has been no major disturbance for more than 150 years, individual tree mortality induces a gradual shift towards an uneven-aged structure (Harper et al. 2002), where the date of the most recent fire event becomes difficult to determine, as the time since last fire may exceed the age of the oldest trees. Bergeron et al. (2001, 2004) have shown that the recent fire cycle in this region was long enough to allow a large proportion of such old-growth uneven-aged forests in the landscape. Thus, an alternative method must be used to date old fire events.

The paleoecological method proposed here consists of using radiocarbon to date the charcoal layer remaining from the most recent fire event. Dating charcoal from soils is commonly used to reconstruct a region's fire history over a long period of time (Gagnon and Payette 1985; Hörnberg et al. 1995; Lavoie and Payette 1996; Carcaillet 1998; Larocque et al. 2000; Gavin et al. 2003). This method takes advantage of the fact that charcoal is well preserved in peaty forest soils (Zackrisson et al. 1996) of the kind found in the forests of the Clay Belt. If these old-growth forests have never been affected by fire since the end of the last glaciation, they should then be characterized by a total absence of macroscopic charcoal (fragments of which the longest segment is greater than 500 μm and that are considered to be of local origin (Clark 1988; Ohlson and Tryterud 2000)). If macroscopic charcoal is present but the dating indicates very long time intervals without any fire event, this may suggest that the site in question is not vulnerable to fire. In either case, there are important implications for appropriate forest resource management. Sites of this kind, characterized by longer term forest continuity, might serve as refuges for species

Fig. 2. Complete charcoal profiles from the old-growth forests. Charcoal fragments larger than 2 mm are considered in these profiles. The presence of smaller charcoal fragments belonging to the 500-µm class is indicated by an asterisk (*). The upper part of the profile (white) consists of the organic horizons, while the lower part (grey) consists of the mineral part. The radiocarbon-dated horizons are indicated by a grey arrow.



that are sensitive to disturbances and as high-biodiversity sites, as has been observed in a number of Fennoscandian swamp forests (Zackrisson 1977; Esseen et al. 1992; Karström 1992; Segerström 1997; Hörnberg et al. 1998). These areas, being protected from fire, would enjoy a privileged status from an ecological standpoint, and forest management practices aimed at sustainability should take them into account. On the other hand, if these forests are swept periodically by fire and have escaped for so long merely by chance, it might be possible to integrate them dynamically into an appropriate forest management system.

Adopting a dendrochronological approach, Bergeron et al. (2001, 2004) reconstructed the fire history of the past 300 years in the part of the Clay Belt under study and demonstrated the prominence of old-growth forests in this forest mosaic. The main objective of the present study was to determine whether these old-growth forests burned in the past and, if so, the time that had elapsed since the most recent fire. We also wished to determine whether these old-growth forests were part of the dynamic fire-regulated mosaic or whether they were protected by natural hydrographic or topographic firebreaks and thus constituted a spatially distinct subset characterized by a lower fire frequency.

Materials and methods

Study area

The sampled area (Fig. 1) comprises approximately 7800 km^2 between latitudes 49°00′N and 50°00′N and longitudes 78°30′W and 79°30′W. The site is located in the northern part of the Abitibi region, at the southern limit of the coniferous boreal forest zone, and is part of the Clay Belt forest region of Quebec (Rowe 1972). Clay deposits originate from the proglacial Lake Ojibway (Vincent and Hardy 1977). Organic deposits are more prominent in the northern part of the study area (latitude > 49°20′N), accounting for 62% of all surface deposits found there. The topography is flat, while drainage is imperfect to poor over most of

Table 2. Results of radiocarbon dating.

Site	Profile	Sample No.[a]	Conventional (uncalibrated) radiocarbon date (years BP)[b]	Calibrated date or confidence interval (years AD)[c]	Date used for computation purposes[d]
12	a	Beta-139618	Modern	Post-1950	1779 (tree-ring date)
12	b	Beta-139619	Modern	Post-1950	1779 (tree-ring date)
12	c	Beta-139620	Modern	Post-1950	1779 (tree-ring date)
416	a	Beta-139621	430±70	(1405, 1640)	1445
419	b	Beta-139624	70±60	(1670, 1780) and (1795, 1955)[e]	1700[f]
419	c	Beta-139625	20±70	(1680, 1745) and (1805, 1935) and (1945, 1955)[e]	1700[f]
9722	a	Beta-139626	560±70	(1290, 1450)	1405
9950	a	Beta-139627	1270±60	(655, 890)	773[g]
9950	c	Beta-139628	680±60	(1250, 1405)	1295
417	a	Beta-139629	1950±60	(60 BC, 215)	605[g]
417	b	Beta-139630	1150±60	(720, 1005)	890

[a] Assigned by Beta Analytic Inc.

[b] The associated error is equal to one standard deviation (σ).

[c] The database used is INTCAL98 (Stuiver et al. 1998). The date is expressed in years AD unless otherwise indicated. The confidence interval = 2σ.

[d] Intersection between the calibration curve and the radiocarbon date (years BP).

[e] Multiple intervals are possible because of oscillations in the calibration curve.

[f] Data from tree-ring analyses ruled out the more recent intervals and indicate a minimum age corresponding to AD 1700.

[g] Subsequent examination of the profile suggested the possibility that a level below the charcoal horizon had been dated; consequently, the result was not considered.

the area (Hills 1959; Robitaille and Saucier 1998). Mean annual temperature and precipitation are 0.8 °C and 857 mm, respectively (Environment Canada 1993).

Fire history

Fire history was reconstructed using data from 137 stations previously dated by Bergeron et al. (2001, 2004), using SOPFEU (Société de protection des forêts contre le feu; http://www.sopfeu.qc.ca) archives, aerial photo interpretation, and growth sampling. The sites dated by means of dendroecological analyses could yield either an uncensored or a censored date, depending on the presence or absence of indication of the postfire cohort. When the postfire cohort could not be clearly identified, the date was considered censored, indicating only a minimum age, as the most recent fire was probably greater than the age of the oldest trees sampled. Further methodological details about the dendroecological analyses, including the censoring criteria, can be obtained in the original papers (Bergeron et al. 2001, 2004). Of the 137 sites considered in those previous studies, 32 were considered censored (23%).

Dating old-growth forests

Charcoal analysis

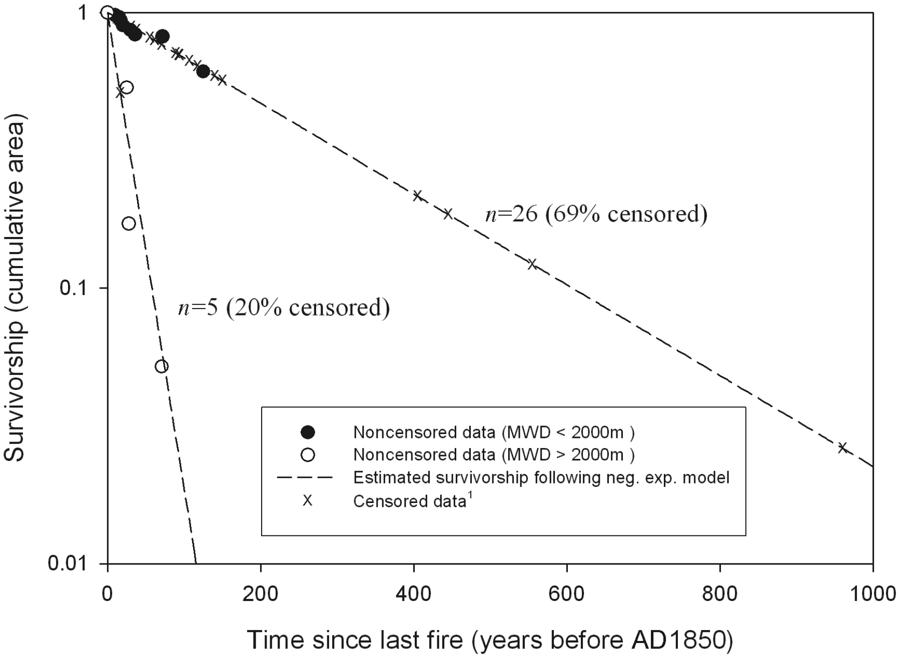
Organic matter decomposes less quickly than it accumulates in this type of forest; therefore, it is possible to find raw humus (mor) consisting of sphagnum mosses and pleurocarpous mosses (mainly *Pleurozium schreberi* (Brid) Mitt.) from which stand history can be reconstructed to some extent. Three monoliths of the thick mor humus were taken with a Wardenaar sampler (Wardenaar 1987) from each of six randomly selected old-growth forests for which only a minimum age was known from the original dendroecological reconstructions. The cross-section of each of these monoliths measured 10 cm × 10 cm, and they varied in length depending on the depth of the mineral soil. The profile had to include the interface between the mineral deposit and the organic matter. Each monolith was immediately wrapped in plastic film and placed in a cardboard box to preserve its shape. The monoliths were subsequently frozen and cut with a serrated blade into slices approximately 1 cm thick. Each slice was deflocculated in warm KOH solution (1%) for 24 h and sieved through a 2-mm mesh with a moderate water jet.

For easier identification of the charcoal fragments, the retained material was washed in a 5% HCl solution. The fragments were then sorted, dried, and weighed to within 0.01 mg. As we considered only fragments that had been filtered by a 2-mm mesh screen, we concluded that charcoal fragments located nearest the surface in the stratigraphic profile constituted the charcoal horizon corresponding to the most recent local fire event. Charcoal fragments larger than 2 mm are good local fire indicators and constitute 94% of the total mass of charcoal deposited on a site after a fire (Ohlson and Tryterud 2000).

Radiocarbon dating

The liquid scintillation radiocarbon method was used to date the samples. Samples received a standard acid–alkali–acid pretreatment to eliminate all traces of carbonates and minimize contamination by organic acids. Roots and root hairs were removed to minimize contamination by more recent carbon. The results were calibrated in calendar years in accordance with INTCAL98 (Stuiver et al. 1998), using the method proposed by Talma and Vogel (1993). Dating and calibration work were performed by BETA Analytic Inc., Miami, Florida.

Fig. 3. Cumulative survival distribution (before AD 1850) for that portion of the area characterized by clay and organic deposits. MWD, mean water-break distance. [1]No survival estimates are produced for censored observations even though they are considered in the model. Those observations are illustrated on the modelled curve at the appropriate time.



Since we found only one charcoal horizon at the base of almost every profile, we considered that many fire events might have been represented in each charcoal horizon. We thus chose to date the organic matter accumulated just above the charcoal horizon instead of charcoal fragments, to eliminate the risk of dating an older fire event that happened prior to the last one. This may underestimate the time since the last fire. It is difficult to quantify this underestimation, as the time required for accumulation of the material in question is not known. It is also possible that the residence time of the organic matter may restrict the temporal scope of the dating method, further contributing to this underestimation. However, poor drainage and the presence of sphagnum or feathermosses in all the profiles suggest a relatively slow decomposition rate. Dating operations in similar profiles from northern Sweden revealed material that was over 2000 years old (Bradshaw and Zackrisson 1990).

Survival analyses

The standing age distribution was modelled as a survival distribution using SAS (version 8) package's LIFEREG procedure. Survival estimators were computed by means of the Kaplan–Meier nonparametric method (Kaplan and Meier 1958), which takes censored data into account. This procedure also allows the comparison between the Weibull model and the negative exponential model, the latter being a special case of the first one with a constant hazard function. Assuming that the probability of a given site being swept by a forest fire is independent of stand age, the age-class distribution over the landscape should therefore follow a negative exponential distribution (Van Wagner 1978; Johnson 1992; Bessie and Johnson 1995). We can compare the validity of the two models by testing whether the modelled shape parameter *c* is significantly different from one, a value indicating a constant hazard function and thus a negative exponential distribution. This comparison is achieved through a Lagrange multiplier statistic provided by the LIFEREG procedure (Allison 1995).

To ensure that departures from the negative exponential model were caused by direct or indirect effects of the forest age on the fire hazard, it was necessary to control for other variables potentially affecting fire susceptibility. Bergeron et al. (2001, 2004) demonstrated that the fire cycle has varied over time in the study area. Additionally, the type of surface deposit can influence forest fire frequency (Harper et al. 2002; Bergeron et al. 2004). It is possible to control the temporal variability by partitioning the survival curve into several constant fire-cycle periods. The main fire cycle changes occurred after the end of the Little Ice Age (ca. AD 1850; Lamb 1982; Bergeron and Archambault 1993). Therefore, survival analysis was performed on a subset of the data set originally studied by Bergeron et al. (2001, 2004), where points were distributed systematically over the portion of the area that had not burned since AD 1850 (cf. Fig. 1) and that were located on clay or organic deposits. Clay and organic deposits cover approximately 75% of the whole study area (Robitaille and Saucier 1998). Each point was weighted on the basis of the proportion of the area occupied by forests that had not burned since AD 1850 in each of the 100-km^2 sampling units. The sample size was 30, where 57% of the points were censored. Six of the dates originated from radiocarbon-dating operations.

Mean distance to potential firebreaks was integrated into the survival model, as it can influence a site's susceptibility

Table 3. Pre-1850 fire-cycle estimates (for clay and organic deposits combined).

Mean distance to potential firebreaks (m)	Fire-cycle estimate (years)	95% confidence interval
≥2000 m (*n* = 6)	36	9–150
<2000 m (*n* = 24)	682	234–1986
Global	446	190–1047

to fire (Larsen 1997). Distance to a potential firebreak in the direction from which the prevailing winds blow during the fire season (northwest) was also considered individually. Mean distance to potential firebreaks was determined for each site using a method similar to the one described by Larsen (1997). We considered watercourses as potential firebreaks as well as wetlands (mainly bogs) and rocky outcrops (very rare in this region). The LIFEREG procedure described earlier also allows the testing of the influence of such covariables in the survival models (Allison 1995; Larsen 1997). Finally, the LIFEREG procedure was also used to produce a maximum-likelihood estimate for the fire cycle.

Results

Charcoal analyses

Of the 18 monoliths analyzed (Table 1), four were discarded, as the charcoal layer and the mineral horizon had not been reached owing to a loss of material at the base of the profile caused by handling when the monoliths were being cut. In the other monoliths, charcoal layers were found at a depth of between 11 and 47 cm; these layers might range from 2 to 19 cm thick. Only a single distinct charcoal horizon was present in each of the monoliths taken in these old-growth forests (Fig. 2), although multiple charcoal horizons were observed in other forests that are not part of the present study (Cyr 2001).

Radiocarbon dating

Of the 14 prima facie datable profiles, only 11 met the conditions required for a date to be obtained: the 1 cm thick slice taken immediately above the charcoal horizon had to contain enough carbon to be dated by conventional radiometric methods. Fortunately, at least one sample per site fulfilled that condition.

Some discrepancies between the dates of different profiles from the same sites (9950 and 417) were observed (Table 2). Subsequent examination revealed charcoal fragments smaller than those considered up to this point in the study, but large enough (>500 μm) to be considered of local origin, above the dated horizon in profiles 9950a and 417a and, for that reason, the dates yielded from those profiles were not considered. Those were the only two profiles where such 500-μm fragments were present while 2-mm fragments were not. Furthermore, the organic matter that had accumulated above the charcoal horizon in the profiles from site 12 proved to be of modern origin, that is, it appeared to have formed after 1950, whereas it was known with certainty, from tree-ring data, that the forest was at least 219 years old in 1998. This suggests that the underestimation resulting from our method is greater than what we first expected. Contamination by modern carbon mainly due to vertical elemental migration through the peat and the adsorption capacity of charcoal may explain this. Since it is practically impossible to tell whether this is also an issue with the other sites that we dated, we decided to consider all our radiocarbon dates as indicating minimum ages of stands instead of the slightly underestimated ages that we first expected. These data were thus considered as censored in the survival analyses that we conducted. In general, the confidence intervals (2σ) were in the order of 160–285 years, but only the intersection with the calibration curve will be considered for purposes of subsequent computations.

Survival analyses

The Weibull model was not significantly better than the negative exponential model, both with and without the mean distance to potential firebreaks as a covariable ($\chi^2 = 1.59$; df = 1; $P = 0.205$ and $\chi^2 = 1.60$; df = 1; $P = 0.205$, respectively). Mean distance to potential firebreaks had a significant influence in the survival model when considered as a continuous variable ($\chi^2 = 3.90$; df = 1; $P = 0{,}048$) as well as when considered into two contrasting classes (<2000 m and >2000 m; $\chi^2 = 10.50$; df = 1; $P = 0.001$; Fig. 3). The influence of potential firebreaks appeared to be slightly stronger when considering only those in the prevailing wind direction during the fire period (i.e., northwest; $\chi^2 = 10.73$; df = 1; $P = 0.001$). The fire cycles, as computed by maximum likelihood, are listed in Table 3. The large confidence intervals can be explained by the relatively high proportion of censored data in the data set used for these analyses.

Subsequent examination of the complete data set for the study area on clay or organic deposits, including the portions of the landscape that burned after AD 1850, revealed that sites located near potential firebreaks have generally been exempted from fire for much longer intervals than those located farther away (Fig. 4). However, some of the sites located near potential firebreaks have also been swept by fire quite recently, while few sites associated with great distances to potential firebreaks were spared for more than 100 years.

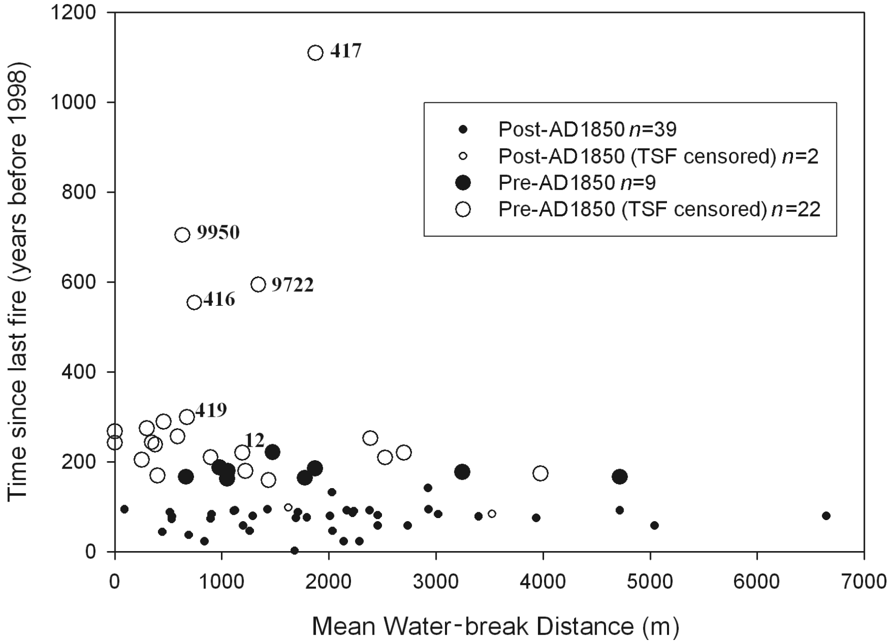
Discussion

Spatial and temporal variability of fire cycle

The presence of macroscopic charcoal fragments in all complete profiles shows that all these old-growth forests have burned in the past. Therefore, the old-growth forests investigated in this study do not constitute ecosystems that are immune from major disturbances. This is consistent with the fact that even wetter ecosystems with less available fuel, such as peatlands, may burn during extreme droughts (Wein 1983; Zoltai et al. 1998; Pitkänen et al. 1999). Moreover, we found that the negative exponential distribution is statistically as good as the Weibull distribution in describing the survival of those forests, suggesting that fire hazard is independent of stand age.

The fire cycle is not spatially homogenous throughout the forested landscape under study, as demonstrated by the significant influence of potential firebreaks in the survival analyses. The proximity of watercourses and peatlands could

Fig. 4. Stand age as a function of the mean distance to potential firebreaks. Labels identify the radiocarbon-dated sites.



affect the fire cycle, even though none of the aforementioned firebreaks are likely to be absolute, as illustrated in Fig. 4. Thus, although the fire cycle may be lengthened by the proximity of potential firebreaks, it is unlikely that those sites will be completely protected from fires, since areas closely surrounded by peatlands or watercourses may have burned quite recently. The amount of heat generated by the very intense fires (up to more than 100 000 kW/m) typical of black spruce and jack pine stands can dry out and ignite nearby fuels without direct contact with the main front. During such fire events, flaming brands can be thrown ahead over a certain distance (Van Wagner 1983) and, as a consequence, such fires may jump over narrow rivers. The presence of only one charcoal layer at the base of almost every profile suggests the last fire event in those stands was indeed very severe, thus, probably also very intense. Furthermore, the efficiency of peatlands as firebreaks probably varies substantially between normal conditions and long periods of droughts, when the superficial *Sphagnum* moss layer dries and may form a continuous fuel bed that can carry a fire (Wein 1983; Hellberg et al. 2004).

A large proportion of the firebreaks considered in the present study were peatlands (54%; data not shown). Paludification is indeed an important phenomenon in the region under study (Heinselman 1981; Boudreault et al. 2002), because of the flat topography and the ubiquitous presence of clay deposits left by proglacial Lake Ojibway (Vincent and Hardy 1977). Since the accumulation of peat, which is a function of the last fire's severity, edaphic factors, and time since last fire, contributes to decreasing the fire cycle, it seems surprising that we could not detect an influence of stand age on fire hazard. It may be that the relationship between time since last fire and paludification is overwhelmed by the other factors. Future studies may provide a better understanding of how paludification may affect the distribution of potential firebreaks and how this distribution may vary over time.

Fire cycle

The fire cycle that we estimated from our survival model is much longer than the one estimated by Bergeron et al. (2001, 2004) for the same study area. Bergeron et al. (2004) reported a 101-year fire cycle for this region during the Little Ice Age, compared with our 446-year estimate. While our study mainly focussed on clay and organic deposits, Bergeron et al. (2004) considered sites on till, sand, and rock as well, which are more vulnerable to fire. This could partly explain disparity between these estimates. A shorter fire cycle is also supported by dendroecological reconstructions of the Canadian Drought Code (Bergeron and Archambault 1993; Girardin et al. 2004), which indicate that the Little Ice Age was a drier period in this region. On the other hand, the disparity is fairly substantial; it is also possible that the first part of the Little Ice Age (prior to AD 1700) that was not covered by the dendroecological studies was characterized by a longer fire cycle, which would increase our estimate of the fire cycle. There was also, prior to the Little Ice Age, a period known as the Medieval Warm Period (approx. AD 800–1300; Hugues and Diaz 1994) when there was probably more precipitation in the Clay Belt region; some sites might be remnants of a past landscape subjected to a lower fire frequency, which would affect our fire-cycle estimate. Carcaillet et al. (2001) detected only two fire events around a lake in the same region during the whole period covered by our study (approx. 1108 years) that support the hypothesis of a longer fire cycle prior to AD 1700. However, information is still too fragmentary to get a good picture of the variations of the fire cycle during the entire Little Ice Age and Medieval Warm Period in this region.

Conclusion

The sites occupied today by old-growth forests are part of the fire-regulated mosaic, as we detected evidence of local past fire events in each old-growth forest that we investigated. The fire hazard does not appear to change with the time since last fire; however, the fire cycle is not homogenous throughout the landscape. The proximity of firebreaks indeed contributes to a considerable lengthening of the fire cycle in some places.

Although the whole forest landscape is likely affected periodically by fire, we found that forests may escape fire over periods of several hundred years or, in some instances, for as long as 1000 years and more. Since these forests are swept periodically by fire and have escaped for so long mostly by chance, it might be possible to integrate them dynamically into an appropriate forest management system. However, further investigations should be conducted to ascertain whether the presence of these old-growth stands, which show exceptionally long forest continuity, plays a key role for biological diversity.

Our results clearly show the extent of the variability of the intervals between two catastrophic disturbances, and this has considerable implications in the way we should manage forest resources if we wish for the management regime to be in greater harmony with natural processes. The intervals of time since the last major disturbances are indeed often long enough for the postfire cohort to begin dying off and for secondary disturbances affecting smaller areas to become the dynamic driving force (Harper et al. 2003). Current silvicultural practices in Quebec rely on the myth that the recurrence of fire is such as to justify even-aged management and rotation periods that are as short as 60–100 years. The great variability in time elapsed since the last fire highlighted by our results is thus not taken into consideration by those practices and, in turn, these are leading to a normalization of the forested landscape, where only even-aged stands younger than the rotation periods will eventually be found. Bergeron et al. (1999) have put forward forest management guidelines designed to take the natural disturbance pattern characteristic of Clay Belt forests more adequately into account. One of these guidelines is to diversify silvicultural treatments to maintain a certain proportion of stands that would possess attributes similar to those of natural old-growth stands. We believe that the findings of this study constitute an additional argument in favour of such an approach.

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