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Short Communication

Recent Permafrost Degradation in Bogs of the James Bay Area, Northern Quebec, Canada

*Simon Thibault and Serge Payette**

Centre d'études nordiques and Département de Biologie, Université Laval, Québec, Canada

ABSTRACT

Small palsas with very thin frozen layers are present within the peat deposits east of James Bay. Most of these permafrost landforms are in an advanced stage of decay within raised bogs between 51°45′N and 55°N. Air photographs, air-borne surveys and ground-truthing of permafrost indicate a recent northward recession of the permafrost boundary by about 130 km, most of which likely happened in the past 50 years. Copyright © 2009 John Wiley & Sons, Ltd.

KEY WORDS: bog; permafrost; climate change; fire; palsa; peatland

INTRODUCTION

Recent palsa and permafrost degradation has been observed at many sites in the northern hemisphere, likely caused by warmer and wetter conditions in summer in combination with greater snowfall (Seppälä, 1982; Sollid and Sörbel, 1998; Payette and Delwaide, 2000; Zuidhoff and Kolstrup, 2000; Lloyd *et al*., 2003; Payette *et al*., 2004; Arlen-Pouliot and Bhiry, 2005; Vallée and Payette, 2007). The long-term monitoring of a permafrost peatland in subarctic Québec, for example, showed an 87 per cent decrease of the total permafrost area between 1957 and 2003 (Payette *et al*., 2004). In western Canada, Kwong and Gan (1994) demonstrated that the southern limit of sporadic permafrost in the Great Slave Lake region has migrated northwards by about 120 km. In eastern Canada, Dionne (1978) showed that without the presence of peat deposits, permafrost would not be able to form and persist in the James Bay region.

The objective of this study was to evaluate the recent dynamics of permafrost in bogs located at their northernmost range limit in the James Bay area (Québec), an area which mainly falls within the isolated patches permafrost zone (Heginbottom *et al*., 1995). In particular, we wished to investigate permafrost degradation which is an active ecosystem process in these bogs. Based on preliminary aerial surveys, it was hypothesised that the area covered by permafrost has diminished substantially over the last 50 years and that the southern limit of peatland permafrost has moved northwards.

STUDY AREA

The study area extends from 51°45′ to 55°N and 75° to 78°W (Figure 1). All seven study bogs are located 100 km east of James Bay, with the exception of the Lemoyne site which is located 275 km from the coast. The region became ice-free around 7900 yr BP but was still submerged by the Tyrrell Sea waters up to 6000 yr BP (Hardy, 1976; Hillaire-Marcel *et al*., 1981). The landforms surrounding the bogs are mostly low plateaus covered by tills and fluvio-glacial sands with depressions filled with marine clays and silts. According to data collected at the LaGrande A weather station from 1971 to 2002 (Environment Canada, 2006), the study area is characterised by a mean annual temperature of

* Correspondence to: Serge Payette, Centre d'études nordiques and Département de Biologie, Université Laval, Québec, Canada, G1K 7P4. E-mail: serge.payette@bio.ulaval.ca

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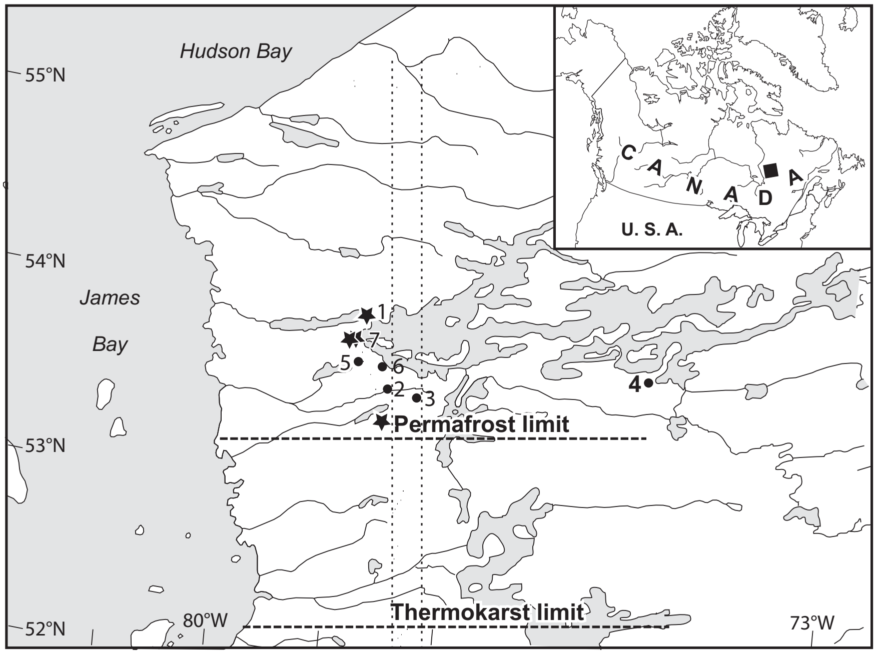

Figure 1 Study area. The seven studied bogs are marked by stars (with palsas) or dots (without): 1: Radisson; 2: Castor; 3: Yasinski; 4: Lemoyne; 5: Desaulniers; 6: Duncan; 7: LaGrande. Limits of permafrost and thermokarst were assessed from aerial and ground-based surveys along two south-north transects (dotted lines).

−3.1°C, with a minimum monthly temperature of −23.2°C (January) and a maximum monthly temperature of 13.7°C (July). Mean annual precipitation totals 700 mm, with 40 per cent falling as snow.

The dominant vegetation cover corresponds to the open boreal forest or taiga (lichen woodland) zone (Payette, 1983). Fire is a recurrent disturbance in the region (Arseneault, 2001; Parisien and Sirois, 2003; Arseneault and Sirois, 2004) and the seven bogs represent a post-fire chronosequence from 1898 to 1998 (Table 1) based on scar-dating using dendrochronology and field records of the Société de protection contre les feux (2004).

METHODS

Survey transects were established in each bog in late-summer 2004 to record surface topography, peat depth, position of water table and plant cover. The survey transect was located along the longitudinal axis of each bog, except at the LaGrande bog where the transect was transverse because of the abundance of ponds. At the Yasinski, Radisson and Desaulniers bogs, the transects crossed the entire peatland whereas at the Lemoyne, Duncan and Castor sites, they ran from the border to the centre of the bogs. Surface topography (using a total station Leica T1010) and peat thickness (using a

Table 1 Description of the study sites. For the Desaulniers and Lemoyne sites, the first date indicates the last fire which reached the borders of the bog, whereas the second date corresponds to the last fire which burned the bog entirely.

Site name	GPS coordinates	Elevation (m)	Year of most recent fire(s)	Transect length (m)
Radisson	53°43′15″ N 77°42′31″ W	158	1922	670
Castor	53°24′47″ N 77°35′05″ W	165	1998	310
Yasinski	53°20′43″ N 77°14′19″ W	164	1989	250
Lemoyne	53°28′33″ N 75°04′33″ W	274	1965 1914	685
Desaulniers	53°32′34″ N 77°39′55″ W	158	1922 1898	275
Duncan	53°30′55″ N 77°28′43″ W	163	1922	385
LaGrande	53°38′29″ N 77°42′14″ W	163	1941	600

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5 × 30 cm wide hand auger) were measured every 25 m along the transects. Snow depth was recorded once in mid-March 2005 using a graduated snow corer. All plant species were identified every 5 m and their relative abundance evaluated (Mueller-Dombois and Ellenberg, 1974). Stabilised water levels were recorded every 5 m in hand dug pits.

The presence of palsas was recorded in all the studied bogs in mid-October 2004 and 2005 at the time of year when the active layer is at its maximum. Palsas are usually identified in the field by their continuous, light-coloured lichen carpets interrupted by scattered ericaceous shrubs and stunted black spruce trees (*Picea mariana* [Mill.] B.S.P.) either dead (charred stems) or alive. Each palsa was located using a GPS, and all plant species colonising the palsa surface were recorded and classified according to their abundance. The thickness of the active layer was measured with a 1.5-m long graduated steel probe and this was also used to measure permafrost thickness where the frozen layer was thin (10–25 cm). Permafrost thickness up to almost 1 m was measured with a powered drill.

Permafrost area and degradation over the last 50 years at the study sites were examined by comparing the distribution of palsa mounds and thermokarst landforms (rounded ponds, collapse scars, disturbed peat surfaces, barren peat protruding from the surface of ponds, and hummocks) on aerial photographs taken in 1957 and more recently (1982, 1984, 1989 and 1991 depending on availability of photos) and in the field in 2004 and 2005. Palsas are associated with uplifting of the bog's surface because of ice accumulation in peat. This causes drier conditions at the surface (Seppälä, 1986, 1988; Payette, 2001) and *Sphagnum* mosses are then replaced by light-coloured lichens of the genus *Cladonia* which have a higher albedo. The distribution of light-coloured lichen-covered hummocks was used as an indicator of the presence of permafrost. Distinguishing between thermokarst and other ponds is possible based on shape since the former have a characteristic rounded outline (Halsey *et al*., 1995).

A second regional assessment of permafrost and thermokarst landforms was done by helicopter in October 2004 and 2005 along two 350-km long south-to-north transects positioned at 77°50′W and 77°30′W, respectively, from 51°45′N to 55°00′N (Figure 1). Observations from the helicopter consisted of identifying and locating lichen-covered mounds distributed in peatlands. The presence of permafrost was validated *in situ* in the field using a steel probe in all the peatlands (at least 15) where lichen-covered mounds were identified from the air. The southern limit of air-borne transects corresponded to sites where permafrost was absent, according to field-based sampling, and also where thermokarst landforms were absent. The distribution and relative abundance of terrestrial, fruticose lichens (mostly of the genus *Cladonia*, sub-genera *Cladina*) dominating post-fire sites and palsas were evaluated qualitatively in all the surveyed bogs.

RESULTS AND DISCUSSION

Vegetation Change

Peat thickness in the studied bogs varied between 2 and 4 m, and maximum elevation of the peat surface (topography) along each transect was only 70 cm. The same vascular species were observed in all the studied bogs. However, differences were found in lichen abundance associated with fire occurrence (Figure 2). The more recently burned section of the Castor bog

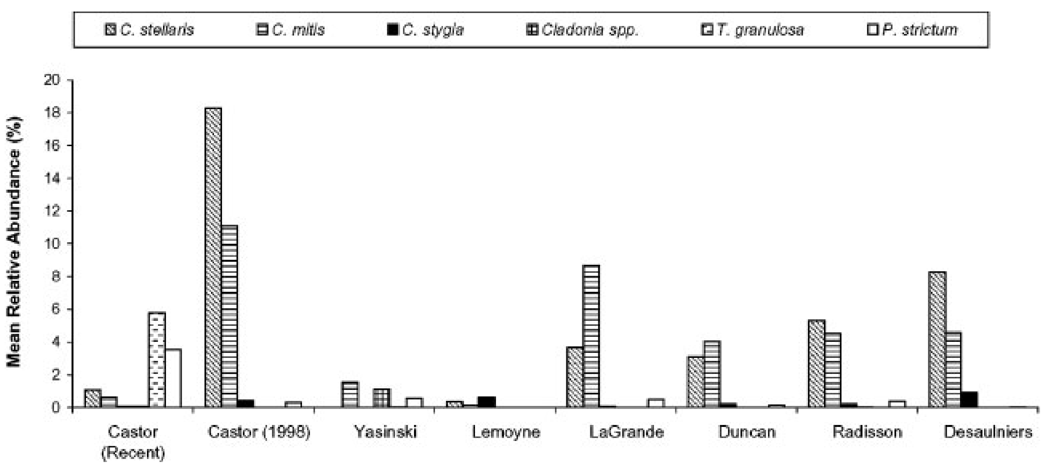

Figure 2 Lichen abundance along a post-fire chronosequence. The 'old' Castor site was burned at some time prior to the latest fire in 1998.

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was dominated by *Trapeliopsis granulosa* [Hoffm.] Lumbsch and *Polytrichum strictum* Brid. Severe fires which occurred in the studied bogs also caused greater peat combustion resulting in the dominance of *T. granulosa* and the local extinction of most shrub species, and the dominance of *P. strictum* in less damaged peat surfaces. *Trapeliopsis* is known to colonise bare, well-drained soil surfaces after fire (Morneau and Payette, 1989) and to slow down the post-fire successional stages. The Yasinski bog, which burned entirely in 1989, showed a marked abundance of *Cladonia sulphurina* [Michx.] Fr. and *Cladonia cristatella* Tuck. The LaGrande bog was dominated by *Cladonia mitis* [Sandst.] Hustich, whereas the Radisson and Desaulniers bogs and the middle part of the Castor bog, which escaped the most recent fire, were dominated by *Cladonia stellaris* [Opiz] Brodo. At the Duncan site, both *C. mitis* and *C. stellaris* were more abundant than other lichen species. Finally, the surface of the Lemoyne bog, which is located in a hilly area, was colonised by *Cladonia stygia* [Fr.] Ahti.

The post-fire seral stages in the studied bogs are similar to those found in dry-mesic lichen woodlands (Maikawa and Kershaw, 1976; Johnson, 1981; Morneau and Payette, 1989). Lichen species like *C. sulphurina* and *C. cristatella* were common within bogs burned in the last few years. *T. granulosa* and *P. strictum* are also common pioneer species of recently burned sites like the Castor bog. Bogs burned in 1922 were dominated by *C. stellaris*, whereas bogs burned more recently were colonised by *C. mitis*. The presence of lichens in bogs of the James Bay area is due to fire and permafrost aggradation, both creating drier micro-environments in a wet ecosystem. If permafrost disappears and wetter conditions prevail, it is likely that lichen abundance in bogs, which is still currently high, will decrease considerably.

Permafrost Change

Ground-truthing showed that only two of the bogs investigated contained palsas in October 2004: the Radisson bog with seven small palsas, and the La Grande bog with 51 small palsas. The palsas consisted mainly of frozen peat with occasional lenses of segregated ice. They were all located in the middle of the bogs or adjacent to large ponds where thin snowpacks are maintained by wind-scouring (Figure 3). However, a year later in mid-October 2005, the permafrost survey revealed only one palsa still present at the Radisson site and five palsas at the La Grande site (Figure 4). In 2004, the average

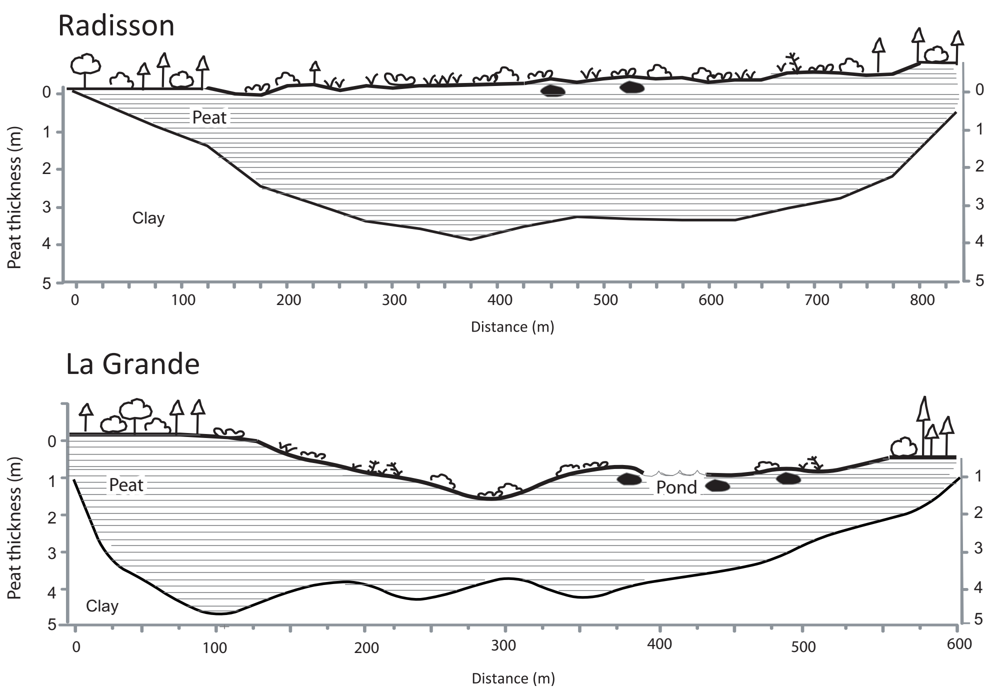

Figure 3 Cross-sectional view of two surveyed palsa bogs, the Radisson and the LaGrande sites. Only marginal permafrost prevails at these sites. Permafrost occurrence is represented by black spots.

Figure 4 Photographs of palsas. Upper — ice-poor, peat permafrost (less than 25 cm thick in mid-October 2005) extracted from a palsa mound in an advanced stage of degradation; lower — the largest palsa (1 m high, 7 m long) observed in the study area. This figure is available in colour online at www.interscience.wiley.com/journal/ppp

thickness of the active layer was 48 cm (n = 58) and the average permafrost thickness only 19 cm (n = 58) with a maximum of 30 cm. These data cannot be compared with the 2005 survey because of the small number of palsas remaining. These permafrost mounds had been observed during previous projects within the study area, so it is clear that they did not represent seasonal frost activity. Recent air photos also show a much smaller number of light-coloured lichen-covered mounds than on the 1957 air photos, confirming the widespread degradation of permafrost. These two sets of observations indicate that permafrost is marginal and may soon disappear from these northernmost *Sphagnum* bogs. Since the presence of permafrost in the James Bay area is closely linked to peat deposits (Dionne, 1978), it is likely that permafrost will no longer be present in the area in the short term.

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The distance between the southernmost range limit of permafrost and thermokarst features established from the air-borne surveys and ground-truthing (Figure 1) suggests a 130-km regression of permafrost within the study area. The distribution of thermokarst landforms, such as rounded ponds and collapse scars, is closely associated with the occurrence of palsas, but thermokarst features can be found in areas where palsas have disappeared because they have a larger distribution at the landscape scale (Luoto and Seppälä, 2003; Hjort, 2006). Because most ponds identified on 1957 aerial photos have now been terrestrialised by *Sphagnum* mosses, it is likely that current thermokarst ponds originated after 1957. Furthermore, this implies that the permafrost features from which the existing ponds originate were still present 40–50 years ago. Permafrost studies in the James Bay area conducted in the 1970s (Vincent, 1977; Dionne, 1978) identified sites where permafrost was present and these are now permafrost-free. Most of these sites were located south of the current limit of permafrost distribution.

The changes in permafrost in the region are suggestive of climatic change impacts, as have been observed elsewhere (Sollid and Sörbel, 1998; Payette *et al*., 2004). However, due to the lack of long-term climatic data in the area, it is not possible to confirm this.

CONCLUSION

We conclude that permafrost in bogs of the James Bay area is currently in an advanced stage of degradation between 51°45′N and 55°N. Over the last 50 years, the permafrost boundary has receded northwards by about 130 km to 53°N. To better understand the interactions between permafrost mounds, which create drier conditions and fire in bogs of the James Bay area and their respective impact on lichen abundance, a stratigraphic analysis of the uppermost part (corresponding to the ca. 1-m thick *Sphagnum* layer) of the peat cover, coupled with a retrospective analysis of forest stands, would be useful.

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