The impact of birch seedlings on evapotranspiration from a mined peatland: an experimental study in southern Quebec, Canada

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SUMMARY

Dense stands of birch (*Betula* spp.) on abandoned peat workings have often been identified as potential barriers to site restoration, but little research has been conducted to evaluate their impact on water resources. The objective of this experimental study was to determine whether birch seedlings established on an abandoned mined peatland in eastern Canada had a significant impact on evapotranspiration. Transpiration rates from birch seedlings planted in containers filled with *Sphagnum* compost were measured gravimetrically. Unplanted containers were used to similarly measure evaporation rates from bare peat. On average, the measured rates of evaporation (per unit area) from peat were 2.5 times the rates of transpiration from birch leaves. However, if the total leaf area of a dense birch population established on an abandoned mined peatland is considered, the total amount of water lost through birch transpiration could be higher than that lost by evaporation from the peat surface. This study provides a rough estimate of potential water losses due to birch seedling transpiration, and indicates that a dense population of birch on a mined peatland may influence site hydrology even at the early establishment phase (seedlings). Consequently, recently abandoned mined peatlands should be restored rapidly to prevent the establishment of birch trees.

KEY WORDS: *Betula papyrifera*, hydrology, mire, restoration.

INTRODUCTION

In order to extract peat for the production of horticultural compost, many peatlands in North America and Europe are drained and their vegetation is completely removed. A thick peat layer is then extracted over several decades using tractor-drawn vacuum machines. When the residual peat deposit is no longer of suitable quality for the production of high-quality compost, mining operations cease and these peatlands are abandoned. The water table in abandoned mined peatlands is lower and more variable than in un-mined sites (Price 2001). Also, less water is stored because there is no acrotelm - the surface layer of peat with a live matrix of growing plant material (Ingram 1978, Waddington & Price 2000, Price 2001). Furthermore, the residual peat layers are particularly susceptible to oxidation and erosion (Rochefort 2001). These harsh conditions are not suitable for the establishment and growth of most plant species (Campbell *et al.* 2003, Lavoie *et al.* 2005b, Poulin *et al.* 2005), but some plants with wide ecological tolerances are able to colonise and proliferate in the absence of competition. One such plant is the birch tree (*Betula* spp.).

Birch can tolerate a wide range of environmental conditions and grow on many types of soil, from sandy to organic and from very wet to very dry (Bergeron *et al.* 1988, Farrar 1996). The seeds are easily dispersed over large distances by wind, enabling rapid colonisation of habitats newly created by human disturbance (Farrar 1996, Furlow 1997, Fralish & Franklin 2002, Campbell *et al.* 2003), and the plants have a high nutrient absorption rate allowing rapid growth in open environments (Walters *et al.* 1993). Consequently, many birch species are able to establish and grow for at least two or three decades on the dry, acidic and nutrient poor peat deposits of abandoned mined peatlands. Dense birch populations have been observed on mined peatlands in Canada and the United Kingdom (Jonsson-Ninniss & Middleton 1991, Meade 1992, Lavoie & Rochefort 1996, Lavoie & Saint-Louis 1999, Bérubé & Lavoie 2000, Diamond *et al.* 2003). These may be either exotic (*Betula pendula* (Roth) in Canada) or native (*B. papyrifera* Marsh. and *B. populifolia* Marsh. in Canada; *B. pendula* and *B. pubescens* (Ehrh.) in the United Kingdom). In southern Quebec and New Brunswick (Canada), the density of birch on abandoned mined peatlands may reach 45,000 to 660,000 individuals ha^{-1} (Fay 2006).

A dense birch population in a mined peatland could lower the water table, at least temporarily, because a large amount of the water in the soil is absorbed by the root systems and lost by transpiration (Heathwaite 1995). In addition, birch leaves intercept precipitation and seasonally alter the amount of water reaching the ground (Ingram 1983, Bragg 2002). In Britain, a 20-year-old birch stand can intercept up to 30% of the precipitation and lower the water table by 20 cm (Price *et al.* 2003). Lowering of the water table could in turn prevent the establishment of other peatland species and thus impede restoration of the ecosystem.

Planting birch has recently been considered as an option for the reclamation of highly disturbed peatlands (Renou *et al.* 2007, Huotari *et al.* 2008). Birch colonisation has also been identified as a potential ecological problem for peatland restoration (Heikurainen 1964, Heathwaite 1995, Lavoie & Saint-Louis 1999, Price *et al.* 2003, Tomassen *et al.* 2004). However, little research has been conducted to evaluate the impact of birch on water resources. The objective of the experimental study reported here was to determine whether birch (*B. papyrifera*) at the early establishment phase (seedlings) on an abandoned mined peatland had a significant impact on the evapotranspiration rate. We hypothesised that such a site loses more water if heavily colonised by birch seedlings than if it has no vegetation.

METHODS

The Saint-Henri-de-Lévis peatland (46° 42′ N, 71° 03′ W) is an ombrotrophic peatland of total area 150 ha, located near Quebec City in the southern part of Quebec Province, Canada. Data from the Quebec City meteorological station (46° 48′ N, 71° 23′ W) indicate that the mean temperatures in January (coldest month) and July (warmest month) are -13°C and 19°C respectively, the mean annual temperature is about 4°C and the mean annual precipitation is 1,230 mm, 26% of which falls as snow (Environment Canada 2008).

This site was selected because it is one of the most densely birch-invaded peatlands in eastern Canada (Fay 2006). The original vegetation was probably dominated by mosses (*Sphagnum* spp.) and ericaceous shrubs. Peat extraction began at the end of the 1960s (Marcoux 2000). Today, approximately 80% of the bog area has been mined using the vacuum method and 30% of the mined area has been abandoned. Some of the abandoned sectors are dominated by cottongrass (*Eriophorum vaginatum* L.), while others have been colonised by paper birch (*B. papyrifera*). In the birch sectors, birch densities ranged from 8,200 to 25,500 individuals ha^{-1} in 2005, but could reach 47,600 individuals ha^{-1} locally (Fay 2006).

In the spring of 2005 (01 May), paper birch seedlings (height: 25–50 cm) grown in a nursery were individually planted in small plastic containers (volume: 1 L or 1,000,000 mm^3) filled with *Sphagnum* compost. A minimum of 30 days was allowed for the roots to integrate with the compost matrix. The experiments were conducted during 12 consecutive weeks of the summer, from 30 May to 22 August, using new birch individuals every week. Each week, six containers with a birch seedling and 12 containers filled only with the *Sphagnum* compost were used in an experiment. The containers with birch seedlings were used to measure transpiration rates, half of those without seedlings were used to measure evaporation rates from bare peat, and the remainder were used as controls. In order to prevent water from becoming a limiting factor, the compost in all 18 containers was saturated with water before the experiment.

At the beginning of each experiment, the openings of the control containers and those with birch seedlings were sealed with plastic wrap in order to prevent water loss by evaporation. The birch stems were allowed to pierce the plastic. The transparent plastic wrap was covered with aluminum foil to minimise any possibility of heating of the containers by a ‘greenhouse effect’. Each container was weighed with a high precision balance (0.01 g) and the initial weight noted. The containers were then placed in holes dug in an abandoned peat field (bare peat with no trees). The dimensions of the holes corresponded to those of the containers, and there were six rows of three holes located one metre apart. One container with a birch seedling, one without a birch seedling and one control were placed randomly in each row (Figure 1). Seventy-two hours later, the containers were weighed again. The weight change of the containers with birch seedlings corresponded to the amount of water lost by leaf transpiration, and that for the non-sealed containers to the amount of water lost by evaporation (if there was no major rainfall event during the experiment). The control containers (filled with compost, saturated and sealed) were not expected to lose water (and thus weight) during the experiment. The total amount of precipitation during the 72 hours of each experiment was measured with a raingauge installed nearby, and the daily minimum and maximum temperatures for each day of the study were obtained from the Quebec City meteorological station.

When each experiment was complete (i.e. 72 hours after the containers were placed in the peatland), the birch seedlings were removed from the containers, their leaves were detached, and the leaf area (upper sides of the leaves) for each seedling calculated using an area meter (LI-COR©, model 3100; LI-COR Biosciences, Lincoln). The transpiration rate per unit leaf area was then calculated for each seedling using the equation:

$$T = \frac{\Delta p}{t \times S} \quad [1]$$

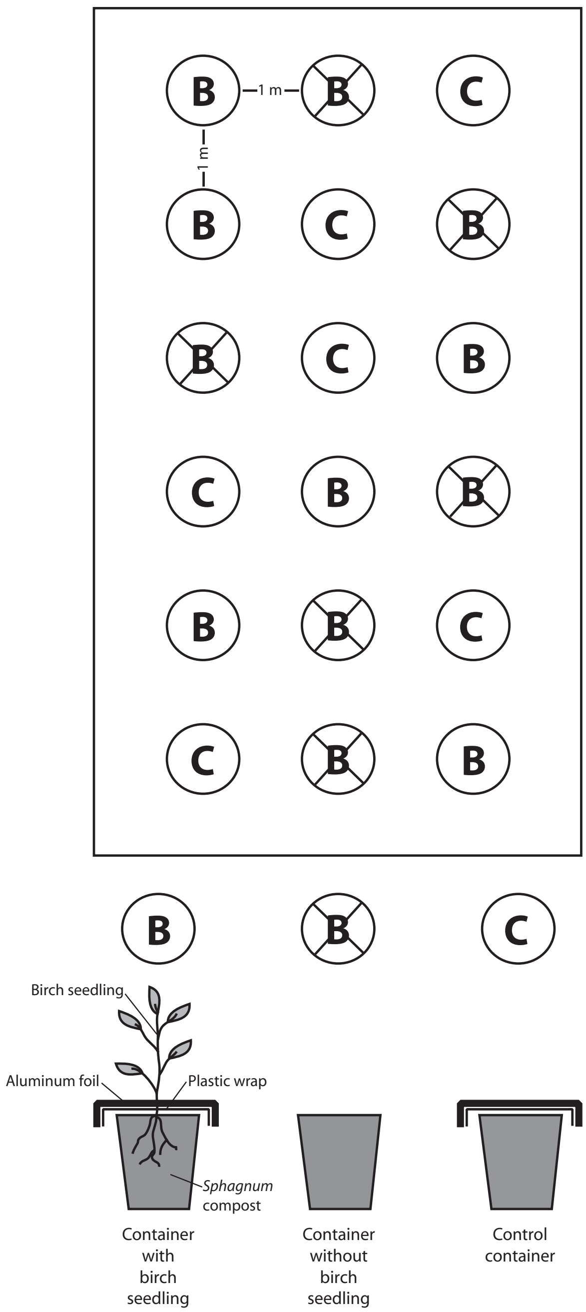

Figure 1. Example of the experimental set-up that was used to measure evaporation and transpiration rates at the Saint-Henri-de-Lévis peatland, southern Quebec, Canada, during the summer of 2005.

where T is the transpiration rate (mm day^{-1}), Δp is the difference between the initial and final weights of the container (1 g of water = 1,000 mm^3 of water), t is the duration of the experiment (days), and S is the leaf area of the birch individual (mm^2). The same equation was used to calculate the evaporation rate from peat, but the leaf area was replaced by the exposed peat surface area of the non-sealed container (12,270 mm^2). Weekly averages of evaporation and transpiration rates were compared using a mean comparison t-test (Zar 1999). The evaporation rates for experiments with major rainfall events (> 7.2 mm) were not calculated due to the potential impact of rainwater on the weights of the non-sealed containers (> 0.1 g).

RESULTS

During the experimental period (summer 2005), the temperatures recorded at the Quebec City meteorological station ranged from 5°C to 32°C (Table 1). The lowest temperatures were recorded at the beginning and end of the summer and the highest temperatures occurred mainly during the month of July. The total amount of precipitation received at the Saint-Henri-de-Lévis peatland during the 72 hours of each experiment varied between 0 and 45 mm.

The non-sealed containers and those with birch seedlings lost 4–349 g per 72-hour experiment, and the mean birch transpiration and peat evaporation rates were estimated at 0.29–2.89 mm day^{-1} and 1.65–5.26 mm day^{-1} respectively (Table 1). The evaporation rate was significantly higher ($p < 0.01$) than the transpiration rate for seven of the nine weeks during which this comparison was possible. The change in weight of each control container during the experiments was always < 0.9 g, indicating that the method used to seal the containers was efficient in preventing water loss other than by transpiration.

DISCUSSION

The evaporation rates measured from peat at the Saint-Henri-de-Lévis peatland during the summer of 2005 were similar to those measured in other abandoned vacuum-mined sites in southern Quebec (0.8–6.9 mm day^{-1}; Price 1996, Waddington & Price 2000, Price 2003). On average, the peat evaporation rates were 2.5 times the birch transpiration rates (Table 1). However, the total amount of water lost through birch transpiration could be higher than that

Table 1. Evaporation rates from peat and transpiration rates from birch seedling leaves, measured at the Saint-Henri-de-Lévis peatland during the summer of 2005. For each period of measurement, precipitation received at the peatland and the temperature range (minimum–maximum values) recorded at the Quebec City meteorological station are also shown.

Dates	Mean evaporation rate (mm day^{-1})	Mean transpiration rate (mm day^{-1})	Ratio (evaporation/ transpiration)	Precipitation (mm)	Temperature range (°C)
30 May – 02 June*	3.32	1.78	1.87	1.2	9–29
06 – 09 June	n/a	0.29	n/a	22.8	7–23
13 – 16 June	n/a	0.32	n/a	45.1	10–29
20 – 23 June*	3.95	1.62	2.44	2.0	5–27
27 – 30 June*	5.26	2.89	1.82	0	16–32
04 – 07 July	n/a	1.18	n/a	24.8	11–29
11 – 13 July*	4.76	2.27	2.10	0	16–31
18 – 21 July	3.10	1.37	2.80	5.0	14–30
25 – 28 July	1.65	1.11	1.49	7.2	10–28
01 – 04 August*	4.56	1.30	3.51	2.6	12–29
08 – 11 August*	4.84	1.87	2.59	2.2	13–31
15 – 18 August*	3.59	0.99	3.63	2.8	6–29

* Significant ($p < 0.01$) difference between evaporation and transpiration rates; n/a: not available.

lost through evaporation from the peat surface, due to the large total leaf areas of birch populations at the densities that can be attained in abandoned mined peatland. For instance, Fay (2006) estimated that some sectors of the Saint-Henri-de-Lévis peatland had, in 2005, a total birch leaf area (for seedlings, saplings and mature trees) of more than 48,000 m^2 ha^{-1}, i.e. approximately five times the soil surface area. Furthermore, the amount of water intercepted by birch leaves during rain events was not measured or taken into account. On the other hand, seedling leaves may have higher hydraulic or stomatal conductance than those of older trees, so that the transpiration rates measured are not necessarily representative (and possibly over-estimates) for mature stands of trees (Kärenlampi *et al.* 1998, Ryan *et al.* 2006, Martínez-Vilalta *et al.* 2007). A dense mature birch stand may also have a sheltering effect (less irradiance, less wind), which may reduce transpiration by creating a moister microclimate. We nevertheless consider that this study provides an estimate of potential water loss by birch transpiration at the early establishment phase (seedlings), and indicates that the development of a birch population on a previously mined peatland is likely to further impact the already severely disturbed hydrology of the site.

Abandoned vacuum-mined peatlands are usually too dry to allow the establishment of mosses and vascular plants (Lavoie *et al.* 2005b), and any additional water losses caused by birch may further impede natural revegetation processes. High evapotranspiration rates can lead to drying of the soil surface, and may eventually affect the water table level. When the water table is more than 50 cm below the soil surface, groundwater ceases to contribute to evapotranspiration and the soil moisture of the surface peat layers becomes depleted (Price *et al.* 2003). Furthermore, drying of the soil surface favours peat compression and increases soil water pressure (Schouwenaars 1993, Price & Schlotzhauer 1999). A soil water pressure below (more negative than) -100 mb prevents the establishment and growth of *Sphagnum* species because these mosses are poorly adapted to generate the capillary forces needed to extract moisture from the peat surface (Price & Whitehead 2001, Schouwenaars & Gosen 2007). As *Sphagnum* mosses are key species in the peatland restoration process, their absence seriously reduces the probability of rapid and successful restoration of mined peatland (Rochefort 2000, 2001).

Birch trees do not usually establish on sites that are very wet. A high water table impedes root respiration in vascular species that are not adapted to very wet soil, and this can prevent their establishment or cause their death (Black 1957, Salonen 1990). This seems especially true for birch (Meade 1992). Furthermore, *Sphagnum* mosses are particularly competitive with birch trees on sites where nitrogen is limited and water abundant (Limpens *et al.* 2003, Tomassen *et al.* 2004). Therefore, simply blocking drainage ditches to raise the water table to 20 cm below the surface during the summer period could probably prevent massive birch establishment in a mined peatland (Fay 2006).

Raising the water table may prevent the establishment and growth of birch, but may also favour the establishment of other species such as cottongrass (Tuitilla *et al.* 2000, Lavoie *et al.* 2005a) or rushes (*Juncus* spp.; Meade 1992). There is no consensus about the impact of cottongrass in peatlands; some authors suggest that this plant is an 'ecological engineer' facilitating the re-establishment of mosses in mined bogs (Grosvernier *et al.* 1995, Matthey 1996, Tuittila *et al.* 2000), while others have found no evidence of facilitation processes (Lavoie *et al.* 2005a). In addition, large cottongrass populations on abandoned peatlands produce large amounts of methane (Marinier *et al.* 2004). There have been few studies on rushes, but the litter produced by this plant may create favourable conditions for the growth of *Sphagnum* (Meade 1992) - although this hypothesis requires further testing. Whatever the beneficial or detrimental impacts of these species, recent research on peatland restoration techniques suggests strongly that, at least in North America, very similar vegetation cover to that of undisturbed bogs can be successfully re-established on mined sites by restoring their hydrological characteristics and re-introducing plant diaspores (Rochefort & Lode 2006). We conclude from our work that preventive restoration measures should be implemented very soon after mined sites are abandoned. If it is not possible to restore the abandoned peat fields immediately, annual harrowing should be conducted to prevent the establishment of birch seedlings, their development into dense tree populations, and thus the detrimental repercussions for hydrology.

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