Establishing trees on cut-over peatlands in eastern Canada

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SUMMARY

Four major tree-planting trials on cut-over peatlands in eastern Canada were surveyed in 2002, in order to evaluate the potential use of trees in rehabilitation following horticultural peat extraction. At one of the sites, an experiment to determine the appropriate fertilisation rate for trees planted on cut-over peatlands was also conducted over several years. Tree performance was assessed by measuring survival, total height and annual growth of red maple (*Acer rubrum* L.), tamarack (*Larix laricina* (Du Roi) Koch.), black spruce (*Picea mariana* (Mill.) B.S.P.), jack pine (*Pinus banksiana* Lamb.) and hybrid poplar (*Populus* spp.). Establishment and growth of tamarack and black spruce in cut-over peatlands showed good potential when compared to performance in conventional forestry plantations. Red maple and jack pine gave poor productivity but promising survival, whilst hybrid poplar plantings failed. Adding nutrients was essential for growth but dosages above 122.5 g of 3.4N-8.3P-24.2K per tree gave no further improvement. Therefore, several different tree species can be planted to reclaim cut-over peatlands in eastern Canada, so long as the appropriate species are chosen and nutrients are provided.

KEY WORDS: afforestation, management, nutrients, peatland reclamation, tree plantation.

INTRODUCTION

Most of the peat moss extracted in Canada comes from the eastern provinces of New Brunswick and Quebec (Daigle & Gautreau-Daigle 2001). To date, 6,800 ha of bog in New Brunswick and 6,000 ha in Quebec have been commercially worked for peat (Poulin *et al.* 2004), and approximately 12% of the total area has been worked out and abandoned (Poulin *et al.* 2005). Several ecological and commercial considerations encourage the industry to undertake ecosystem restoration on the abandoned workings (Rochefort & Lode 2006). Restoration or reclamation may involve planting trees in certain sectors to serve as windbreaks, to improve site aesthetics, or to reproduce the wooded margins and isolated stands of trees that occur in natural bog landscapes. In contrast with northern Europe, little is known regarding the performance of trees planted on bare peat in North America. There have been experimental plantations in a few locations since the early 1990s, but no scientific analyses have been carried out.

Certain characteristics of cut-over peatlands do not favour the early growth of trees. These include very low nutrient concentrations and the generally low and widely fluctuating water table (Price *et al.* 2003). On the other hand, peat extraction removes competing weeds (Salonen 1987) and possibly also pathogenic microbes (Croft *et al.* 2001).

Several studies in northern Europe have examined the introduction of saplings to cut-over peatlands (Pikk & Valk 1996, Renou & Farrell 2005), but the species utilised (*Betula pendula* Roth, *B. pubescens* Ehrh. and *Pinus sylvestris* L.; Kaunisto & Aro 1996) are not native to North America. In any case, European techniques often cannot be transposed directly to the peatlands of eastern Canada due to the different conditions and practice. In Finland, for example, the optimal distance between drainage ditches is estimated at 40 m (Aro *et al.* 1997), while it is usually around 30 m in Canada (Daigle & Gautreau-Daigle 2001). Extraction ceases in Canada when the peat quality becomes unsuitable for horticultural use (von Post scale ≥ 5; Parent 2001), so that a basal peat layer 1–2 m thick is often left behind. In Europe, on the other hand, the more highly humified peat is used as an energy source (Asplund 1996), and its extraction results in a much thinner layer of residual peat (Poulin *et al.* 2005).

Cut-over peatlands are very acidic and deficient in plant nutrients (Wind-Mulder *et al.* 1996), so fertilisation is believed to be necessary for forest tree growth in Europe if a substantial peat layer remains (Kaunisto & Aro 1996, Pikk & Valk 1996, Noormets *et al.* 2004, Renou & Farrell 2005). Three methods exist for ensuring that the nutrient requirements of tree seedlings planted on cut-over peatlands are met, which involve: 1) mixing the mineral substrate with the remaining peat; 2) planting the seedlings on thin peat so that their roots quickly penetrate to the mineral substrate; and 3) addition of fertiliser. The first two options would be logistically difficult in Canada because the thickness of residual peat is greater than 1 m, which leaves fertiliser application as the only practical choice. In addition, cut-over peatlands in North America have slightly different contents of mineral elements from those in Europe. In Finland, the peat has high nitrogen content and forest plantations are fertilised with phosphorus and potassium only (Kaunisto & Aro 1996, Renou & Farrell 2005). Canadian peat has similarly low phosphorus and potassium contents, but also relatively low nitrogen (Wind-Mulder *et al.* 1996). Thus it appeared that application of all three minerals might be necessary for tree growth on cut-over peatland in Canada.

The first objective of this project was to survey three plantations in New Brunswick and one in Quebec, in order to determine which tree species can grow successfully on cut-over peatland in eastern Canada. The second objective was to evaluate experimentally the effectiveness of a commercial fertiliser at various application rates, and thus to inform future large-scale reclamation projects on abandoned cut-over sites.

METHODS

Plantation survey

Study areas

The peat bogs of Baie-Sainte-Anne (47° 01' N, 64° 50' W), Bay du Vin (47° 02' N, 65° 06' W) and Pointe-Sapin (46° 59' N, 64° 52' W) are all situated on the east coast of New Brunswick. This region receives on average 1,240 mm of precipitation annually, of which 874 mm falls as rain (data from Kouchibouguac meteorological station at 46° 46' N, 65° 00' W). Mean monthly temperature varies from -10.0°C in January to 19.3°C in July, with an annual mean of 5.0°C (Environment Canada 2008a).

These three ombrotrophic mires were originally ditched at 20–24 m spacing, as required for extraction using the vacuum technique (Daigle & Gautreau-Daigle 2001). Peat extraction ceased in the autumn, 6–9 months before the trees were planted. At Baie-Sainte-Anne and Bay du Vin, the ditches were dammed before planting because the sites were judged to be too dry. Residual peat thickness ranged from 22 to 183 cm (mean 84 cm) at Baie-Sainte-Anne, from 27 to 144 cm (mean 69 cm) at Bay du Vin and from 15 to 114 cm (mean 54 cm) at Pointe-Sapin. The surface peat had decomposed to H3–H4 at Baie-Sainte-Anne and to H3–H5 at Bay du Vin, according to the von Post humification scale (Parent 2001). Humification was not measured at Pointe-Sapin because the plantation was established 8–13 years prior to the survey and the condition of the surface peat no longer reflected the situation at planting. All of the New Brunswick sites were relatively dry, with water tables more than 50 cm below the surface from early May to late August 2002 (PERG unpublished data). The summer of 2002 was, however, particularly dry (Environment Canada 2008b).

The peat bog of Saint-Bonaventure (45° 57' N, 72° 42' W) is located in south-western Quebec where mean annual precipitation is 1,125 mm, of which 876 mm falls as rain. Mean monthly temperature is -10.7°C in January and 20.8°C in July, with an annual mean of 5.9°C (data from Drummondville meteorological station at 45° 52' N, 72° 28' W; Environment Canada 2008a).

The original preparation of this bog was for extraction by the Haku-Peco method, and is described by Andriesse (1988). Ditches at 11–48 m spacing were added when working ceased in the year preceding planting, because the existing drainage was deemed insufficient for forestry. Residual peat thickness was 47–115 cm (mean 78 cm). This site was also relatively dry in 2002, the water table remaining more than 50 cm below the bog surface from early July to late September (Environment Canada 2008b).

The plant nutrient contents of residual peat at the four survey sites were lower than those generally found in east Canadian peatlands, whether in natural or exploited condition (Wind-Mulder *et al.* 1996). Whilst pH was characteristic of naturally acid bogs, electrical conductivity varied widely between the sites (Table 1).

Plantations

Each site was planted with more than one tree species, arranged in single-species blocks, using a range of planting techniques (Table 2). Red maple (*Acer rubrum* L.), tamarack (*Larix laricina* (Du Roi) Koch.), black spruce (*Picea mariana* (Mill.) B.S.P.), jack pine (*Pinus banksiana* Lamb.) and hybrid poplar (*Populus* spp., various unknown varieties) were tested. Transplant size, planting density, fertilisation rate and intervention to control competing vegetation varied both within and between the trials (Table 2). Tree height was not measured at planting, which involved several companies, and we hold only qualitative data on this.

Table 1. Chemical characteristics of peat and mineral substrate at the four plantation sites. The measurements were made on 05 August 2002 at Baie-Sainte-Anne, Bay du Vin and Pointe-Sapin; and on 23 August 2002 at Saint-Bonaventure.

	n	pH	Corrected conductivity (µS cm^{-1})	NH_4 (mg kg^{-1})	NO_3 (mg kg^{-1})	total N (mg kg^{-1})	P (mg kg^{-1})	K (mg kg^{-1})	Cu (mg kg^{-1})
Baie-Sainte-Anne									
Peat	2	3.3	31	166.6	8.6	8,300	41	93	19
Substrate	1	3.6	0	7.1	4.9	500	40	11	2
Bay du Vin									
Peat	5	3.2	9	104.2	9.8	4,700	53	91	15
Substrate	2	3.6	0	6.5	1.6	400	42	13	2
Pointe-Sapin									
Peat	4	3.4	178	170.9	9.1	9,500	67	144	8
Substrate	3	3.7	27	6.8	1.9	900	23	21	2
Saint-Bonaventure									
Peat	2	3.7	338	195.5	8.3	12,900	28	121	9
Substrate	-	-	-	-	-	-	-	-	-

The ground surface was not worked prior to planting unless the peat field was very uneven, in which case it was levelled. The black spruce planted at Pointe-Sapin in 1990 was considered as a single experimental unit, even though different fertiliser dosages were applied to sub-units at planting (ANOVA results non-significant, data not shown). The blocks at Saint-Bonaventure listed in Table 2 were also part of the fertilisation experiment described later in this paper.

Measurements and analysis

The three New Brunswick sites were surveyed in late July 2002. Sampling plots measuring 6 m x 6 m were distributed systematically across the blocks and peat fields. Survival was evaluated for the nine individuals originally planted within each sampling plot, whilst tree height and length of the terminal shoot (the latter an indicator of annual growth in conifers only) were measured on six pre-determined individuals. Annual growth was not estimated for the deciduous species.

The Saint-Bonaventure survey took place in mid-August 2002. Here, sampling of each block was carried out in three 6 m x 2 m sub-plots, which were systematically and evenly distributed on the peat fields between ditches. Tree height and (for conifers) length of the terminal shoot were measured on nine individuals per block, and survival was calculated for the whole block. Data for experimental units having a single fertiliser application rate (122.5 g per plant of 3.4N-8.3P-24.2K) were selected for this analysis.

The mean value of each variable was calculated for each plantation (or population) in order to allow comparison of the results with those published for trees of the same age and species grown elsewhere.

Fertilisation experiment

Various nutrient treatments were tested at Saint-Bonaventure in order to determine the appropriate fertilisation rates for different tree species.

Experimental design

Four different nutrient rates were tested on red maple, tamarack, black spruce and hybrid poplar. Seedlings grown in 110 cm^3 containers were planted at 2 m spacing (2,500 stems ha^{-1}) in early summer 2000. The effect of fertiliser rate was tested using a randomised complete block design ($n = 2–7$, according to species; see df in Table 3). Because the peat fields varied in width, the blocks were not all the same size, and each contained between 38 and 144 trees. Application rates were based on recommendations for trees planted in open field nurseries (Hamel 1986) and soil analyses prior to planting. We used a granular fertiliser (3.4N-8.3P-24.2K), composed of a mixture of ammonium nitrate, superphosphate and potassium muriate, which had a recommended application rate of 245 g per plant or 612.5 kg ha^{-1}. The four application treatments were: an unfertilised control, 122.5 g per plant, 245 g per plant and 490 g per plant. The three experimental treatments thus corresponded,

Table 2. Description of the species plantation trials in the four experimental sites that were surveyed in 2002, arranged by tree species. NA = not available.

Species	Site	Year planted	Time since planting (years)	Volume of container (cm^3)	Density (stems ha^{-1})	*n*[a]	Area studied (ha)	Fertilisation rate (g of N-P-K per plant)	Presence of surface minerals[c]	Competing vegetation / details of intervention
Acer rubrum	Saint-Bonaventure	2000	3	110	2,500	2/3/-	0.1	122.5 g of 3.4-8.3-24.2 (surface)	No	Forbs / mowing 2–3 times a year
Larix laricina	Pointe-Sapin	1994	9	NA	1,600	6	1	200 g of 12-5.2-14, 1994–1996 (surface)	No	Pioneer broadleaf spp. / tilled annually to 1996
	Baie-Sainte-Anne	2001	2	50	2,500	25	3	10 g of 20-4.4-4.1[b]	No	Almost absent
				110		13	2			
				350		3	0.4			
		2002	1	110		8	1			
	Bay du Vin	2001	2	50 (Jiffy)	2,500	17/17/11	1	10 g of 20-4.4-4.1[b]	In places	Almost absent
		2002	1	110		12	2	None	No	
	Saint-Bonaventure	2000	3	110	2,500	3	0.1	122.5 g of 3.4-8.3-24.2 (surface)	No	Forbs / mowing 2–3 times a year
Picea mariana	Pointe-Sapin	1990	13	NA	2,500	24	1	Various at planting; 200 g of 12-5.2-14, 1991–1996 (surface)	No	Pioneer broadleaf *spp.*, Ericaceae, forbs / tilled annually to 1996
		1991	12		1,600	6	1	200 g of 12-5.2-14, from 1991 to 1996 (surface)	No	
	Baie-Sainte-Anne	2002	1	110	2,500	13	1	10 g of 20-4.4-4.1[b]	No	Almost absent
	Bay du Vin	2001	2	50 (Jiffy)	2,500	40/39/33	4	10 g of 20-4.4-4.1[b]	In places	Almost absent
	Saint-Bonaventure	2000	3	110	2,500	7	0.3	122.5 g of 3.4-8.3-24.2 (surface)	No	Forbs / mowing 2–3 times a year
Pinus banksiana	Bay du Vin	2001	2	50 (Jiffy)	2,500	8	1	10 g of 20-4.4-4.1[b]	Yes	Almost absent
Populus spp.	Saint-Bonaventure	2000	3	110	2,500	2/-/-	0.1	122.5 g of 3.4-8.3-24.2 (surface)	No	Forbs / mowing 2–3 times a year

[a] *n* = Number of sampling plots measured in each trial for survival/ height/ length of the terminal shoot. A single value indicates an identical number of sampling plots for all variables (*i.e*., no missing data). A sampling plot includes 9 trees.
[b] Slow-release capsule (Planting Tablets, Evergro, Delta, BC, Canada) added to the planting hole (2% S, 2.5% Fe, 2% Mn, 2.25% Mg and 0.18% Zn).
[c] Minerals spread on the surfaces of peat fields by flushing the drainage ditches prior to planting.

respectively, to half, the same as, and twice the rate recommended by Hamel (1986). The fertiliser was applied after planting by placing the granules on the soil around each transplant.

Measurements and analysis

Sampling took place after three growing seasons (in August 2002) in three sub-plots of 6 m x 2 m which were systematically distributed within each experimental unit. Tree height and length of the terminal shoot were measured on three trees per sub-plot. Survival was calculated on the basis of the total number of trees originally planted in each experimental unit.

For each species, analysis of variance with polynomial contrasts was carried out on mean values of each variable (significance threshold was set at $P < 0.05$). Comparison of means was appropriate for uneven sample sizes. Polynomial contrasts were chosen *a priori* in order to determine objectively the response rates of dependent variables to different application rates. Statistical analyses were performed using the GLM procedure of SAS software (version 8, SAS Institute Inc.). Normality and heterogeneity of variances were examined, and consequently length of the terminal shoot for tamarack and tree height for black spruce were transformed using $\log_{10}(x+1)$.

RESULTS

Plantation survey

The single block of red maple at Saint-Bonaventure showed a survival rate of 72% and mean height of 81 cm three years after planting (Figure 1).

Survival of tamarack was 100% in two of the recent plantings, including one at Baie-Sainte-Anne (350 cm^3 containers) (Figure 1). The lowest survival rates for this species were recorded after nine years at Pointe-Sapin (52%) and after two years at Baie-Sainte-Anne (62%; 50 cm^3 containers). Mean height after one year was 71 cm at Baie-Sainte-Anne and 29 cm for unfertilised trees at Bay du Vin. Tamarack at Baie-Sainte-Anne and Bay du Vin were 25–101 cm tall, depending on the size of the container, after two growing seasons. The trees at Saint-Bonaventure measured 165 cm after three years while those at Pointe-Sapin reached 461 cm after nine years. After one year, length of the terminal shoot was just under 6 cm at Baie-Sainte-Anne and Bay du Vin. After two years, annual growth was around 14 cm at Bay du Vin and 7–11 cm at Baie-Sainte-Anne, varying little as a function of size at planting. The greatest terminal shoot length for tamarack was recorded after three years at Saint-Bonaventure (65 cm), followed by 9-year-old plantings at Pointe-Sapin (39 cm).

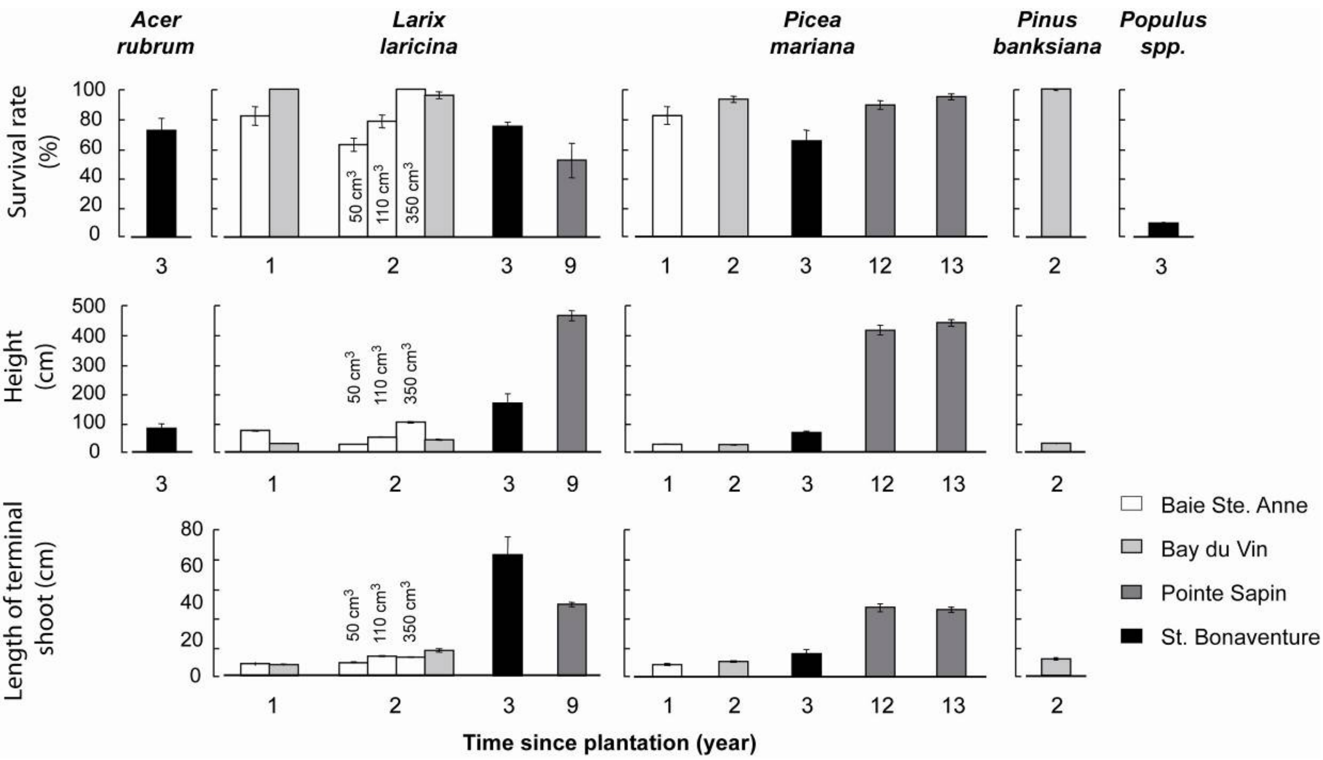

Figure 1. Survival and growth (total height and length of the terminal shoot) of five tree species (*Acer rubrum*, *Larix laricina*, *Picea mariana*, *Pinus banksiana* and *Populus* spp.) according to time (years) since planting in four cut-over peatlands. Container volume is shown if it varied (see Table 1); error bars indicate standard errors.

Survival of black spruce exceeded 80%, except at Saint-Bonaventure where only 65% survived for three years (Figure 1). The highest survival rate (94%) was observed in the oldest plantation, at Pointe-Sapin. Height was 26 cm after one year at Baie-Sainte-Anne, 24 cm after two years at Bay du Vin, 66 cm after three years at Saint-Bonaventure and 413 or 437 cm after 12 or 13 years, respectively, at Pointe-Sapin. Length of the terminal shoot was 7 cm after one year at Baie-Sainte-Anne, 8 cm after two years at Bay du Vin, 13 cm after three years at Saint-Bonaventure and 38 or 37 cm after 12 or 13 years at Pointe-Sapin.

All of the jack pine survived for two years in the single plantation at Bay du Vin, where they reached 28 cm in height, including a terminal shoot of 9 cm (Figure 1). Only 9% of the single planting of hybrid poplars at Saint-Bonaventure survived for three years (Figure 1). Height of poplars was not measured because sample sizes were insufficient.

Fertilisation experiment

Black spruce survival declined significantly (from 75% to 24%) with increasing fertiliser dosages (Figure 2, Table 3). Survival of hybrid poplars (8%) was too low to evaluate the effect of treatments. For the other species, survival was not significantly affected by fertilisation rate (Figure 2, Table 3).

Increasing the fertilisation rate affected growth differently according to species. The total height of red maple increased linearly from 38 cm in controls to 92 cm for the highest dosage tested. A quadratic relationship was also significant, indicating that a height plateau was attained at the low application rate of 122.5 g per plant (Table 3). Maximum height for tamarack (165 cm) was also reached at the lowest fertilisation rate tested. The shortest tamarack were the unfertilised controls, with a mean height of 105 cm. In contrast, black spruce responded negatively to fertiliser, its height decreasing from 67 cm (control) to 54 cm (highest application rate).

Annual growth of tamarack was still influenced by the initial fertilisation three years after planting. The terminal shoot was longest (65 cm) at the lowest rate tested (122.5 g per plant) and shortest (39 cm) for the controls. In contrast, mean length of the terminal shoot was 10 cm for black spruce and did not vary with fertilisation rate.

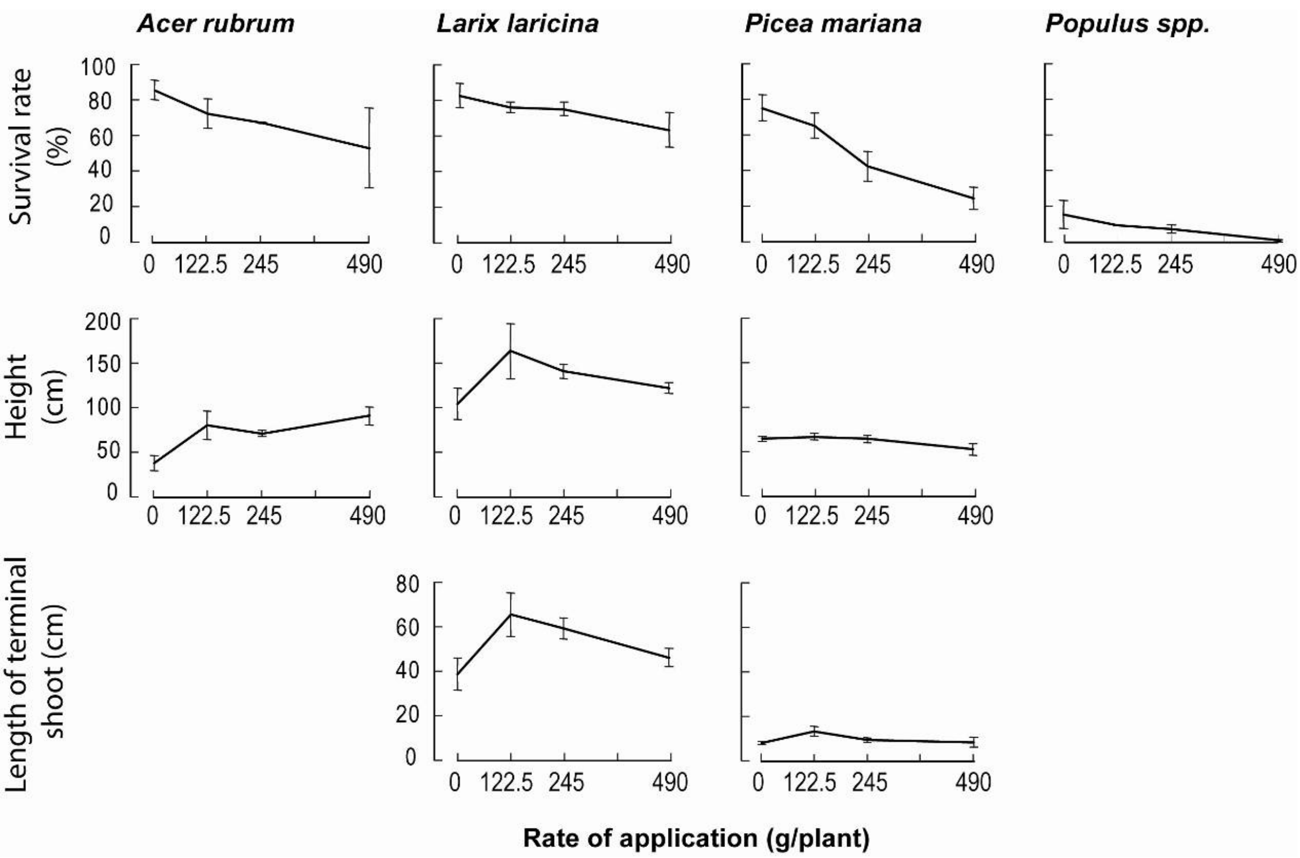

Figure 2. Survival and growth (total height and length of the terminal shoot) after three years for four tree species in response to four application rates of fertiliser (3.4N-8.3P-24.2K). Seedlings were surface fertilised at planting in cut-over peatland at Saint-Bonaventure, Quebec. Error bars represent standard errors.

Table 3. Analyses of variance with polynomial contrasts on survival, height and length of the terminal shoot of four tree species planted in cut-over peatland at Saint-Bonaventure, Quebec, in response to four application rates of fertiliser (0, 122.5, 245 and 490 g per plant of 3.4N-8.3P-24.2K).

	Acer rubrum			***Larix laricina***			***Picea mariana***			***Populus spp.***		
Source of variation	df	*F*	*P*	df	*F*	*P*	df	*F*	*P*	df	*F*	*P*
Survival												
Block	1	1.03		2	2.08		6	12.49		1	1.68	
Rate	3	1.21	0.44	3	2.01	0.21	3	38.04	**<0.01**	3	2.59	0.23
Linear	1	3.51	0.16	1	5.81	0.05	1	110.02	**<0.01**	1	7.51	0.07
Quadratic	1	0.06	0.82	1	0.01	0.91	1	1.11	0.31	1	0.11	0.77
Cubic	1	0.05	0.84	1	0.21	0.66	1	3.00	0.10	1	0.15	0.72
Experimental error	3			6			18			3		
Total	7			11			27			7		
Height												
Block	2	4.05		2	6.33		6	1.72		-		
Rate	3	7.58	**0.03**	3	4.44	0.06	3	2.61	0.09	-		
Linear	1	11.02	**0.02**	1	0.02	0.89	1	7.23	**0.02**	-		
Quadratic	1	3.82	**0.02**	1	8.69	**0.03**	1	1.27	0.28	-		
Cubic	1	5.71	0.06	1	4.61	0.08	1	0.07	0.79	-		
Experimental error	5			6			16			-		
Total	10			11			25			-		
Length of the terminal shoot												
Block	-			2	9.19		6	1.74		-		
Rate	-			3	9.75	**0.01**	3	2.30	0.12	-		
Linear	-			1	0.52	0.50	1	0.34	0.57	-		
Quadratic	-			1	23.99	**<0.01**	1	2.95	0.11	-		
Cubic	-			1	4.75	0.07	1	3.66	0.07	-		
Experimental error	-			6			16			-		
Total	-			11			25			-		

Annual measurements after planting confirmed the positive effect of early fertilisation on tamarack growth (Figure 3). After the fifth growing season, the height of fertilised trees was almost twice that of the controls. Six years after planting, the controls were 211 cm tall while the fertilised trees measured 406 cm on average, irrespective of the application rate. For spruce, long-term observations indicated that initial fertilisation had no marked effect on growth until the sixth growing season after planting, after which the mean height of unfertilised spruce was 92 cm while the tallest trees (143 cm) had been treated at the lowest application rate of 122.5 g per plant (Figure 3).

DISCUSSION

Plantation survey

The experimental units differed in terms of species, size of trees at planting, time since planting, planting method and subsequent intervention (fertilisation, mowing and tilling). Also, each was located at a different site with its own physical and chemical characteristics. Thus the observed differences in sapling establishment could be due to intrinsic features of the sites. However, the small number of sites meant that more detailed analyses to reveal the influence of additional factors were not possible.

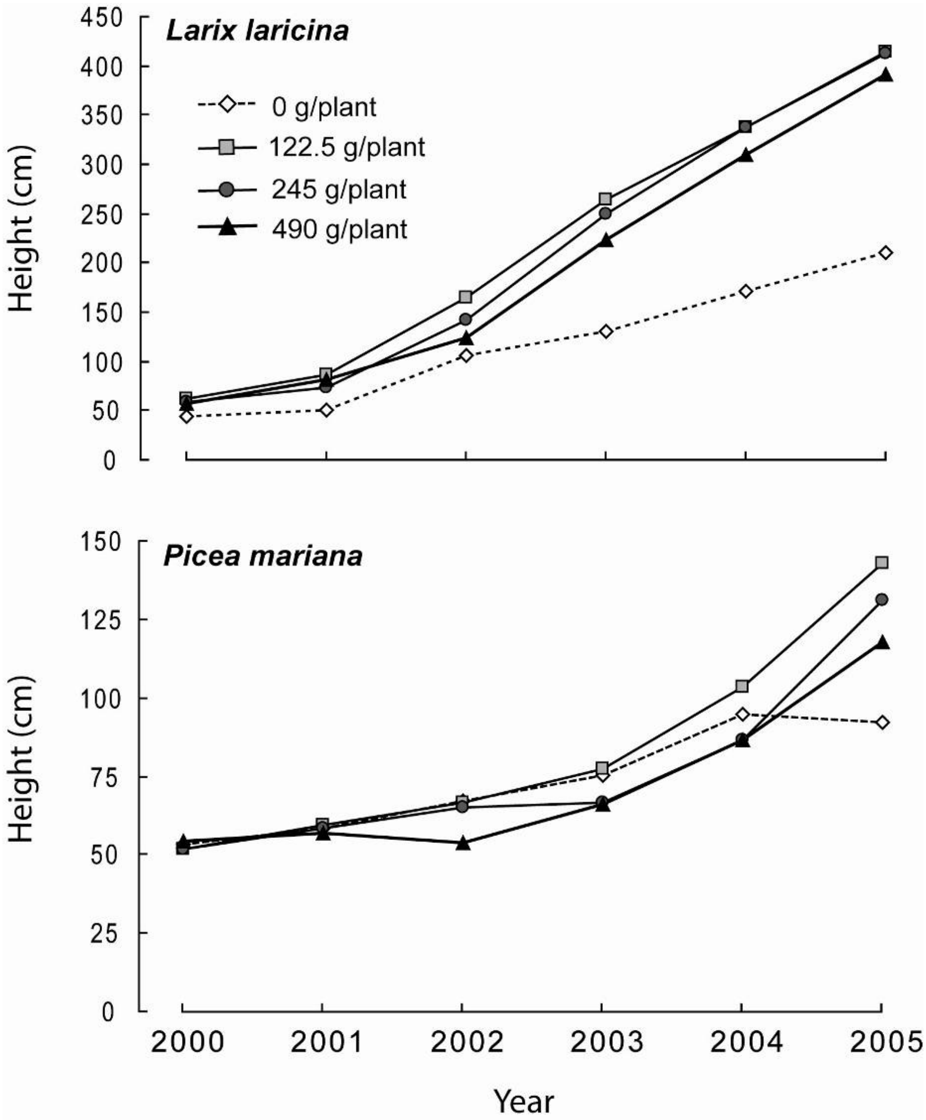

Figure 3. Height of *Larix laricina* and *Picea mariana* trees planted in cut-over peatland at Saint-Bonaventure in 2000 and followed for six years. Different lines indicate different application rates of fertiliser at planting.

Acer rubrum

Survival of red maple (72%) was lower than the 95% observed two years after planting on an open field in Missouri by Huddle & Pallardy (1999). Accidental mowing during mechanical weeding and/or over-fertilisation appears to have reduced survival in our study. Also, mean height after three growing seasons (81 cm) was less than that found in ornamental red maple trials in Quebec province by Richer-Leclerc *et al.* (1995), who recorded heights of 101–300 cm for red maples of the same age.

Larix laricina

Survival rates of tamarack varied greatly between plantations (52–100%) but were generally lower than those found for similar-sized trees in conventional forest plantations throughout Quebec (85–98%; Trottier 1998). Several factors could explain these low success rates, such as poor quality of transplants, inadequate drainage (*e.g*., due to blocked ditches), over-fertilisation at planting, and accidental mowing or burial of young trees by material eroding from adjacent peat workings (Campbell *et al*. 2000, McNeil *et al*. 2000).

The mean height of tamarack grown in forestry plantations was 39 cm after one year, and 62 cm or 54 cm after two years for seedlings grown in containers of 50 or 110 cm^3 respectively (Trottier 1998). Reduced growth in some of the peatland plantations is likely to have been due to a lack of fertilisation or to the utilisation of spindly seedlings that wilted when transplanted (casual observation).

On the other hand, fertilised trees at Saint-Bonaventure had a mean height of 165 cm after only three growing seasons, and were thus taller than the mean of 126 cm for 5-year-old tamarack in forestry plantations. Good performance was also observed in the older fertilised peatland plantation at Pointe-Sapin, where the mean height after nine years was 50% greater than the mean of 266 cm recorded after eight years in forestry plantations.

Similarly, mean length of the terminal shoots of tamarack seedlings was generally less than for forest plantations, where the range is 10–16 cm after one year and 17–27 cm after two years (Trottier 1998). In contrast, 3-year-old tamarack in the Saint-Bonaventure plantation showed twice the annual growth of 5-year-old tamarack in forestry plantations (32 cm). Also, the 9-year-old trees at Pointe-Sapin had similar annual growth to 8-year-old tamarack in forest plantations.

Picea mariana

Survival rates of young black spruce were lower in peatland plantations than the 95–97% recorded for forestry plantations (Trottier 1998). Survival after 12 or 13 years was higher than the mean of 85% recorded after only eight years in forestry plantations, however. Although survival did not seem to be affected, extremely cold temperatures in the winter of 1992 (Environment Canada 2008b) may have influenced the trees. Indeed, several of the spruce planted in 1990 (73%) and 1991 (41%) grew more than one stem (J. Bussières, unpublished data). Since the cut-over peat fields were extensive and devoid of ground vegetation (Campbell *et al*. 2002), little snow accumulated during winter in some places so that the stems of the young trees were exposed to risk of desiccation. Freezing has also been identified as a major barrier to establishment of certain tree species on cut-over peatlands in Ireland (Renou & Farrell 2005) and Finland (Kaunisto & Aro 1996).

Height and annual growth of young spruce were slightly lower than in forestry plantations, where heights were 31 or 34 cm and lengths of the terminal shoots were 8 or 9 cm after one or two years respectively (Trottier 1998). After only three years, the mean height (66 cm) and length of the terminal shoot (13 cm) at Saint-Bonaventure approached the values for 5-year-old spruce in forestry plantations (80 and 17 cm respectively). Furthermore, the height at Saint-Bonaventure was equal to or slightly greater than the range of 43–76 cm measured for spruce of similar age growing in mineral soil, which varied according to the site and treatment (Küßner *et al.* 2000). The trees at Pointe-Sapin were almost three times taller and showed almost 50% more annual growth after 12 and 13 years than 8-year-old spruce in forest plantations (Trottier 1998).

Pinus banksiana

Survival of jack pine in the single peatland plantation was excellent, but growth was low compared to that of forestry plantations of the same age where containers of the same size were used (height 44 cm, terminal shoot 17 cm; Trottier 1998). Mohammed *et al.* (1998) measured an annual growth of 14 cm for jack pines planted in sandy soil in a region of Ontario that is slightly less mild than Bay du Vin. Since forest productivity is not the primary objective in peatland reclamation, jack pine could be an interesting species for these projects.

Hybrid Populus spp.

The survival of hybrid poplars in peatland plantations was very low. Two factors could explain this result. First, there was evidence of white-tailed deer (*Odocoileus virginianus*) browsing on poplars at Saint-Bonaventure (casual observation) and secondly, hybrid poplars are not well adapted for cut-over peatlands because they require warmth and relatively high soil humidity to develop an extensive root system (C. Kaiser, Alberta-Pacific Forest Industries Inc., personal communication 2005).

Effect of fertilisation

Fertiliser reduced tree survival at the application rates tested, particularly for black spruce. This result contrasts with the outcomes of European studies (e.g. Kaunisto & Aro 1996, Renou-Wilson *et al.* 2008) which show improved survival of young trees planted on cut-over peatlands when fertilised, albeit at lower rates.

Both the total and the annual growth of surviving trees did increase with light fertiliser application, however, as has been observed in similar plantations in Europe (Renou *et al.* 2000, Aro & Kaunisto 2003). Black spruce reacted more slowly to the fertiliser than the other species, but a positive effect on growth was observed after six years.

An application of 122.5 g per plant of 3.4N-8.3P-24.2K (the lowest rate tested) is thus presently recommended for red maple, tamarack and black spruce in North America. This rate is equivalent to 4.2 g nitrogen, 10.2 g phosphorus and 29.6 g potassium per tree, which is higher than the recommended dosage for trees planted on cut-over peatlands in Europe (Renou *et al.* 2000, Aro 2001). It is difficult to compare amounts of nitrogen because this mineral is applied only when necessary in Europe and European sites generally receive more nitrogenous deposition from the atmosphere than those in North America (Holland *et al.* 2005). The rate of phosphorus applied in our study was more than three times that applied at planting in Finland (2.7 g per plant) and slightly higher than that applied in Ireland (8.4 g per plant). Our rates of potassium application were approximately six times those applied in Finland (5.1 g per plant).

Because the application rates for our experiment were chosen before the rates used in Finland and Ireland became available, future experiments should examine lower fertilisation rates and also other N:P:K ratios. At present, we propose the use of no more than half the rate commercially recommended for planting trees in mineral soil (Hamel 1986), *i.e.*, 122.5 g per plant of 3.4N-8.3P-24.2K. Moreover, it will be important to monitor the experimental blocks at Baie-Sainte-Anne and Bay du Vin where slow-release capsules providing only 2 g nitrogen, 0.4 g phosphorus and 0.4 g potassium per plant, and the tamarack blocks at Bay du Vin which were not fertilised at all, for signs of nutrient deficiency in future years.

All of the surface fertilised blocks were invaded by competing vegetation, and mechanical intervention was required to reduce the impact. No such invasion occurred in the absence of fertilisation or where the fertiliser was placed in the planting hole. It is well known that competing vegetation has a negative effect on young coniferous trees (reviewed by Thiffault *et al.* 2003) and so we recommend burying the fertiliser when planting in cut-over peatlands.

CONCLUSION

Black spruce and tamarack, the two most abundant tree species occurring naturally on Canadian peatlands, performed well in the various plantations on cut-over sites. These results support the utilisation of these coniferous species in peatland restoration and in any rehabilitation project that aims for wood production. Red maple and jack pine showed poor productivity, but excellent survival or somewhat reduced survival that could be easily corrected, in this environment. Thus these two species are potentially useful for management situations where high productivity and use of naturally occurring species are not prime concerns.

It is necessary to fertilise young trees planted on cut-over peatlands. At the moment we recommend a low dose of NPK fertiliser, buried close to the planting hole. Further experiments should assist in establishing optimal nutrient application rates and also determine the long-term influence of fertilisation for tree growth.

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