UNIVERSITÉ DU QUÉBEC

REMISE EN PRODUCTION DE DÉNUDÉS SECS À CLADONIES DU DOMAINE DE LA PESSIÈRE À MOUSSES DU QUÉBEC: RÉPONSE HÂTIVE DES SEMIS D'ÉPINETTE NOIRE (*Picea mariana*[Mill]).

MÉMOIRE DE RECHERCHE

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RÉSUMÉ

Le domaine bioclimatique de la pessière noire à mousses du Québec est parsemé de milieux ouverts présentant un fort recouvrement au sol en lichens qui portent le nom de dénudés sec à cladonies (DSc). Ce type de milieu est souvent créé par des accidents de régénération survenus dans des peuplements d'épinette noire (*Picea mariana* Mill) ayant subi des perturbations successives au cours d'un intervalle de temps ne permettant pas la constitution d'une banque de graines viables en quantité suffisante pour régénérer les peuplements à leur densité initiale. La reconstitution de l'historique de certains de ces sites démontre qu'ils ont déjà supporté des peuplements plus denses et plus productifs, ce qui laisse supposer qu'un aménagement et des travaux sylvicoles appropriés pourraient conduire à une remise en production. La récolte, le scarifiage et le reboisement ont donc été appliqués sur 6 peuplements de ce type et six pessières à mousses (PM) fermées adjacente (témoin) afin de tester cette hypothèse. Les plants de reboisement (deux gabarits, IPL 67-50 et IPL 126-25) ont été mis en terre dans des sillons de scarifiage et dans des sentiers de débardage. Un an après la plantation, les plants des PM présentent une croissance plus élevée que ceux des DSc mais ne présentent aucune différence au niveau du contenu foliaire en nutriments et des échanges gazeux. Le scarifiage pour sa part a augmenté la survie, la hauteur et la biomasse totale des plants. Pour ce qui est des gabarits de plants, une différence dans l'indice d'élongation racinaire (REI) a conduit à des différences au niveau des statuts hydrique et nutritionnel favorisant les plants de plus petites dimensions. Les résultats à court terme (1 an) suggèrent que la remise en production des DSc est envisageable lorsqu'une préparation de terrain adéquate est appliquée. Certaines limitations à la croissance semblent toutefois affecter les plants des DSc durant la phase d'établissement, ce qui mériterait un approfondissement dans les travaux à venir.

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TABLE DES MATIÈRES

LISTE DES TABLEAUX

LISTE DES FIGURES

CHAPITRE 1

INTRODUCTION

The black spruce-feathermoss (BSFM) bioclimatic domain is the most important part of Quebec in terms of extracted resinous wood volume (Coulombe *et al.*, 2004). Actually this bioclimatic domain is divided in two sub-domains, the Eastern and the Western BSFM domain both of which cover 412 400 km^2 (28% of the province forested land) and are separated on the basis of their respective precipitation regime and wildfire occurrence (Coulombe *et al.*, 2004). At the confluence of these eastern and western sub-zones, there is a 'transition zone' where precipitations, spruce budworm outbreaks and wildfire regimes sometimes generate, more often than elsewhere, unproductive open woodlands called lichen woodlands (LW).

Over the approx. 23 Mha of Quebec's BSFM domain under forest management, seven percent (~1.6 Mha) are covered by LWs (Anonymous, 2005). Since 1950, the expansion of LWs between 70° W and 72° W of longitude substantially decreased the closed-crown black spruce-feathermoss (BSFM) stand cover (Girard et al., 2008). This stand shifting (BSFM to LW) is caused by regeneration failure following consecutive disturbances (wildfire and/or insect defoliation) occurring over a short time interval on formerly BSFM stands (Arseneault et Payette 1992; Payette et al., 2000; Gagnon and Morin, 2001). As BSFM stands may be transformed into LWs and not backward (Jasinsky and Payette 2005), questions are arising on how successful afforestation of LWs could represent a gain in productive closed-crown stand cover, and a significant means of greenhouse gas mitigation through increased carbon sequestration (Gaboury et al., 2009).

In Québec, LWs larger than 4 ha with less than 25% of tree cover and more than 40% of lichen ground cover are legally excluded from forest management since 1986 (Article 95, Anonymous, 2010). In addition to this legal restriction, the low timber yield is not of great interest (Riverin and Gagnon, 1996; Gagnon and Morin, 2001). The lichen mat in LWs contributes to the putative, but still poorly documented, fragility and lack of fertility of LWs (Riverin and Gagnon, 1996).

As LW cover a significant fraction of the central part of the BSFM domain it could be interesting to investigate their afforestation potential following harvesting and sylvicultural treatment. Up to now, only a few studies have been carried out on the afforestation potential of LWs (Hébert et al., 2006; Gaboury et al. 2009). Some limitations to the afforestation success of boreal open woodlands have been identified in a similar stand type to LWs, known as *Kalmia-Ledum* heaths, which share similarities with LWs in terms of low tree density and abundance of ericaceous shrubs (Mallik, 1993; Inderjit and Mallik, 1996; Yamasaki et al., 1998). These limitations have been attributed to allelopathic interferences, water stress, nutrient pool depletion by competitive species and/or reduced soil fertility (Inderjit and Mallik, 1996; Thiffault et al., 2004; Hébert et al., 2006). Results indicate that these limitations can be partly overcome with an appropriate site preparation, in particular soil scarification and herbicide, which can decrease the impact of competitive vegetation on planted seedlings (Thiffault et al., 2004; Hébert et al., 2006).

The negative influence of ground lichens on conifer seedling growth is not well understood (Steijlen et al., 1995). Fisher (1979) showed that the deposition of *Cladina* *stellaris* mulch over the growing medium of black spruce (*Picea mariana*[Mill]*B.S.P.*) seedlings significantly reduced their growth, nitrogen and phosphorous foliar concentrations in a greenhouse experiment. Houle et Filion (2003) found that although a lichen mat has a negative impact on growth and survival during the establishment phase of young spruce seedlings, it has a positive effect on growth once the seedlings are established.

In addition to the limitation produced by biological factors such as the presence of competitive or possibly allelopathic species, LW are reputed to be drought-prone habitats. This reputation generates some questioning on the afforestation potential of lichens woodlands. While considering the work of Kershaw and Harris (1971) who demonstrate that the lichen mat act as a restriction to water evaporation from the upper ground layer, which may theoretically lead to higher water availability for the trees, the drought-prone habitat reputation appear as interesting field of investigation.

Water stress is an important factor contributing to planted conifer growth check (Burdett 1990; Bernier, 1993), especially in drought-prone habitats. Water relations of planted conifers in LW have been investigated by Hébert et al. (2006), who showed that with an appropriate site preparation, i.e. disk scarification, the water status of black spruce and jack pine (*Pinus banksiana* Lamb.) seedlings planted in site-prepared LW is not different from that of seedlings planted in an adjacent managed BSFM stand which is recognized to be a less water limiting environment. How the water relations of planted seedlings in LW interact with photosynthesis or other internal mechanisms to control seedling growth remains an open question.

There is a lack of scientific evidence that LW are less fertile than more productive stand types in the boreal forest, such as BSFM stands. Girard (2004) found that there was no significant difference in the nutrient concentration of the soil solution between site-prepared LW and managed BSFM stands. One of the very first reports on the nutritional status of LW was based on visual observations: "*The yellow-green colour and reduced growth of coniferous on* ***'poor'*** *lichen-covered sandy soils is common sight in the boreal forest*" (Fisher, 1979). This assumption was not supported by several other studies, where the colour of the foliage was considered a weak indicator of seedling growth, grade or outplanting performances (Sutton, 1979; Linder, 1980; Landis, 1985; Heiskanen, 2005). However, more sound evidence for nutrient limitations to growth in LW may be found in studies on *kalmia*-dominated heaths in the boreal forest, which share with LW the open stand structure and the abundant ericaceous shrubby layer (Yamasaki et al., 1998; Thiffault and Jobidon., 2006; LeBel et al., 2008; Moroni et al., 2009). However, the site fertility correspondence between LW and *kalmia* heaths has not been demonstrated yet.

The low density of merchantable trees in LW (Riverin and Gagnon, 1996) may also be regarded as an indicator of poor site fertility. However, the stochastic stand disturbance history of LWs, rather than its intrinsic site fertility, explains the low stand density typical of LWs (Arseneault et Payette, 1992; Payette et al., 2000; Gagnon and Morin, 2001; Jasinsky and Payette, 2005; Girard et al., 2008). This particular stand dynamic, where LWs are alternative stable-states of former BSFM stands, has given grounds to the hypothesis of an inherent support capacity of LW for the growth of a high tree density following afforestation (Gagnon and Morin, 2001; Jasinsky and Payette, 2005; Hébert et al., 2006).

In managed LW, competition for light is weak and light availability at the seedling level is greater than what is necessary to achieve maximum photosynthesis (Girard, 2004; Jobidon 1994). As the light availability is not a limiting factor, the use of large seedlings is not necessary to test the afforestation potential of LW. Since 1996 effort have led to the creation of a low cost and quickly produced small black spruce seedlings. These containerized seedlings are produced in containers of 126 cavities (25 cm^3 each) (IPL 126-25) and are smaller than the conventional seedlings used in Québec's boreal forest (67-50 and 45-110). The use of smaller seedlings (126-25) may be advantageous in 'drought prone' habitats since they are less sensitive to water stress than larger one (Lamhamedi et al,1997). In addition to this potential physiological advantage, these smaller seedlings can be produced, transported and planted at a lower cost, which is interesting in regard to the elevated price of this operation. Theses seedlings are experimentally used since 1996 with approximately 200 000 seedlings planted and are officially used by the Québec's MRNF who planted more than 20 millions of theses seedlings since 2003, with a prevision of more than 13 M a year for 2008 and 2009.

Hébert et al (2006) suggested that the lower growth of seedlings planted in LWs compared to the growth of seedlings planted in comparable BSFM stands could originate from differences in the intensity of sylvicultural treatments applied in each stand type. Disturbance level should therefore be considered while comparing seedlings performance and this suggestion have been taken in to account in the present study.

This paper presents the first year results of a new experimental plantation network established in LWs and BSFM stands in 2005, where both stands were equally disturbed by sylvicultural treatments. The experiment was designed to test the afforestation potential of LWs with different sylvicultural treatments and containerized stocks of black spruce seedlings. The objectives were to evaluate if harvested and site prepared LWs could lead to seedling survival, growth and physiological functions comparable to those observed in BSFM stands at equal disturbance. Since afforested LWs do not present light limitations to black spruce seedling growth (Jobidon, 1994; Girard, 2004), and because smaller sized seedlings can provide an advantage over larger seedlings in drought-prone habitats (Lamhamedi et al., 1997), another objective was to evaluate the performances of smaller size containerized seedlings compared to the conventional containerized seedling stock. It is hypothesised that (i) LWs and BSFM stands will lead to equal seedlings survival, growth and physiological functions; (ii) scarification will increase seedling survival, growth and physiological functions and (iii) planting stock type won't affect seedling performances.

CHAPITRE 2

MATÉRIEL ET MÉTHODES

2.1 Site description

The experiment has been carried out on six experimental blocks (replications) located on two different sites at the junction of the BSFM and the balsam fir paper birch bioclimatic domain of the Québec's boreal forest, at the north of the Lac Saint-Jean (Saucier et al., 2009). These sites were located at the southern limits of the Péribonka Lake (4 blocks) (centred at 49° 42' 579''N, 71° 20'512'' W) and near the shore of the Mistassibi North-East river (2 blocks) (centred at 50° 17'822''N, 72° 02'664''W) (Fig 1). The climate of this area is cool continental with a mean annual temperature varying from -1.8 °C to 1.4°C with total precipitations varying from 919.8 mm to 970.9 mm, with 237.8 mm to 309.3 mm as snow. The number of degree days >5°C range from 970.9 to 1235.4 and the number of days without freezing from 133 to 151, depending on which of the four nearest weather stations is consulted (Environment Canada, 2004: 1- Chapais 49° 46' N, 74° 51' W, 2- Hémon 49°, 4'N, 72°, 36' W, 3- Bonnard 50° 43' N, 71° 3' W, 4- Mistassini 48° 51' N 72° 12' W).

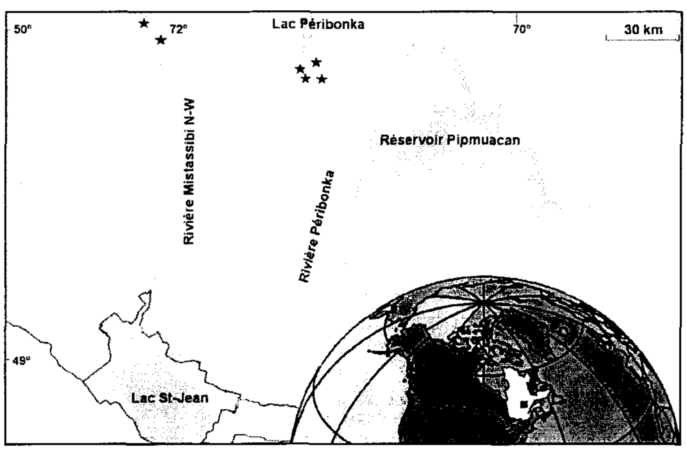

Figure 1: Localisation of the six experimental blocks at the North of the Lac St-Jean, Québec Canada.

Each experimental block was selected on the basis of two criteria: (i) the proximity of a pure BSFM stand of high density (60 to 80 % of crown cover) and a LW (<25% of crown cover and >40% of lichen ground cover) showing the same geomorphologic characteristics (aspect, slope, soil deposit, drainage); (ii) both stand types had to be over 70 years old and show the same age (±10 years) at ground level, to make sure they originate from the same major disturbance.

The BSFM stands were all dominated by black spruce representing at least 75% of the basal area of each stand (1300 to 2250 stems/ha, mean height = 16.5-17.3 m, mean dhp = 14 cm), with jack pine (*Pinus banksiana* Lamb.) and trembling aspen (*Populus tremuloïdes* Michx.) as companion species. The understory included black spruce advance regeneration, *Kalmia angustifolia* L., *Rhododendron groenlandicum* (Oeder) Kron & Judd, *Vaccinium myrtilloides* Michx., *Vaccinium angustifolium* Ait., and *Gaultheria hispidula* (L.) Mühl. Ex Bigel., and a dense mat of mosses, mostly *Pleurozium shreberi* (Brid.) Mitt., *Hylocomium splendens* (Hedw.) B.S.G., *Ptilium crista-castrentris* (Hedw.) De Not., *Rhythiadelphus triquetrus* (Hedw.) Warnst., *Polytrichum* spp., and some *sphagnum* spp.

The adjoining LW stands showed a tree crown cover lower than 25%, with black spruce representing at least 75 % basal area of each stand (175 to 775 stems/ha, mean height = 9.7-16.0 m, mean dhp = 15 cm) with *P. banksiana* and *P. tremuloïdes* as companions species. The lichen ground cover was more than 40 % and dominated by *Cladina mitis* (Sandst.) Hustich, *Cladina stellaris* (Opiz) Brodo, and *Cladina* *rangiferina* (L.) Nyl. The selected LWs had a dense shrub layer, composed of the same species found in the BSFM stands.

Three out of the 4 blocks of the Péribonka site were located on deep (>100 cm), coarse textured glacial till deposit, overtopped by a mor humus varying from 6 to 32 cm deep. The other block was located on a deep glaciofluvial outwash deposit overtopped by a mor humus of 6 to 14 cm thick. In the Mistassibi North-East river site, the 'Mista 1' block stand was on a moderately deep (<100 cm), medium to coarse textured glacial deposit with a mor humus of 18 to 32 cm thick. In the 'Husky 2' block, the LW was located on a moderately deep (<100 cm), coarse textured glaciofluvial deposit and the Husky 2 BSFM stand was located on a thin (<50 cm), medium to coarse textured deposit. Both stands were overtopped by a mor humus of 10 to 18 cm thick.

2.2 Experimental design and biological material

The experimental setup is a 6 complete block full factorial experiment arranged a split-split plot design. Each block consists of 2 ha of a harvested BSFM stand adjoining 2 ha of harvested LW. Each stand type (main plot) has been split into two subplots which were randomly submitted to two treatments; with (S1) or without (S0) mechanical or hydraulic TTS soil scarification. Each subplot was then split into two sub-subplots which were randomly assigned to the planting of two types of containerized black spruce seedling stocks, the larger 67-50 (number of plugs per container–plug volume in cm^3) and the smaller 126-25 stock type. In average, scarification furrows were 16 cm deep and 65 cm wide and they occupyied 21% of the scarified plot area. As a result, there were 8 experimental units (e.u.) per block (48 total).

Harvesting operations were made in summer 2005 following the careful logging around advance growth (CLAAG) stem-only method, the conventional harvesting method in Québec's boreal forest. Following harvest, the S1 plot were scarified also in summer 2005 with either a mechanical TTS disc trencher (Péribonka site) or the hydraulic TTS disc trencher (Mistassibi site), both in and between the skid trails.

Containerized *P. mariana* seedlings produced from local seed sources (EPN-V1-LEV-2-3/6gT-026-2001) were planted. The growing medium for both planting stocks was a mix of peat moss and vermiculite (3:1 v/v). Conventional 67 cavities containers with 50 cm^3 root plug per cavity (67-50, IPL Saint-Damien, Qc, Canada) were used to produce the first type of seedlings (Height=204 mm, Root collar diameter=2.20 mm at plantation time, n=60). For the second type of seedlings, we used 126 plug-containers of 25 cm^3 per root plug (126-25, IPL Saint-Damien, Qc, Canada) have been used (Height=122 mm, Root collar diameter=1.39 mm at plantation, n=60). The size differences between both stocks originate from the seeding date at the nursery, the 67-50 being 6 weeks older than the 126-25, and from the short day's treatment that have been applied to the 126-25 before planting. The 67-50 seedlings have been produced outdoor at the Girardville private nursery (49° 00' N, 72° 33' W) for their first year and the 126-25 seedlings have been produced outdoor at the Normandin governmental nursery (48° 50' N, 72° 32' W) for the first year as well. For both planting stocks, the second growing year took place at the University of Quebec at Chicoutimi's nursery (48° 25' N, 71° 03' W) following the fertilizing schedule and dosage of their original nursery. The 126-25 seedlings have been submitted to a short-day treatment (14 hrs of light/day instead of 18 hrs of light/day) 14 days prior to planting, in order to stop their height growth and improve their frost and drought tolerance (D'Aoust, 1981; Bigras and D'Aoust 1992; Tan, 2007). At the time of planting, both planting stock sizes responded to the classification criteria mentioned in MRNF's norm (Anonymous, 2007). Preliminary results showed that both seedling stocks have equal survival rates regardless of the planting date (unpublished results). A total of 49 000 seedlings were planted with a 2 meter spacing, both in the skid trails (S0) and the scarification furrows (S1). Plantation took place during the last week of august 2005 at the Péribonka site (4 blocks) and during the first week of September 2005 at the Mistassibi river site (2 blocks).

2.3 Abiotics variables monitoring

In one block per site (2 blocks total), 2 data loggers (CR10X, CAMPBELL Scientific, Canada Corp), one per stand type, were installed at 2,5 m to monitor air temperature and relative humidity (CS500, CAMPBELL Scientific, Canada Corp). Mineral soil temperatures at 10 cm depth were measured in and between the skid trails and in the scarification furrows using temperature probe (107B, CAMPBELL Scientific, Canada Corp). Measurement were taken every 5 minutes and averaged by hours all year long.

Soils water contents (SWC) were measured using the gravimetric method (w/w) (Rundel and Jarrell, 1991) the days following the Ψx measurements. Sampling was done with an AUGER soil sampler on two perpendiculars transects. Samples were weighted at 65°C for 72 hrs until they reach a constant mass.

2.4 Physiological measurements

Shoot level gas exchange was measured on two randomly chosen seedlings per e.u. (16 seedlings/block) at two sampling dates, i) 1-7 June (4 blocks) and ii) 8-23 august (5 blocks) 2006, the year following planting. For the first sampling date, one-year old foliage (developed in the nursery) was used, while current year foliage was used for the second sampling date. Measurements were made on clear days around the zenith (between 10:30 and 14:30 hrs EST) at full sunlight to constantly provide the foliage with light saturation (i.e. photosynthetically active photon flux density above 1200 μmol photons m^{-2} s^{-1}). Measurements were taken using a Li-6400 portable photosynthesis system (LI-COR, Inc., Lincoln, NE) with a conifer chamber maintained at 25°C, 400 ppm of CO_2 and the air flow set at 500 μmol/sec. Once extracted on the field, shoot samples were immediately stored inside a transparent plastic bag, with a small piece of humid towel, and measured within 10 minutes. Previous tests showed that photosynthesis was stable up to 45 minutes after extraction when the samples were stored this way. Measurements were done block by block, and a complete block was cleared in maximum 80 minutes, so that the time effect did not confound with treatment effects. After measurements, samples were put in plastic bags and stored in a cooler for the rest of the day, after what they were put in a freezer until further manipulation (see below).

For each measurement of photosynthesis, a sub-sample of needle placed inside the conifer chamber was used to determine total foliar surface area. Needle surface area estimation method was similar to that in Bernier et al. (2001) with balsam fir (*Abies balsamea* (L.) Mill.) except that no correction factor has been determined, because a maximum number of cross section have been used to determine foliar surface of each needles used in leaf dry mass per area unit (LMA) determination. LMA was calculated using 10 randomly chosen needles (total = 20) per planting stock size for the first sampling date and on 2 needles per e.u. for the second sampling date (total = 80). Once LMA was determined, the rest of the needles placed in the chamber for each measurement were oven dried at 65°C for 48 hrs and their mass were then converted into foliar surface on the basis of the LMA.

Pre-dawn (between 2:00 and 4:00 hrs EST) xylem water potential (), measurements were performed on 2 randomly chosen seedlings per e.u following a minimum 24 hr rain free period. Each excised apical shoot was rapidly put in a plastic bag and placed in a cooler with ice until measurement. All shoots in a block were collected within 40 minutes and measured within 2 hrs following sampling. Ψx was determined using a pressure chamber (PMS Instruments, Corvalis, OR, Model 610) (Scholander et al., 1965). The day following Ψx measurements soil sample were taken in scarification furrows and skid trail in order to analyse nutrient concentration.

2.5 Survival and morphological measurements

In each e.u., 100 seedlings (except for the Husky 2 block where this number was reduced to 50) have been identified to evaluate the survival i) at fall 2005 (the year of plantation) and ii) at fall 2006 (i.e. after the first complete growing season following planting). Seedlings were considered alive when they showed at least 10 % of their foliage still turgescent and green.

Morphological measurements were performed in the lab on 3 seedlings per e.u. Samples were carefully dug out during the last week of October 2006, with special attention to the root system in order to extract roots down to a minimal diameter of 2 mm, and rapidly put into a cooler until measurement. Following washing of the root system, the two longest roots of each seedling (R_l; nearest mm), total seedling height (from ground to the apical bud) (H_t: nearest mm), stem diameter (1 cm above the first root) (D_s; nearest 0.1 mm), dry mass of the root, stem and foliage (65°C for 48 hrs) were measured. We divided the sum of the length (mm) of the two longest roots of each seedling have been divided by the root total biomass (g), in order to determine what was called the root elongation index (REI). Composite foliage sample (3 seedlings) from each e.u. were collected for analyses of the nutritional status (N kjeldahl, P, K, Ca, Mg (H_2SO_4)).

Seedling relative growth rates (RGR) have been calculated as; $RGR = \dfrac{\overline{\ln(W_2)} - \overline{\ln(W_1)}}{t_2 - t_1}$ where W_2 is total biomass of seedling at t_2 and W_1 is total seedling biomass at t_1. This equation takes in account the initial seedling sizes and yields an unbiased estimate of RGR under all conditions (Hoffmann and Poorter, 2002)

2.6 Statistical Analyses

Analyses of variance (ANOVA) were performed using a 6-complete block, split-split-plot design for each seedling morphological variable, with the stand types as the main plot, the site preparation treatment as the subplot and the planting stock size at the sub-subplot level. For physiological variables, the sampling dates were considered as another split level (2 dates).

For the seedling nutritional status, the plot levels were the same as for physiological variables but with 3 dates instead of 2. When a factor interacted with the date factor, polynomial contrasts were performed to determine if the interaction with the date factor was linear or quadratic, and the most significant was taken into account (Steel and Torrie, 1980). Additionally, another contrast was made on the last sampling date to determine if there was a difference between stand types, treatments or planting stocks in seedling foliar nutrient concentration. The Bonferroni correction has been applied in order to diminish type I error rate, so that $P \leq 0{,}025$ was deemed significant (Zar, 1999). For the soil nutritional concentrations, ANOVAs on a 6-complete split-plot design were performed with the stand type at the main plot and the treatment (S0 or S1) at the sub-plot level.

For each variable, homogeneity of the variance was verified by visual analysis of the residuals (Devore and Peck, 1994). When necessary, data were transformed in order to respect ANOVA assumptions (Zar, 1999) but original data are presented. ANOVA's were performed using the REML procedure of JMPin 7.0 software (SAS Institute, Cary, NC) and polynomial contrasts with the GLM procedure of SAS 9.1 software (SAS Institute, Cary, NC).

CHAPITRE 3

RÉSULTATS

3.1 Seedling survival and growth

Planting stock size significantly affected the seedling survival rate, the 67-50 stock size showing a 6 % higher survival rate than the 126-25 stock size (Table 1, Fig 2A). Seedling survival was similar between stand types but was significantly influenced by site preparation, seedlings in scarified plots (S1) as showed a 6 % higher survival rate compared to seedlings in unscarified condition (S0) (Table 1, Fig 2B).

Table 1: Summary of ANOVA resultsfor survival rate of planted black spruce seedlings in lichen woodlands and black spruce feather moss stands, one year after plantation, in scarified or unscarified plots and with smaller (126-25) or larger (67-50) containerized stock size.

Sources of variation		Survival*	
	ndf	ddf	P
Block	5	3,996	0,8460
Stand type (ST)	1	4,056	0,0811
Scarification (S)	1	10,19	**0,0012**
ST*T	1	10,19	0,2238
Planting stock size (PS)	1	19,6	**0,0006**
ST*PS	1	19,6	0,8607
S*PS	1	19,6	0,9917
ST*S*PS	1	19,6	0,7443

Bold indicates significance ($P \leq 0.05$), ndf = numerator degrees of freedom, ddf = denominator degrees of freedom

*Analysis performed on transformed data; $(\sin^{-1}(\sqrt{(\text{survival}*0.1)})*180*3.141592^{-1})$

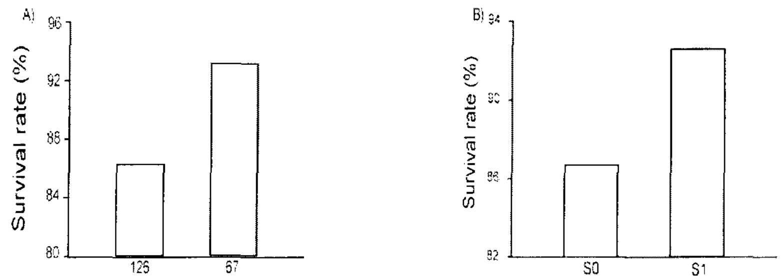

Figure 2: Significant Planting stock size and Scarification effects on survival rate of black spruce seedlings one year after plantation in lichen woodlands and black spruce feather moss stands (n=144). Abbreviations: 126 = 126-25 (smaller) seedling stock size, 67 = 67-50 (larger) seedling stock size, S0 = without soil scarification, S1 = with soil scarification.

Stand types significantly affected seedling total biomass (B_t) and stem diameter (D_s), with respectively 27 and 12 % higher values for the BSFM than for the LW seedlings (Table 2, Fig 3A and 3F). Scarification also significantly increased seedling growth, with 33 % higher total biomass and 8 % higher total height for seedlings in S1 plots compared to seedlings in S0 plots (Table 2, Fig 3B and 3E). Finally, B_t, H_t and D_s were significantly higher in the 67-50 stock size compared to the 126-25 stock size one year after plantation, as expected for initially larger seedlings (Table 2, graph not shown), but the biomass relative growth rate (RGR) of the smaller 126-25 stock size was significantly higher, nearly twice, compared to the 67-50 stock size (Table 2, Fig 3 C). Seedling RGR was also higher in BSFM stands compared to seedlings in LWs (Fig 3D).

Stand types significantly affected root elongation indices (REI) (Table 3), seedlings in LWs showing higher values of REI than seedlings in BSFM stand (Fig 3 H). Scarification and planting stock size significantly interacted to affect seedling REI, with the seedling REI being negatively affected by scarification only for the smaller (126-25) stock size (Table 3, Fig 3 G). A Stand types*Scarification*Planting stock interaction significantly influenced the seedling root/shoot dry mass ratio (*R/S*); the *R/S* of smaller (126-25) seedlings was reduced by scarification only in BSFM stands, while that of larger (67-50) seedlings was significantly reduced by scarification in LWs, but significantly increased in BSFM stands (Fig. 3 I).

Table 2: Summary of ANOVA results for the total biomass (B_T), total height (H_T), stem diameter (D_S) and relative growth rate (RGR) of black spruce seedlings planted in lichen woodlands and black spruce feather moss stands, one year after plantation, in scarified or unscarified plots and with smaller (126-25) or larger (67-50) containerized stock size.

Sources of variation		B_T		H_T		D_S		*RGR*	
	ndf	*ddf*	*P*	*ddf*	*P*	*ddf*	*P*	*ddf*	*P*
Block	5	5	0,2577	5,1	0,2252	5,09	0,1816	5	0,1337
Stand Types (ST)	1	5	**0,0116**	5,108	0,0683	5,096	**0,0097**	5	**0,0018**
Scarification (S)	1	10	**0,0363**	10,05	0,0538	10,05	0,1516	10	0,0543
ST*S	1	10	0,8284	10,05	0,4126	10,05	0,6826	10	0,6524
Planting Stock Sizes (PS)	1	20	**<,0001**	19,99	**<,0001**	20,15	**<,0001**	20	**0,0011**
ST*PS	1	20	0,5809	19,99	0,7759	20,15	0,6494	20	0,4026
S*PS	1	20	0,4358	19,99	0,6217	20,15	0,9345	20	0,2368
ST*S*PS	1	20	0,8871	19,99	**0,0462**	20,15	0,7170	20	0,5570

Bold indicates significance ($P \leq 0,05$). ndf = numerator degrees of freedom. ddf = denominator degrees of freedom

Table 3 : Summary of ANOVA (degrees of freedom and *P*-values) for the total biomass (B_T), root/shoot dry mass ratio (*R/S*) and root elongation indices (*REI*) of black spruce seedlings planted in lichen woodlands and black spruce feather moss stands, one year after plantation, in scarified or unscarified plots and with smaller (126-25) or larger (67-50) containerized stock size.

Sources of variation		R/S_{Ratio}		*REI**	
	ndf	*ddf*	*P*	*ddf*	*P*
Block	5	4,999	0,7512	5,08	**0,0451**
Stand Types (ST)	1	5,045	0,2240	5,16	**0,0447**
Scarification (S)	1	9,688	0,6031	10,05	**0,0029**
ST*S	1	9,696	0,5308	10,05	0,2298
Planting Stock Sizes (PS)	1	20,9	**0,0246**	20,39	**<,0001**
ST*PS	1	20,92	0,4756	20,39	0,5422
S*PS	1	20,9	0,2778	20,39	**0,0221**
ST*S*PS	1	20,92	**0,0190**	20,39	0,6858

Bold indicates significance ($P \leq 0,05$). ndf = numerator degrees of freedom. ddf = denominator degrees of freedom

* = ln transformed data

REI = Root Elongation Indices (mg of root biomass/sum of the 2 longest root mm)

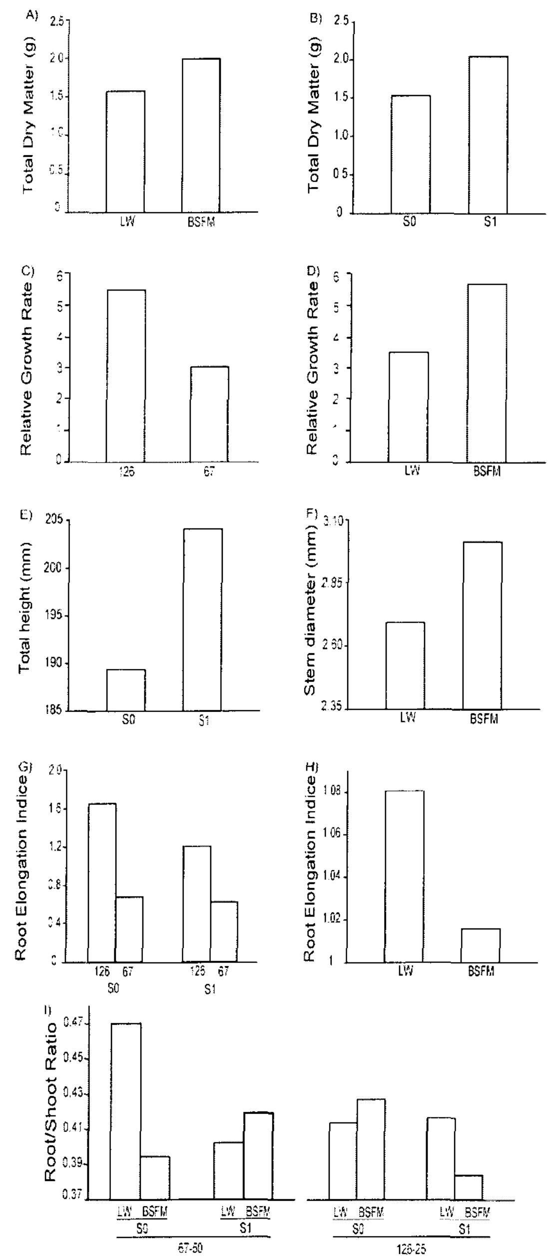

Figure 3. Stand types (ST), scarification (S) and planting stock (PS) size effects on the total dry mass (A and B), relative growth rate (C), height (D), stem diameter (E), root elongation indices (F and G (S*PS)) and Root/Shoot ratio (I ST*S*PS) of containerized black spruce seedlings one year after plantation on lichen woodlands and black spruce feather moss stands, (n=72 (a, b, c, d, e, f, h), n=36 (G) and n=18 (i)). Abbreviations are as in Fig 1. Graph (C) shows the detransformed relative growth rate of seedling which are unit less, original data are 126= 1.29 $g*g^{-1}*year^{-1}$ and 67=0.68 $g*g^{-1}*year^{-1}$.

3.2 Physiological response

Seedling nutrient foliar concentrations were not significantly influenced by stand types (Table 4).

Soil scarification decreased the foliar nutrient concentrations for magnesium, Ca and Mg (Table 4, Fig 4 C, 4E, 4G).

The smaller (126-25) seedling stock size generally exhibited significantly higher levels of foliar nutrient concentration for 4 out of 5 nutrients analysed (Table 4). The initially higher nutrient levels in the smaller seedlings tended to decrease through time but foliar N, K, P and Mg show higher values for the 126 at the end of the experiment (Fig. 4 A, B, D, H).

Table 4 : Summary of ANOVA results for the nutrient concentration (N, P, K, Ca, Mg) in current year foliage of black spruce seedlings planted, one year after plantation, on lichen woodlands and black spruce feather moss stands, in scarified or unscarified plots and with smaller (126-25) or larger (67-50) containerized stock size.

Sources of variation		Foliar N		Foliar P		Foliar K		Foliar Ca		Foliar Mg	
	ndf	*ddf*	*P*	*ddf*	*P*	*ddf*	*P*	*ddf*	*P*	*ddf*	*P*
Block (B)	5	8,867	0,8042	9,056	0,3573	9,03	0,6334	8,54	0,4567	9,12	0,4805
Date (D)	2	8,886	0,4977	9,059	0,3156	9,03	0,1790	8,593	**<,0001**	9,13	**<,0001**
Stand types (ST)	1	13,87	0,1201	14,16	0,6597	13,77	0,8819	14,03	0,0652	13,56	0,5662
D*ST	2	13,87	0,2141	14,16	0,9292	13,77	0,5256	14,02	0,2887	13,56	0,8379
Scarification (S)	1	27,84	0,2584	27,45	**0,0095**	27,28	0,9884	26,84	**<,0001**	27,35	**0,0415**
D*S	2	27,85	0,7031	27,45	0,0684	27,28	0,2891	26,84	**0,0034**	27,35	0,1759
Contrasts											
D (Linear)*S		_	_	_	_	_	_	26,80	**0,0002**	_	_
D (Quad)*S		_	_	_	_	_	_	26,88	**0,0001**	_	_
S0 vs S1 (D 427)		_	_	_	_	_	_	26,78	**0,0024**	_	_
ST*S	1	27,84	0,5920	27,45	0,6095	27,28	0,6999	26,84	0,3278	27,35	0,9673
D*ST*S	2	27,85	0,9234	27,45	0,6169	27,28	0,6759	26,84	0,7372	27,35	0,6749
Planting Stock size (PS)	1	54,90	**0,0002**	55,03	**0,0034**	54,99	**<,0001**	54,33	0,3094	55,08	**<,0001**
D*PS	2	54,90	0,2282	55,03	**0,0338**	55,00	**<,0001**	54,33	**<,0001**	55,09	**0,0088**
Contrasts											
D (Linear)*PS	1	_	_	54,73	**0,0011**	54,69	**<,0001**	54,21	0,8724	54,81	**0,00014**
D (Quad)*PS	1	_	_	55,35	0,0373	55,33	0,1309	54,45	0,1916	55,38	**0,00013**
126 vs 67 (D 427)	1	_	_	54,63	**0,0242**	54,58	**<,0001**	54,17	0,4629	54,17	0,4629
ST*PS	1	54,90	0,9805	55,03	0,6403	54,99	0,7788	54,33	0,9998	55,08	0,9890
S*PS	1	54,90	0,3652	55,03	0,8205	54,99	0,5825	54,33	0,6941	55,08	0,6729
D*ST*PS	2	54,90	0,8622	55,03	0,7129	55,00	0,7515	54,33	0,9413	55,09	0,6763
D*S*PS	2	54,90	0,6127	55,03	0,8093	55.00	0,6828	54,33	0,9556	55,09	0,9260
ST*S*PS	1	54,90	0,1929	55,03	0,6372	54,99	0,9855	54,33	0,8922	55,08	0,7861
D*ST*S*PS	2	54,90	0,5862	55,03	0,9430	55,00	0,7234	54,33	0,9672	55,09	0,9696

Bold indicates significance ($P \leq 0,05$). Ndf = numerator degrees of freedom, ddf = denominator degrees of freedom

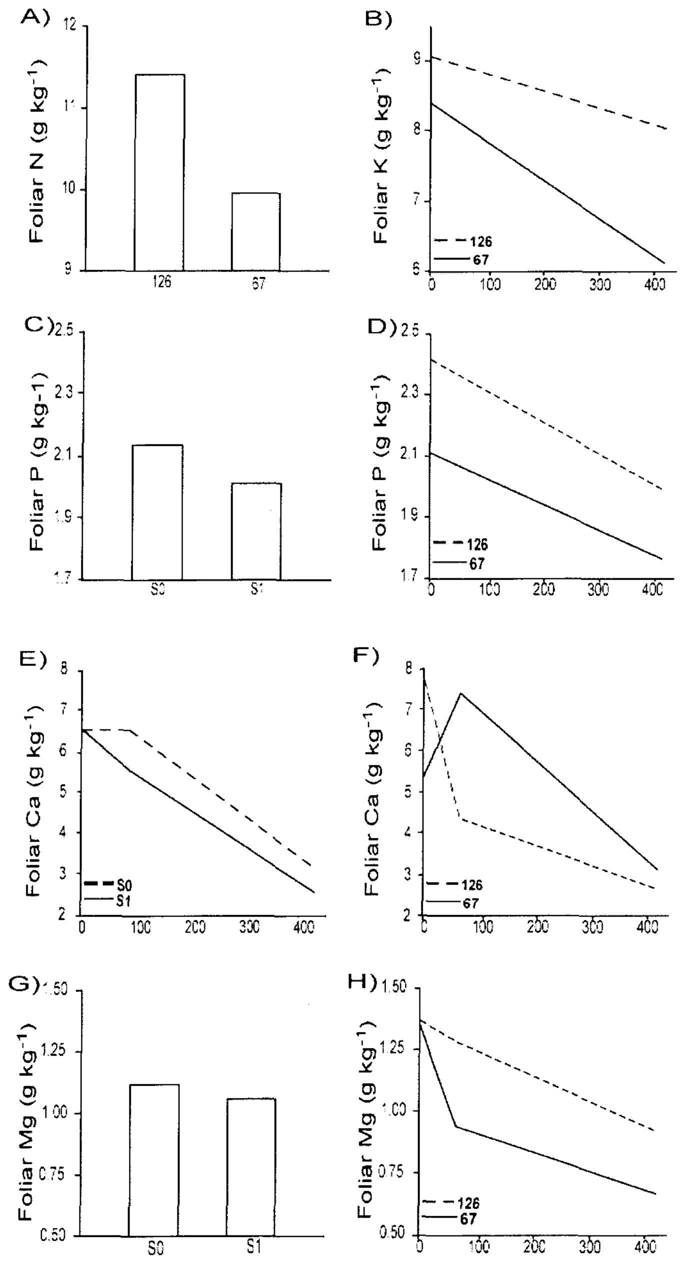

Figure 4 : Stand type (ST), date (D), scarification (S) and planting stock size (PS) effects on (A) foliar N, (B) foliar K (linear D*PS interaction), (C and D (linear D*PS interaction)) Foliar P, (E (quadratic D*S interaction) and (F (quadratic D*PS interaction)) foliar Ca and (G and H (quadratic D*PS interaction) foliar Mg in containerized black spruce seedlings planted in lichen woodlands and black spruce feather moss stands, one year after plantation (n=72 (a, c, g), n= 36 (b, d), n=24 (e, f, h)). Abbreviations are as in Fig 1. The three dates shown are day 1 (plantation time), day 67 and day 427.

Stand types, scarification and seedling stock sizes did not affect seedling gas exchange variables, except for a date factor impact (Table 5).

Table 5 : Summary of ANOVA results for gas exchange (light-saturated CO_2 assimilation rate or *A*, stomatal conductance for water vapour or g_s, and water-use efficiency or WUE) measured during the first growing season after plantation, on black spruce seedlings planted in lichen woodlands and black spruce feather moss stands, in scarified or unscarified plots and with smaller (126-25) or larger (67-50) containerized stock size.

Sources of variation		*A*		g_s*		*WUE*	
	ndf	*ddf*	*P*	*ddf*	*P*	*ddf*	*P*
Block	3	3,079	0,2727	2,991	0,7195	2,893	0,1593
Date (D)	1	3,08	0,0516	2,991	0,4087	2,893	**0,0455**
Stand type (ST)	1	6,172	0,6319	5,342	0,4799	3,986	0,8498
D*ST	1	6,172	0,1506	5,342	0,5902	3,986	0,2679
Scarification (S)	1	11,73	0,3687	8,797	0,8045	9,998	0,8657
D*S	1	11,73	0,9808	8,797	0,7468	9,998	0,6900
ST*S	1	11,73	0,7314	8,797	0,5180	9,998	0,9575
D*ST*S	1	11,73	0,4305	8,797	0,2651	9,998	0,5686
Planting stock sizes (PS)	1	24,4	0,0669	18,58	0,1875	23,48	0,1136
D*PS	1	24,4	0,1872	18,58	0,2814	23,48	0,1211
ST*PS	1	24,37	0,4089	18,58	0,9452	23,46	0,4749
S *PS	1	24,39	0,7785	18,59	0,0788	23,48	0,6637
ST*S *PS	1	24,37	0,4348	18,58	0,2722	23,46	0,3353
D*ST*PS	1	24,39	0,5721	18,59	0,7157	23,48	0,5757
D* S *PS	1	24,39	0,4501	18,59	0,5247	23,48	0,0792
D*ST*S*PS	1	24,39	0,4122	18,59	0,6049	23,48	0,1543

Bold indicates significance ($P \leq 0{,}05$). ndf = numerator degrees of freedom, ddf = denominator degrees of freedom.
* Analysis performed on transformed data; log (Stom cond*10000)

Seedlings Ψx was affected by planting stock size resulting in higher values for the 126-25 compared tothe larger (67-50) seedlings (Table 6, Fig 5A). The stand types*treatment significant interaction (Table 6) revealed that the seedling predawn Ψx was lower in LWs compared to that in BSFM stands in unscarified (S0) plots, but was equivalent between stand types in scarified (S1) plots (Fig 5B).

Table 6 : Summary of ANOVA results for august predawn shoot water potential (Ψx), measured in August of the first growing season after plantation, in black spruce seedlings planted in lichen woodlands and black spruce feather moss stands, in scarified or unscarified plots and with smaller (126-25) or larger (67-50) containerized stock size.

Sources of variation		Ψx_{pd}	
	ndf	*ddf*	*P*
Block	3	3,03	0,1302
Stand type (ST)	1	3,05	0,3873
Scarification (S)	1	6,21	0,1511
ST*S	1	6,21	**0,0232**
Planting stock sizes (PS)	1	12,30	**0,0474**
ST*PS	1	12,30	0,1860
S *PS	1	12,30	0,7778
ST*S *PS	1	12,30	0,9613

Bold indicates significance ($P \leq 0{,}05$). ndf = numerator degree of freedom, ddf = denominator degree of freedom

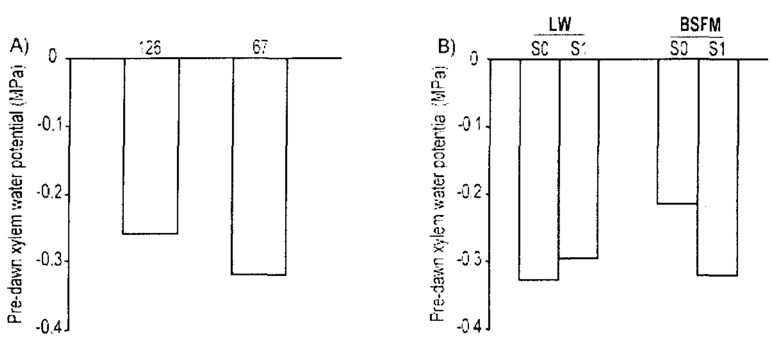

Figure 5 : Planting stock size (A) and Stand types*Scarification interaction (B) effects on the predawn shoot water potential (Ψx) measured during the first growing season after planting in black spruce seedlings planted in lichen woodlands and black spruce feather moss (n= 32 (A), n=16 (B)).

3.3 Environmental data

Over the year, air and soil temperature in LWs and BSFM stands are similar (not shown). On a narrower period air and soil temperature during the spring season (march 21st to June 21st) was in average 4 °C and 3 °C, respectively (no statistic test), lower in LWs than in BSFM stands, regardless of soil scarification (Fig 6A). While air temperature during the summer was similar between both stand types, soil temperature of scarified LW was slightly higher (ca. 0.9 °C) than that of scarified BSFM stands (Fig 6B).

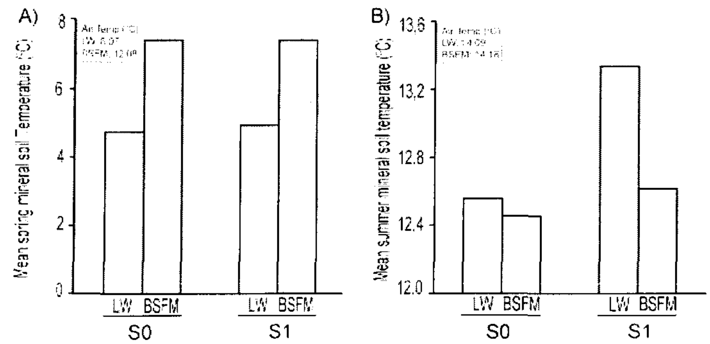

Figure 6 : Mean soil (at 10 cm deep in the mineral soil) and air temperature (°C) of lichen woodlands and black spruce feather moss stands during (A) 2006 spring (March 21st to June 20st) and (B) 2006 summer(June 21st to September 21st).

CHAPITRE 4

DISCUSSION

4.1 Stand type impact

Most of seedling morphological variables measured one year after plantation showed significantly higher values in the black spruce feather moss (BSFM) stands compared to the lichen woodlands (LW). These growth differences cannot be explained by gas exchange parameter, water potential or nutritional responses of seedlings to site conditions. The absence of difference at this level suggests that the morphological and growth differences originate from a factor that influenced growth prior to these physiological measurements as spring temperature.

Despite the potential site nutritional (Girard, 2004) and known water limitations (Hébert et al. 2006) in LWs, there was no direct stand type-related difference in the seedling physiological response. The absence of direct stand type effect on seedling physiology may be explained partially by the higher root elongation indices (REI) of seedlings in LWs, which enabled them to explore a larger soil volume, on a root biomass basis, improving their chance to meet their physiological needs even if the nutrient content in LW soils is initially lower (Girard, 2004; unpublished results). It would imply that black spruce seedlings are able to adjust their root growth pattern and architecture, and not only their biomass allocation, in order to acclimate to different levels of water and nutrient availabilities.

Our results also suggest that seedling growth response may also be partially controlled by factors not related to water or nutrient limitation. The lower spring soil temperatures observed in LWs is most likely caused by the elevated albedo of the lichen mat (Kershaw, 1983) and the thinner and less insulating organic layer (results not shown) than that in BSFM stands. Soil temperature is known to affect growth, and the warmer temperatures observed in BSFM stands have probably resulted in superior seedling growth (Vaganov et al., 1999; Lajzerowicz et al., 2004). Moreover, the main controlling factors of seasonal growth in northern timberline are early summer temperature and date of snowmelt (Vaganov et al. 1999). These factors could have lead to an earlier growth initiation for the BSFM seedlings resulting in higher biomass, height and diameter at the end of the growing season. Warmer soil temperature positively affect seedling growth and water relations through its effects on water viscosity and root membrane permeability (Bowen, 1991; Colombo and Teng, 1992; Nobel, 1999; Dodd et al.,2000; Boucher et al. 2001) thereby favouring cell turgor pressure resulting in improved cells division and elongation (Kramer, 1979; Colombo and Teng, 1992)

The growth difference may also have been caused by the lower LW night air temperatures because less infrared are emitted from ground (Lord at al., 1993). Early 'summer frosts' may also have played a role in this differential growth response in seedlings (Lamontagne et al., 1998) resulting in reduced growth at the end of growing season. The open stand structure of adjacent LWs could also have contributed to the lower values in air temperature observed in LWs, which is known to influence the snow pack cover, and concomitantly the frozen soil depth and melting, as well as the water regimes of the regeneration (Bernier, 1990; Boyce and Lucero, 1999; Neuner et al., 1999; Löfvenius et al., 2003).

The lichen mat in LWs may have played a role in the differential seedling growth between BSFM stands and LWs by limiting resource access via its effect on mycorrhizae. Fisher (1979) showed that the presence of ground lichen on the growing medium reduces infection and growth of ectomycorrhizal fungi on white spruce and jack pine roots. This fungi limitation by cladonia gender lichens have also been demonstrated by Sedia and Ehrendfeld (2003) with bear oak (*Quercus ilicifolia* Wang). This was thought to be an allelopathic effect due to the presence of lichen ground cover. Mycorrhizal infection of seedlings roots improves water and nutrient uptake by increasing the explored soil volume and enabling nutrient storage in the fungi tissues later available for retranslocation and growth (Trofymow and van den Driesssche, 1991).

4.2 Planting stock size impact

Our results show, that the smaller seedlings (126-25) had a higher height, diameter and biomass growth rate than the larger ones (67-50) a phenomenon demonstrated for Norway spruce (Johansson et al., 2007). Higher REI and, possibly, root hydraulic conductivity of the smaller seedlings may explain this growth difference (Kramer, 1983; Lamhamedi et al. 1997). As smaller seedlings make more root elongation, on a biomass basis, they expose more unsuberized and water permeable root tips (Kramer, 1983; Grossnickle, 1988; Rüdinger et al., 1994), An interpretation confirmed by the lower level of water stress experienced by the smaller seedling compared to the standard ones. However, these observations raise question about the duration of the differential growth rate recorded during the first growing season; i) will it last long enough to overcome the initial size difference, and ii) how long will it last?

Water potential data suggests that water stress was not responsible for the lower survival rate of the smaller seedlings, compared to larger ones as the values were far from sterssing and were even higher than that in the larger seedlings. The higher mortality of smaller planting stock was also noted by Johansson et al. (2007) with Norway spruce seedlings, but they were able to establish a causal relationship with frost heaving. We did not observed heaving on our study sites, so the same conclusion cannot be drawn. Freezing tolerance and winter desiccation (Noble and Alexander, 1977; Shaw et al., 1987) may deserve investigation in further experiments, despite the fact that these smaller seedlings have been submitted to a short day treatment at the nursery, in order to stop their growth and improve their freezing tolerance (Folk and Grossnickle, 2000). This short day treatment can sometime result in earlier spring dehardening (Colombo, 1986; Bigras and D'Aoust, 1992) and needle flush therefore increasing susceptibility to frost and mortality.

After one growing season, N, P, K and Mg foliar concentration were higher for the 126-25 than the 67-50. These higher nutrient concentrations may be due to the growth rate and morphology of their root system. Higher hydraulic conductivity of the smaller seedlings roots improves the passive nutrition processes, which may explain a part of their better nutrient status and higher relative growth rate.

The K foliar content quadratic interaction with date reflects that both planting stock have seen their foliar concentration lowered with time but the diminution rate was higher for the 67-50. This diminution indicates that the nutrient availability and/or uptake aren't in equilibrium with seedling growth requirement and this effect is stronger for the 67-50 which have more biomass to service. For the Mg foliar content, the Planting stock size*Date interaction was quadratic revealing that the 67-50 seedlings showed an important diminution between the first and second sampling date, which was not observed for the 126-25. These differences may have been caused by growth dilution, while the biomass accumulation of the 67-50 seedlings was 4 times that of the 126-25 seedlings during this time interval. The foliar Ca also showed a quadratic interaction between planting stock and date. For the three sampling date, 67-50 foliar Ca followed the pattern observed in mineral soil (results not shown) but the 126-25 followed a different pattern showing an important reduction at the second sampling date. It may have been cause by retranslocation of this nutrient to another compartment, not investigated in the present study, or by an unmonitored factor who will need further investigation.

The differences weobserved in nutritional and water status between planting stock size did not influence instantaneous gas exchange measurements. Gas exchange was not influenced by seedling water status, supporting the idea that black spruce seedlings do not adjust their photosynthetic rate and/or stomatal aperture to its water status (Givnish, 1988; Canham, 1989; Bazzaz and Wayne, 1994; Walter and Reich, 2000; Hébert et al. 2006). Furthermore, Tan et al. (1992) suggested that drought response of black spruce is to maximise its photosynthesis.

4.3 **Site preparation impact**

Disk scarification positively influenced black spruce seedling survival, H_T, DM_T and RGR. Site preparation is recognised for its positive effects on seedlings growth and survival (Bassman, 1989; Grossnickle and Heikurinen, 1989; Örlander et al., 1990; Prévost, 1996; Boucher et al., 1998; Bedford and Sutton, 2000). We believe that the removal of the humus and ericaceous shrub layers, which reduce competition for resources to planted seedlings.

In addition to the resource competition decrease, scarification increase mineral soil temperature (Örlander et al., 1990; Boucher et al. 1998). Increase in soil temperature improves root cell membrane permeability and decreases water viscosity (Bowen, 1991; Dodd et al., 2000; Nobel, 1999; Kramer, 1983) which leads to a facilitated water uptake.

Surprisingly water relation results revealed that seedlings of both stand types reacted differently to scarification. Scarification is recognized to improve water relations of planted seedlings (Grossnickle and Heikurinen, 1989). Following scarification, the seedling Ψx in the drought prone LWs were similar to those measured in BSFM (as observed in Hébert et al. (2006)) but reduced the Ψx of BSFM seedlings. We can't explain this interaction so further studies involving a similar experimental design should be carried out.

Our result showed that P, Ca and Mg uptake was higher in the S0 than in the S1 plot. As intensive skid trail use during the harvest and skidding operations resulted in S0 treatment grounding substratum close to a mixing site preparation, S0 seedlings roots were closer to or even directly into organic soil. We thus believe that the absence of competition, the proximity of the nutrient pool and the higher REI of the S0 plot seedlings could explain these differences.

4.4 Sylvicultural implications

Lichen woodlands cover over a million hectares in Québec's allowable cut zone. Many of these stands are located near the existent road network and could therefore be afforested at reasonable cost. To do so, plantations should be preceded by an adequate site preparation, such as disc scarification.

The cheaper, smaller and easily produced 126-25 black spruce seedling containerized stock showed an interesting potential for LW afforestation. The lower production, transport and planting costs associated with the use of these small seedlings should be taken in account as afforestation of LWs is considered a risky investment on the base of fire event risk, establishment phase growth reduction and that afforestation will eventually occur on remote sites. Our results showed that the growth and survival rates of the smaller seedlings were at least comparable to the traditional larger seedlings.

Even if disturbance level was controlled in this experiment, our results showed that there are still some growth differences among stand types. Further experiments are needed to point out what type of site preparations would lead to similar growth between stands, what planting species should be favored. This experiment and the one used by Hébert et al. (2006) should be monitored on a long term basis to determine if a denser tree cover may lead to similar growth between LWs and BSFM via a positive retroactive loop (Moroni et al., 2009).

CHAPITRE 5

CONCLUSION

Our results suggest that water and nutrient limitations are not the driving factor explaining seedling growth on LW sites. Air and soil temperatures and, presumably, allelopathic interferences by cladonia require further investigations. Even if seedlings growth is slightly reduced after one year in LWs compared to seedlings in BSFM stands, afforestation of LW shows an interesting potential. However, more investigations are needed to understand the establishment phase growth limitation of seedlings in LWs. With an appropriate site preparation, the use of smaller seedling stock size seems promising to insure the success of LW afforestation. As the success of a plantation can be defined as the degree to which the planting stock realizes the objectives of management at a minimum cost, there are some arguments in favour of these smaller seedlings who demonstrate that the really important attribute of planting stock are not nursery growth, appearance or sizes but rather the performance of the stock after outplanting in regard to the cost and potential benefit.

The afforestation of these stands could also have a positive environmental effect. Transforming unproductive stand into forest with adequate sylvicultural methods could result into increased carbon sequestration, and help mitigate climate change (Gaboury et al, 2009). As there is lot of lichen woodlands the mitigation potential is environmentally interesting and may also be financially interesting in regard of the incoming carbon market.

CHAPITRE 6

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