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EXPERIMENTAL WORK ON PEATLAND RESTORATION AT MAISONNETTE AND LAMÈQUE, NEW BRUNSWICK (1992-1994)

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EXPERIMENTAL WORK ON PEATLAND RESTORATION AT MAISONNETTE AND LAMÈQUE, NEW BRUNSWICK (1992-1994)

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SUMMARY

From 1992 to 1994, a peatland restoration study was conducted on abandoned areas of two peatlands in northeastern New Brunswick. The objectives of the project were (1) to evaluate some techniques that could help restore the hydrology and vegetation of post-harvest peatlands and (2) to examine how some chemical and physical environmental factors may influence vegetation reestablishment on abandoned surfaces.

Harvesting operations at the Maisonnette site ceased in 1992. In late summer of the same year, the main perimeter drainage ditches of the abandoned area were filled to allow rewetting with water from rain and snowmelt. Water level and chemistry data were collected in 1993 and 1994 and compared to those of an undrained, non-harvested area located nearby. Fragments of *Sphagnum* plants were experimentally reintroduced in 1993 and 1994 on bare peat surfaces at Maisonnette. A first experiment was designed to assess how an irregular microtopography (i.e., alternating ridges and 15-20 cm deep depressions), the presence of companion species (ericaceous shrubs, *Eriophorum angustifolium* or bryophytes other than *Sphagnum*) and phosphorus amendments would affect *Sphagnum* recolonization success on bare peat. A second experiment tested the ability of top spit (the shredded surface vegetation layer of a bog newly opened to harvesting) to serve as a source of moss and vascular plant diaspores for restoration purposes. This second experiment also examined whether the presence of a straw mulch cover improves plant recolonization success.

Blocking the ditches was successful at rewetting the Maisonnette experimental site although water level fluctuations remained more pronounced in the abandoned site than in the undrained site. The chemistry of the abandoned surface did not differ markedly from that of an unharvested bog or poor fen, with the exception of being somewhat nitrogen enriched. Recolonization success was, on average, similar between plots with a flat or an irregular microtopography. However, within plots with irregular microtopography, moss reestablishment tended to be favored in the sheltered depressions in comparison to the ridges. Recolonization success was greater in plots where a significant vascular plant cover (either an

ericaceous shrub cover or an *Eriophorum* sp. cover) was established and offered diaspores some kind of protection against desiccation caused by wind and solar radiation. Phosphorus amendment improved peat moss reestablishment both directly and indirectly by improving companion species success.

The Lamèque site was abandoned approximately 15 years ago and shows areas that are well recolonized by peatland vegetation alternating with bare peat surfaces. The drainage ditches at this site were not blocked when harvesting operations stopped, but are now partly clogged by eroded peat and vegetation. The central, elevated sections of the post-harvest bays are devoid of both vascular plants and sphagna. The experiments and observations conducted at Lamèque suggest that physical conditions (i.e., the absence of snow cover in some years as well as the low water table), more than chemical factors, are likely responsible for the absence of vegetation in the central portion of the bays.

Finally, results of field and greenhouse work on bog vascular plant propagation are presented. Preliminary guidelines for peatland restoration practices are suggested based on the results obtained. Avenues for further restoration studies in New Brunswick are also suggested.

SOMMAIRE

De 1992 à 1994, une étude portant sur la restauration des tourbières abandonnées après exploitation s'est déroulée sur deux tourbières du nord-est du Nouveau-Brunswick. Les objectifs de cette étude étaient (1) d'évaluer certaines techniques visant à restaurer la végétation et les conditions hydrologiques des tourbières abandonnées et (2) d'examiner comment certains facteurs chimiques et physiques peuvent influencer le rétablissement de la végétation sur les surfaces laissées à nu après la récolte de tourbe.

La récolte de la tourbe sur le site de Maisonnette a cessé en 1992. En août de la même année, les canaux de drainage principaux ont été bloqués de façon à permettre le remouillage du site à partir des eaux de pluie et de fonte. Des données de chimie de l'eau et de niveau de nappe phréatique ont été recueillies en 1993 et 1994 sur le site abandonné et comparées aux données recueillies sur un site non-drainé situé à proximité. En 1993 et 1994, des fragments de sphaignes ont été réintroduits sur le substrat de tourbe à nu de façon à évaluer leur potentiel à reformer un tapis végétal. L'effet d'une microtopographie irrégulière (présence de dépressions et de crêtes en alternance), de la présence de plantes-abris (*Eriophorum angustifolium*, autres bryophytes et éricacées) et de la fertilisation au phosphore sur la reprise de la sphaigne ont été testées dans le cadre de cette première expérience. Une deuxième expérience visait à estimer le potentiel de recolonisation du "top spit" (i.e. de matériel végétal provenant de la surface d'une tourbière ombrotrophe et ayant été broyé mécaniquement lors de l'ouverture de nouvelles planches en vue de l'exploitation). Cette seconde expérience avait aussi pour but de vérifier si l'utilisation d'un paillis permet d'améliorer la reprise de la végétation à partir du "top spit".

Le blocage des canaux a permis une remontée substantielle du niveau de la nappe phréatique du site à restaurer bien que les fluctuations de niveau d'eau soient demeurées plus grandes qu'au site naturel. Les données de chimie de l'eau montrent peu de différences entre la zone à restaurer et la tourbière naturelle, sauf pour ce qui est des niveaux d'azote, plus

élevés sur le site abandonné. Les parcelles planes et avec microtopographie irrégulière ont montré, en moyenne, des succès de recolonisation semblables. Cependant, une tendance à une meilleure recolonisation du substrat a été observée dans les dépressions des parcelles avec microtopographie irrégulière. La présence de plantes-abri a favorisé la reprise de la sphaigne dans les cas où un couvert de plantes vasculaires suffisant pour offrir une certaine protection contre la dessiccation causée par l'exposition au vent et au soleil a pu être établi. L'ajout de phosphore a favorisé la reprise de la sphaigne et ce de façon directe, mais aussi de façon indirecte en permettant une meilleure recolonisation de la surface par les plantes-abri.

Le deuxième site expérimental, situé à Lamèque, a été abandonné il y a environ 15 ans. Des bandes bien revégétées en plantes vasculaires et en sphaignes y alternent avec des bandes de tourbe à nu. Les canaux de drainage de ce site n'ont pas été bloqués lors de l'abandon des opérations, mais sont maintenant partiellement remplis par de la tourbe et de la végétation. La végétation est absente sur la section centrale surélevée des planches abandonnées. Les données recueillies à Lamèque suggèrent que les conditions physiques du site (i.e. l'absence de couverture nivale lors de certaines années et un niveau de nappe phréatique relativement bas durant la saison de croissance), plutôt que les conditions chimiques du substrat, limitent la reprise de la végétation sur la partie centrale des planches abandonnées.

Finalement, des résultats d'expériences de propagation de plantes vasculaires de tourbières et des suggestions préliminaires sur les pratiques de restauration des tourbières ombrotrophes sont présentées. Des avenues pour des travaux de recherche futurs sur la restauration des tourbières au Nouveau-Brunswick sont aussi suggérées.

INTRODUCTION

Current peat mining practices involve tremendous changes to the peatland surface. Peatland vegetation is totally removed, and the hydrology of the site is drastically altered by the presence of drainage ditches. Once mining stops, abandoned bare peat surfaces are subjected to wind erosion and desiccation. Post-harvest bogs do not tend to return rapidly to functional peatland ecosystems. Many abandoned surfaces, especially the ones that were vacuum-harvested, are barely revegetated even 10 years after mining operations stop (Famous and Spencer 1989, L. Rochefort, unpublished data). Others are colonized by ericaceous shrubs and cotton-grass, without noticeable recolonization by the *Sphagnum* mosses which are a key component of bog ecosystems. A minority of abandoned sites (often the ones that were harvested by the block-cut method) show good reestablishment of both vascular and bryophyte flora typical of peatlands. These observations suggest that active steps have to be taken to encourage a return to a functional peatland ecosystem within a reasonable time frame.

One of the objective of this project was to evaluate some techniques that could help restore the hydrology and vegetation of harvested and abandoned sites. As the recolonization of bare peat surfaces by *Sphagnum* mosses is one of the main challenges in the restoration of post-harvest peatlands, a special emphasis was given to techniques dealing with reintroducing *Sphagnum* species and promoting their propagation. This project also examined how some environmental factors such as chemistry and physical conditions may influence vegetation reestablishment on post-harvest surfaces. The experiments reported hereafter took place on two abandoned portions of the Maisonnette and Lamèque peatlands. Both peatlands are located in the Acadian Peninsula of New Brunswick (Figure 1) and are still currently harvested for horticultural peat by SunGro Horticulture Canada Ltd. This study was funded by the Minerals and Energy Division of the Department of Natural Resources and Energy of New Brunswick and by SunGro Horticulture Canada Ltd. Field work was initiated in 1992 by Linda Halsey and Isabelle Lavoie under the supervision of Dale Vitt (University of Alberta) and Line Rochefort (Laval University).

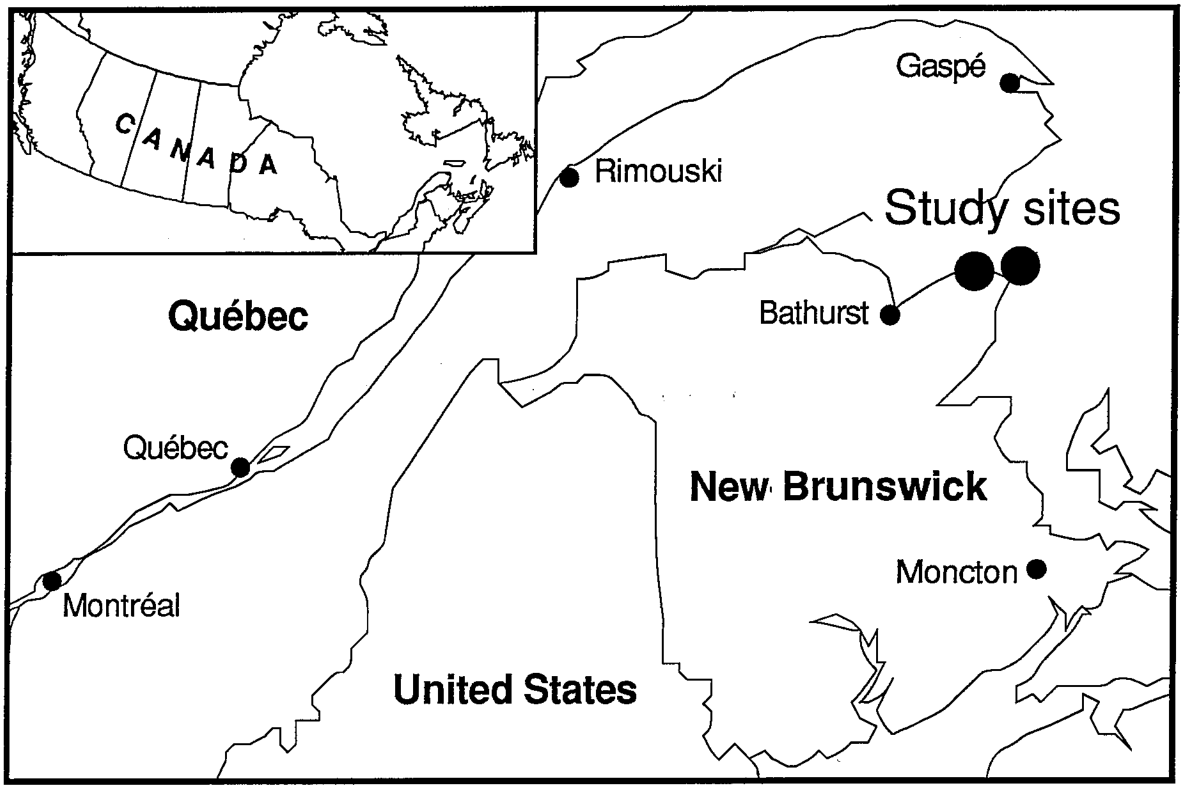

Figure 1. Location of the two study sites (Maisonnette and Lamèque peatlands, NB).

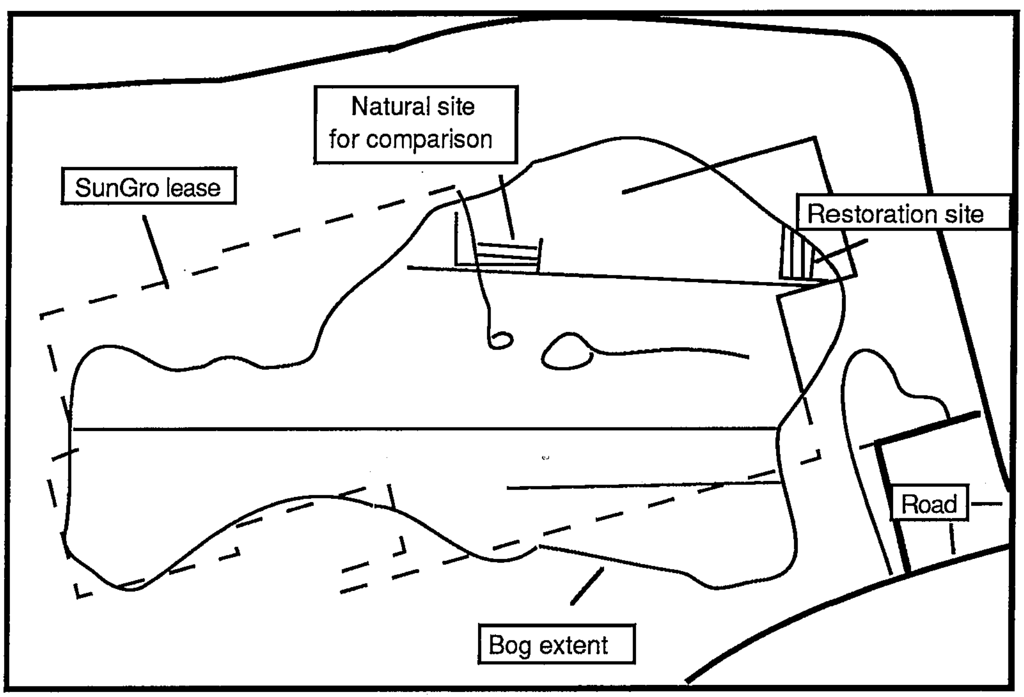

Figure 2. Location of the restoration and natural sites at Maisonnette.

Chantale Ferland (an MSc student from Laval University) established the experiments and pursued the monitoring in 1993 and 1994. SECTION A)

SECTION A) EXPERIMENTS AT THE MAISONNETTE SITE

Site description

The Maisonnette peatland is classified as a Maritime Atlantic Boreal Peatland (National Wetland Working Group 1986) and covers 541 ha (Figure 2). Approximately 340 ha of this bog are currently harvested for horticultural peat by SunGro Horticulture, using the vacuum method. Peat mining at this site began in the early sixties.

In the summer of 1992, peat harvesting operations stopped on a 2.16 ha portion of the harvested site that is now used as a study site for restoration practices. Thickness of the remaining organic layer at this site varies between 40 to 120 cm, 10 to 30 cm of which is *Sphagnum* peat (Rochefort *et al.* 1993). Mean annual temperature at the closest Environment Canada weather station, in Bathurst, is 3.3 °C. Mean annual precipitation is 772 mm, approximately 50% of which is rain.

Rewetting

As mentioned earlier, the hydrology of harvested sites differs markedly from the hydrology of natural peatlands due to drainage. The water table is lowered, a situation which is assumed to be a main factor impeding the reestablishment of peatland vegetation (Schouwenaars 1988). Trying to raise the water table of an abandoned site is thus the first logical step to be taken in order to restore the conditions necessary for plant recolonization.

Methods

In August 1992, the main perimeter drainage ditches of the study site were completely filled and levelled with bulldozed peat to stop water losses from the site and to allow rewetting. In the fall of 1992, a series of 35 water wells were installed to monitor water table level and fluctuations. These wells are made of 5 cm diameter PVC pipes. For comparison purposes, four other wells were installed in a natural area of the peatland. Here we want to warn the reader that this chosen natural comparative site represents a site where peatland vegetation still thrives but might not represent the natural hydrology of a undisturbed peatland. Indeed, this site is perched 2 m above the surrounding excavated peat (Figure 2) and we do not know the effect of this isolation on the water table.

Results and discussion

Blocking the ditches was successful at rewetting the Maisonnette experimental site with rain and snowmelt waters. Rewetting was facilitated by the fact that the abandoned site is lower than the surrounding harvested peatland, and thus tended to collect runoff and drainage water from the neighbouring areas.

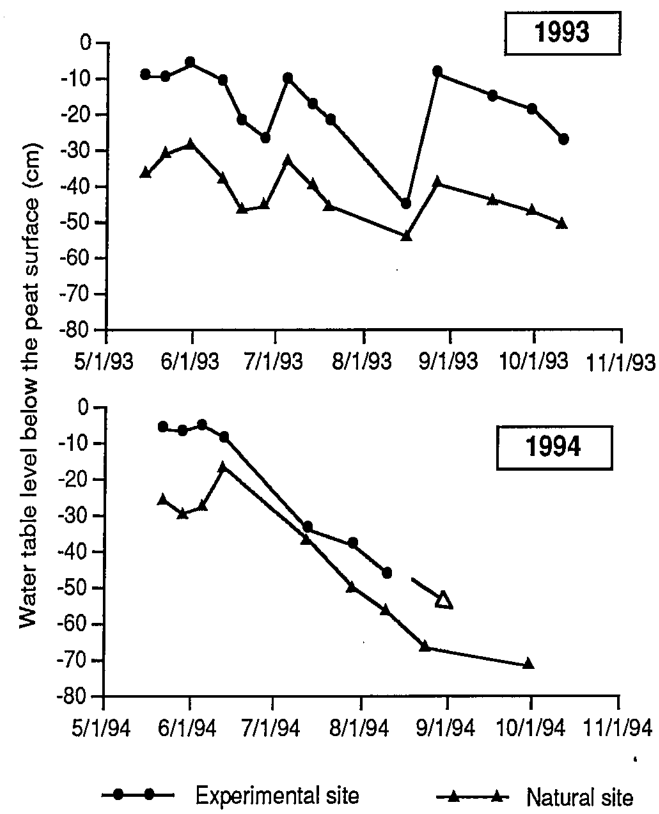

Figure 3. Water table fluctuations at the restoration and natural sites at Maisonnette. The open-headed arrow indicates that the water table was located below -45 cm (minimum measurable depth in the experimental site) at the end of 1994. n=4 for the natural site and n=35 for the experimental site.

Water table fluctuations at the experimental site are compared to those of the natural, non-harvest areas in Figure 3. Water level at the experimental site was generally higher than at the natural site, although the amplitude of the fluctuations tended to be somewhat more pronounced at the experimental site. Dr. J. Price (unpublished data) also documented greater fluctuations of the water table at a post-harvest site with blocked ditches than at a natural site nearby at the Sainte-Marguerite-Marie peatland in Lac Saint-Jean, Québec.

Figure 3 also shows that the spring and early summer of 1994 were wetter than the same periods in 1993. In late summer and fall 1994 though, water levels at Maisonnette dropped to levels comparable or lower than the year before.

Despite what can be considered as a relatively high water level at times, visual observations suggest that the conditions seen by the diaspores, which lay at the peat-air interface, may still at times be very limiting in terms of humidity. Indeed, during warm days, desiccation due to solar and wind radiation tend to cause the formation of a dry peat layer at the surface, even though the peat may be saturated with water a few centimetres below. This suggest that restoring a normal or high water table alone may not be sufficient to ensure adequate humidity conditions for *Sphagnum* moss reestablishment.

WATER CHEMISTRY

As mentioned earlier, post-harvest surfaces differ markedly from natural surfaces in their absence of vegetation and altered hydrological state. Other, more subtle differences may also be present, which would affect restoration efforts. In particular, differences in water and peat chemistry between natural and post-harvest surfaces might be critical for plant reestablishment, as different plant species have distinct tolerances to surrounding chemical environment.

Methods

Water chemistry parameters were monitored at Maisonnette in 1992, 1993 and 1994. To collect water samples, a series of pits (40 cm x 40 cm) were dug to an approximate depth of 10 cm above mineral soil. Four more pits were also dug in a natural, non-harvested area of the peatland. In both the natural area and experimental site, water sample dugouts were located near water wells. Samples from the experimental and natural site were taken in October 1992, May 1993 and May 1994.

Water samples were analysed at the Peat Research and Development Centre Inc., in Shippagan, New Brunswick. Samples were filtered on a 0.45 µm cellulose acetate filter prior to analysis. Conductivity measurements were corrected for temperature and pH according to Sjörs (1950). NH4-N values were obtained by steam distillation. Base cations (Ca, Mg, K, Na) were measured by atomic absorption. Ionic chromatography techniques were used to determine Cl, NO3 and SO4 levels. Total P levels were determined by colorimetry.

Results and discussion

Comparisons between natural and post-harvest surface water and peat chemistry at Maisonnette and at other post-harvest sites throughout Canada are presented and discussed in Wind-Mulder *et al.* (submitted ms).

Table 1. Water chemistry values for the Maisonnette experimental site. Units: Conductivity: µS at 20°C, corrected for pH according to Sjörs 1950. Others: mg/L

	Natural site			Restoration site		
	1992	1993	1994	1992	1993	1994
pH	3.9 - 4.0	3.8 - 4.0	4.1	3.7 - 3.9	3.5 - 4.0	3.8 - 4.1
Conductivity	47 - 60	0	5 - 7	34 - 136	23 - 81	39 - 52
Cations:						
Ca	0.2 - 0.5	0.2 - 0.6	0.2	< 0.05 - 1.36	< 0.05 - 0.79	0.3 - 0.4
Mg	0.5 - 0.6	0.3	0.2	0.7 - 4.9	0.4 - 2.3	0.6 - 01.5
K	0.2 - 0.3	0.2 - 0.4	0.1 - 0.2	0.3 - 0.6	0.6 - 4.2	0.3 - 0.5
Na	4 - 8	2 - 4	2 - 3	6 - 22	3 - 8	4 - 8
Cl	5 - 10	3	3	9 - 26	7 - 20	7 - 23
SO_4	1 - 3	1 - 2	1	8 - 25	6 - 17	2 - 8
NH_4-N	< 0.5	0.4 - 2.8	< 0.5 - 0.8	2 - 6	2 - 16	< 1 - 4
NO_3-N	< 0.05	< 0.5	< 0.05	< 0.05 - 0.88	< 0 .5 - 1.7	< 0.05
P total	< 0.1	< 0.02	0.04	< 0.1 - 0.35	< 0.02 - 0.18	< 0.01 - 0.016
Samples (n)	4	4	2	18	18	7

In general, water chemistry data obtained at the experimental site are comparable to those of the natural site for pH (Table 1). The levels of pH are also within the range of pH generally found in bogs and poor fens (Zoltaï 1988, Rochefort, unpublished data from 50 peatlands of eastern Canada). Levels of conductivity, Na, K, Mg, Ca, Cl and SO4 observed at the experimental site are somewhat higher than the levels observed at the natural site and may be due to the exposure of fen peat and/or due to the mixing of mineral material from previous ditching with the peat. More striking is the difference in the levels of ammonium (NH4-N) between the abandoned site and the natural site, which could be attributed either to the increased aeration of the peat deposit due to drainage, to the absence of vegetation on the exposed peat surface, or to a combination of both factors (Wind-Mulder *et al.* submitted ms). The increased aeration may enhance microbial activity and mineralization rates, while the absence of vegetation would result in low nutrient uptake.

The 1992, 1993 and 1994 chemistry data collected at Maisonnette show the general stability of chemical parameters through time. However, comparison between chemistry values from the natural site and the experimental area suggests a greater variability for the bare substrate experimental site.

These results imply that the surface on which we are trying to restore a typical peatland community do not differ markedly, in term of chemistry, from a natural surface, with the exception of being somewhat nitrogen enriched. Thus, the species that will be best able to reestablish on bare peat will be the ones able to withstand, or take advantage of, these enriched nutrient conditions.

EFFECT OF MICROTOPOGRAPHY, PLANT COMMUNITY AND AMENDMENTS ON PLANT REESTABLISHMENT

From previous observations of post-harvest peatlands and from knowledge of peatland ecology, three factors were pinpointed at the onset of the project as potential key factors affecting the success of vegetation reestablishment in a cutover bog (Rochefort *et al.* 1993). These factors were microtopography, plant community and soil and water chemistry.

Wind desiccation and wind erosion appear to be important factors impeding the establishment of *Sphagnum* species. Protected microsites might create suitable microhabitat for the reestablishment of moss patches, which, once established, will act as the centre of propagation. Likewise, the reintroduction of vascular plants may help create a humid boundary layer at the surface of the peat that enhances the success of *Sphagnum* reestablishment. Finally, based on results from previous experiences in Québec (Rochefort *et al.* in press) and from the work of other researchers (McVean 1959; Boatman and Lark 1971; Aerts *et al.* 1992) we hypothesized that a light substrate amendment of phosphorus might favour vegetation reestablishment on bare peat.

Therefore, the first experimental plant reintroduction done at Maisonnette was designed to assess how microtopography, companion species and phosphorus amendments would affect *Sphagnum* recolonization success on bare peat.

Methods

The experiment testing the effect of microtopography, plant community and amendments on plant reestablishment was designed as a split-split-plot experiment in a completely randomized design (Figure 4).

Six 40 m x 40 m plots were established at the experimental site. In the spring of 1993, surface roughness was increased on three of these main plots by the repeated passage of an excavator. The resulting microtopography consisted of a series of shallow depressions (excavator tracks 50-70 cm wide and approximately 15 cm deep) bordered by ridges (Appendix 1: Plate 1). The other three main plots remained with an undisturbed levelled surface and limited microtopography (Appendix 1: Plate 2).

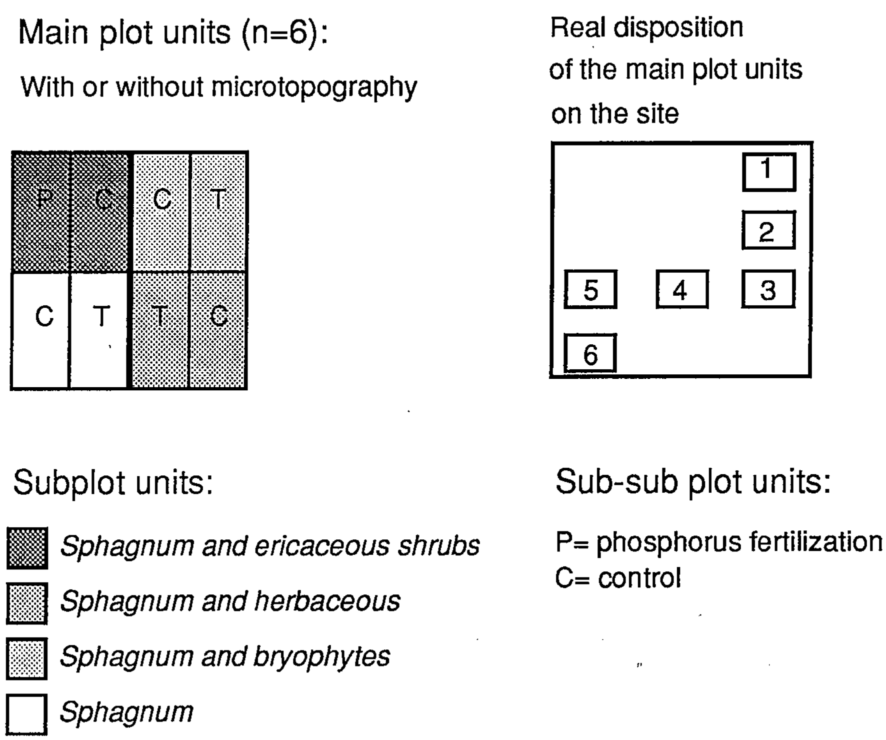

Figure 4. Experimental design (split-split-plot) for the Maisonnette experiment on the effect of microtopography, plant community and phosphorus amendment on *Sphagnum* reestablishment on bare peat

Each of the six main plots was divided into four subplots to which four types of plant communities were randomized. The plant communities tested were:

1) *Sphagnum* mosses only
2) *Sphagnum* mosses and other bryophytes as companion species
3) *Sphagnum* mosses with ericaceous shrubs as companion species
4) *Sphagnum* mosses with herbaceous plants as companion species

The choice of *Sphagnum* mosses and companion plant species used was made according to the local availability of the plants. Companion species were collected from the Maisonnette peatland itself. *Sphagnum* species were collected from a post-harvest peatland in Shippagan. Block-cutting at the Shippagan site stopped 20 years ago and the abandoned area is now partly revegetated, with *Sphagnum* species now locally abundant in patches.

Fragments (3-5 cm) of *Dicranum undulatum* (May 1993) and of *Dicranum undulatum* and *Polytrichum strictum* (May 1994) were used to reintroduce companion mosses on the appropriate subplots. The ericaceous shrubs used as companion plants were *Ledum groenlandicum, Kalmia angustifolia, Chamaedaphne calyculata* and *Andromeda glaucophylla.* The shrubs were transplanted by hand in May 1993 with a 50 cm spacing, for a total of 100 plants for each subplot. *Eriophorum angustifolium* was used as a companion herbaceous plant. As for the shrubs, a total of 100 plants were transplanted in May 1993 in each subplot (Appendix 1: Plate 3). In all four plant communities tested, the mix of *Sphagnum* species used was the same, and consisted of equal number of *S. magellanicum, S. papillosum, S. flavicomans, S. fuscum* and *S. capillifolium.* In the first year, a density of 250 *Sphagnum* plants per square meter was used, which is roughly equivalent to collecting from a 1m^2 natural area and spreading it over 100 m^2 of post-harvest surface (i.e., what we call a density ratio of 1:100). The 10 cm long *Sphagnum* plants were collected by hand and were cut in 2 cm long fragments prior to being reintroduced in the field in the first two weeks of May (Appendix 1: Plate 4).

Finally, within each subplot, two 5 m x 5 m sub-subplots separated by a 5 m buffer zone were established for amendment trials. One of these sub-subplot was fertilized with phosphorus while the other was not. The total number of sub-subplots was thus 48, for a total surface of 1200 m^2 used for plant reintroduction in the first year. That year, a mistake was made for the phosphorus fertilization (a calculation error resulted in the dosage applied being much higher than intended) and these results will not be considered here. As well, the first year results (see below) suggested that the *Sphagnum* densities used were too low to result in a *Sphagnum* ground cover significant for restoration purposes. In consequence, in the spring of 1994, more *Sphagnum* fragments were added to one-half of each sub-subplot, at a density of 1:20 (1 m^2 collected from a natural area and spread over a 20 m^2 post-harvested surface). The species used in the second years were the same as in the first year with the exception of *S. papillosum* which was omitted from the mix. This half sub-subplot was refertilized in 1994 using 6 ppm of P liquid solution of triphosphate fertilizer which was prepared from grinded commercial granular fertilizer (0 - 46 - 0). Each half sub-subplot (12.5 m^2) received 5 to 6 L of fertilizer solution, for an application rate of ~0.025 kg/ha P.

In October 1993 and September 1994, *Sphagnum* recolonization success was estimated by counting the number of capitula in a series of 30 cm x 30 cm quadrats in each sub-subplot (Appendix 1: Plate 5). At the same time, the percentage of the peat surface covered by these capitula was estimated visually. The percentage of cover of shrubs, herbaceous plants and other mosses was also estimated. In 1993, 4 quadrats were counted in each of the sub-subplots without microtopography and 6 in those with microtopography. In 1994, the number of quadrats in the half sub-subplots was increased to 6 without and 9 with microtopography.

The data were analysed by calculating variance using the General Linear Model (GLM) procedure of SAS (Statistical Analysis System) (SAS Institute 1988). Once treatments (e.g., microtopography, plant communities or amendments) were shown significant at the 0.05 level, a Tukey test (Sokal and Rohlf, 1981) was used to locate which level or levels of a treatment was significantly different from the others. Capitula counts data were transformed (square-root of (x+0.5)) to reduce heterogeneity of variances, after being multiplied by 11 so that the number of capitula is now reported by meter square. Counts from the sub-subplots with microtopography were adjusted to account for the increased surface provided by the ridges and depressions. Percentage of cover data were analysed untransformed. Data for the 1993 reintroduction (two growing seasons) and the 1994 reintroduction (one growing season) were analyzed separately.

Results and discussion

Effect of microtopography

The results of both the 1993 and 1994 reintroductions showed that, on the entire plot (ridges and depressions pooled), the increase in microtopography had no significant impact on the average number of capitula per square meter (Table 2 and 3). For the 1994 reintroductions for examples, plots with an increased microtopography had on average 1521 capitula per square meter while plots with an even surface had, on average, 1490 capitula per square meter after one growing season.

Table 2. Analyses of variance to determine the effect of microtopography, plant community and fertilization on *Sphagnum* reestablishment on bare peat for the 1993 Maisonnette reintroductions (density ratio~1:100). Significant differences are marked in bold. Trends are underlined.

A) Number of capitula per m^{-2}, (square-root transformed) after one growing season.

Source	df	Type III SS	Mean Square	F value	Pr > F
Microtopography	1	1.33	1.33	0.75 [1]	0.4352 [1]
Error a	4	7.08	1.77		
Plant Community	3	34.9	11.63	3.69	**0.0431**
Microtop x Community	3	2.39	0.796	0.25	0.8579
Error b	12	37.8	3.15		

[1] Calculated using error a as the error term.

B) Number of capitula per m^{-2}, (square-root transformed) after two growing seasons.

Source	df	Type III SS	Mean Square	F value	Pr > F
Microtopography	1	0.405	0.40	0.01 [1]	0.9317 [1]
Error a	4	194.4	48.6		
<u>Plant Community</u>	3	76.8	25.6	3.12	<u>0.0660</u>
Microtop x Community	3	20.7	6.9	0.84	0.4971
Error b	12	98.3	8.2		

[1] Calculated using error a as the error term.

Table 3. Analysis of variance to determune the effect of microtopography, plant community and fertilization on *Sphagnum* reestablishment on bare peat at Maisonnette for the 1994 reintroductions (density ratio~1:20). Significant differences are marked in bold. Trends are underlined.

A) Number of capitula per m^{-2}, (square-root transformed) after one growing season.

Source	df	Type III SS	Mean Square	F value	Pr > F
Microtopography	1	2.0	2.0	0.00 [1]	0.9588 [1]
Error a	4	2646.7	661.68		
Plant Community	3	95.4	31.8	0.77 [2]	0.5310 [2]
Microtop x Community	3	116.0	38.7	0.94 [2]	0.4517 [2]
Error b	12	493.6	41.1		
Fertilization	1	338.4	338.4	12.5	**0.0028**
Fert x Microtopo	1	38.9	38.9	1.43	0.2485
Fert x Community	3	174.5	58.2	2.15	0.1344
Fert x Micro x Commun	3	81.1	27.0	1.0	0.4191
Error c	16	433.6	27.1		

[1] Calculated using error a as the error term.
[2] Calculated using error b as the error term

B*) Percentage of cover after one growing season.*

Source	df	Type III SS	Mean Square	F value	Pr > F
Microtopography	1	62.0	62.0	0.69 [1]	0.4519 [1]
Error a	4	357.9	89.5		
Plant Community	3	100.4	33.5	3.69 [2]	**0.0433** [2]
Microtop x Community	3	43.5	14.5	1.60 [2]	0.2418 [2]
Error b	12	109.0	9.09		
Fertilization	1	69.3	69.3	10.9	**0.0045**
Fert x Microtopo	1	0.06	0.06	0.01	0.9252
<u>Fert x Community</u>	3	59.4	19.8	3.11	<u>0.0557</u>
Fert x Micro x Commun	3	9.52	3.17	0.5	0.6879
Error c	16	101.7	6.36		

[1] Calculated using error a as the error term.
[2] Calculated using error b as the error term.

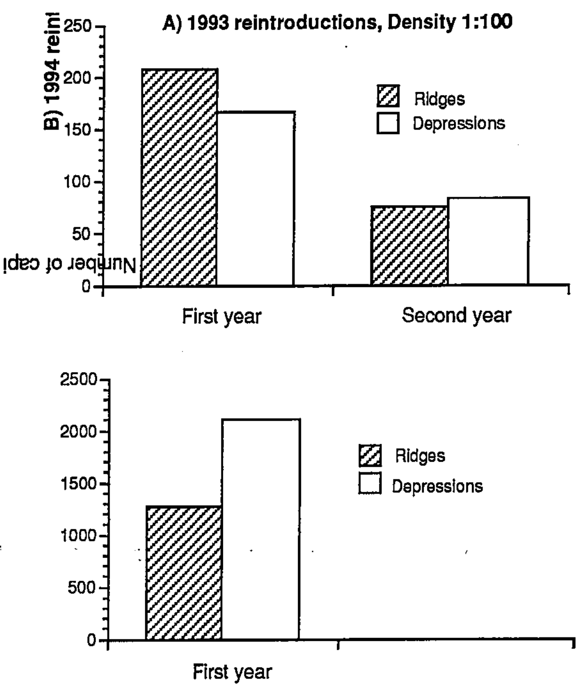

Figure 5. Comparison of *Sphagnum* recolonization between the the ridges and depressions in plots with increased microtopography at Maisonnette.

Within the plots with irregular microtopography, however, *Sphagnum* reestablishment success differed markedly between the ridges and depressions (Figure 5). For the 1993 reintroductions, the density of capitula found in depressions was lower than on the ridges after the first growing season (Figure 5A). In the spring of 1993 , *Sphagnum* diaspores in the depressions tended to be washed out of the plots or buried under fine peat with water movements in the open ended tracks. The number of capitula observed for the 1993 reintroductions was lower after two growing seasons (fall of 1994) than after one (fall 1993). However, Figure 5A suggests that the decrease was more important on the ridges than in the depressions.

For the 1994 reintroductions, water movement and diaspore losses in the depressions (tracks) were reduced by means of small hand-made peat dams located at the edges of the plots. Data for the 1994 reintroductions after one growing season generally show better *Sphagnum* reestablishment in the depressions in comparison to the the ridges (Figure 5B, Appendix 1: Plate 6).

These results suggest that there is a potential for faster moss reestablishment in sheltered depressions, provided that the type of microtopography used does not allow for too much water accumulation and movement that would cause diaspore to be lost or buried. Diaspore losses have also been observed in the spring on some flat areas that tended to collect runoff when the frozen ground still prevented water infiltration. Further work is needed to establish what type of surface modification will provide the best recolonization success in various field conditions.

Reintroduction success of companion species

The establishment of vascular plants and bryophytes used as companion species in this experiment showed variable success (Table 4). During the first growing season, ericaceous shrubs seemed to survive the transplantation well and were able to provide a certain amount of sheltering to the reintroduced diaspores. In the subsequent spring, however, a large number of transplants failed to grow leaves. The plants may have suffered severe frost burn due to a thin snow cover or been impacted by the very wet spring conditions. In the fall of the second season though, some new growth could be observed on many of the transplants that were naked in the spring (Appendix 1: Plate 7). Seedlings were also observed at the base of the plants, especially on the fertilized plots (the shrubs were transplanted just before flowering time in 1993 and many produced seeds) (Appendix 1: Plate 8). In consequence, despite a certain survival and propagation success that may be important in the long run, the ericaceous shrubs were probably not able to play a very important role as cover for *Sphagnum* diaspores in the second year (Figure 6A).

In contrast to what was observed with the shrubs, the transplantation of *Eriophorum angustifolium* was a clear success (Figure 6A). Plant propagation took place readily, with cover increasing from the beginning of the first to the end of the second growing season. *Eriophorum angustifolium* thrived especially well in the wetter habitat provided by the depressions, while in drier areas such as ridges propagation was slower. *E. angustifolium* also benefited greatly from the addition of phosphorus (Figure 6A, Appendix 1: Plate 9 and 10).

Table 4. Analyses of variance to determine the success of vascular plants and bryophytes (other than *Sphagnum*) reintroductions at Maisonnette. Different or no bryophytes and vascular plants were reintroduced in the different plant community treatments.

A) Percentage of cover by vascular plants after two growing seasons

Source	df	Type III SS	Mean Square	F value	Pr > F
Microtopography	1	38.7	38.7	1.71 [1]	0.2610 [1]
Error a	4	90.5	22.6		
Plant Community	**3**	322.9	107.6	8.24 [2]	**0.0030** [2]
Microtop x Community	3	65.7	21.9	1.68 [2]	0.2248 [2]
Error b	12	156.8	13.06		
Fertilization	1	88.8	88.8	22.63	**0.0002**
Fert x Microtopo	**1**	19.1	19.1	4.87	**0.0423**
Fert x Community	**3**	153.6	51.2	13.05	**0.0001**
Fert x Micro x Commun	**3**	39.3	13.1	3.34	**0.0459**
Error c	16	62.8	3.92		

[1] Calculated using error a as the error term.
[2] Calculated using error b as the error term.

B) Percentage of cover by bryophytes (except Sphagnum) after two growing seasons

Source	df	Type III SS	Mean Square	F value	Pr > F
Microtopography	1	1.10	1.10	0.00 [1]	0.9108 [1]
Error a	4	307.9	77.0		
Plant Community	3	50.05	16.69	0.72 [2]	0.5574 [2]
Microtop x Community	3	183.1	61.04	2.65 [2]	0.0968 [2]
Error b	12	276.9	23.08		
Fertilization	1	244.4	244.4	9.8	**0.0064**
Fert x Microtopo	1	11.2	11.2	0.45	0.5121
Fert x Community	3	35.6	11.9	0.48	0.7033
Fert x Micro x Commun	3	145.0	48.3	1.94	0.1641
Error c	16	398.8	24.3		

[1] Calculated using error a as the error term.
[2] Calculated using error b as the error term.

The establishment success of bryophytes varied between the two species tested. *Dicranum undulatum* establishment success was low. In contrast, *Polytrichum strictum*, which is often found on disturbed sites, seemed to multiply easily when reintroduced as fragments. Figure 6B, however, shows that, in general, the sole addition of phosphorus seemed to be sufficient to ensure a certain recolonization by bryophytes other than *Sphagnum* (Table 4B). Viable fragments and spores of other mosses may have either been present on the bare peat, or been reintroduced in association with the *Sphagnum* diaspores.

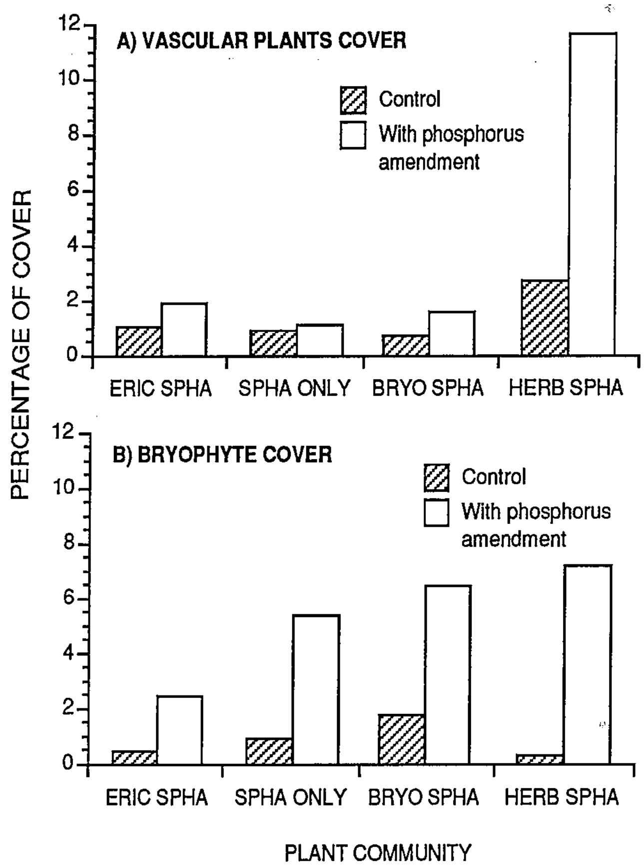

Figure 6. Reintroduction success of A) vascular plants and B) bryophytes, after two growing seasons at Maisonnette. Plants that were actively reintroduced in the different treatments were: ERIC SPHA: Ericaceous shrubs transplants and *Sphagnum* fragments; SPHA ONLY: *Sphagnum* fragments only; BRYO SPHA: *Dicranum undulatum* , *Polytrichum* strictum and *Sphagnum* fragments; HERB SPHA: *Eriophorum angustifiolium* transplants and *Sphagnum* fragments.

Effect of plant community and amendments on Sphagnum

Results for the low density 1993 reintroductions (density ratio 1:100, Figure 7) show a significant difference in *Sphagnum* reestablishment between plant communities after one season, and a similar trend in 1994 (Table 2). For both years, the highest number of *Sphagnum* capitula were observed in the plots where ericaceous shrubs were present. This results is consistent with the fact that, in the first season, the ericaceous shrubs were the only companion species able to provide a cover that would offer a certain protection to the diaspores.

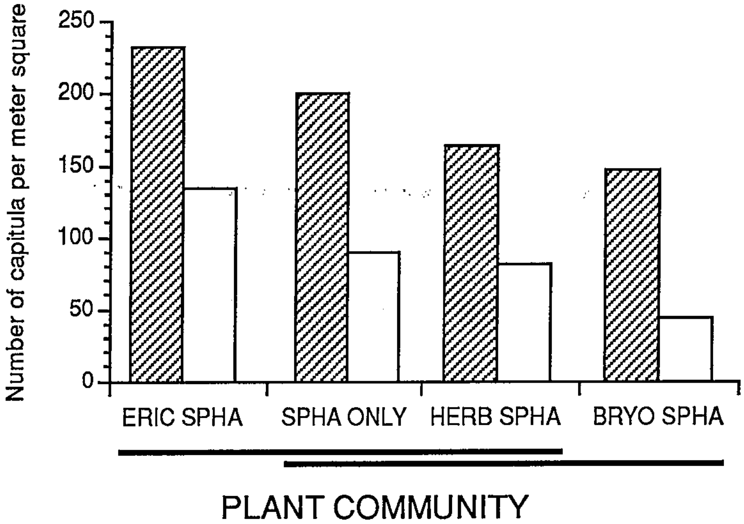

Figure 7. Effect of companion species on *Sphagnum* reestablishment at Maisonnette. The density ratio used in this experiment is approximately 1:100. ERIC SPHA: *Sphagnum* with ericaceous shrubs; SPHA ONLY: *Sphagnum* only; HERB SPHA: *Sphagnum* with herbaceous plants (*Eriophorum angustifiolium*); BRYO SPHA: *Sphagnum* with other bryophytes (*Dicranum undulatum and Polytrichum strictum*). Plant communities underlined together show no significant differences in the number of *Sphagnum* capitula observed after one and two seasons.

One can also notice that, the number of *Sphagnum* capitula declined for all plant communities from the end of the first to the end of the second growing season with the low density 1993 reintroductions (Figure 7). This suggest that either or both the density of material used in this experiment and the conditions provided in term of cover were insufficient to ensure a lasting *Sphagnum* establishment.

By comparing the results presented in Figure 7 (density ratio 1:100) and Figure 8A (density ratio 1:20) we can clearly see the effect of using a higher density of reintroduced diaspores (please note here the one order of magnitude change in scale between the two figures). The percentage of cover obtained when the reintroduction was done at a density of 1:20 were in the order of 5% to 10% after one growing season, depending on the treatments, while cover after one season at the 1:100 density were generally less than 1% after one season.

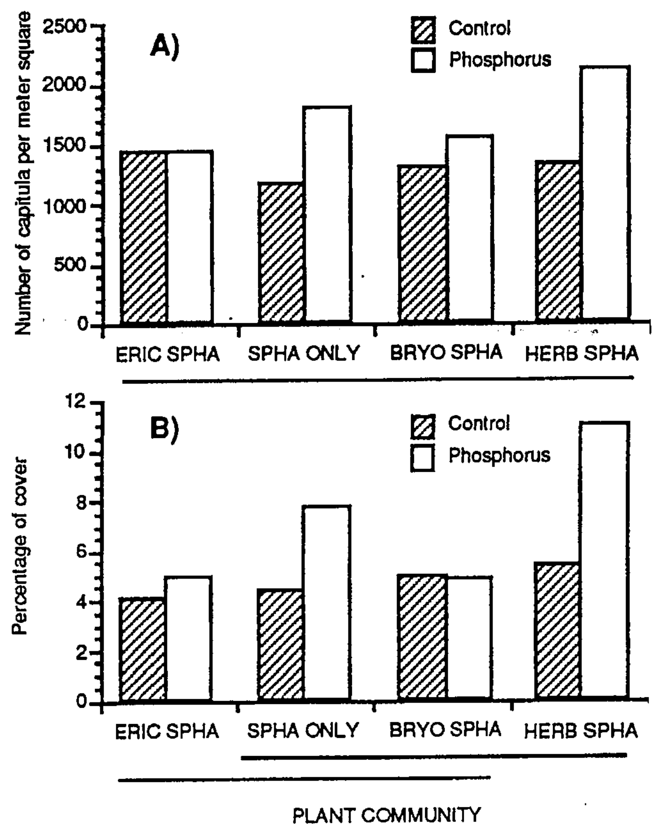

Figure 8. Effect of companion species and amendments on *Sphagnum* reestablishment at Maisonnette. The density ratio used in this experiment is 1:20. Plant community descriptions are as in Figure 7.

Both plant community and phosphorus amendment influenced *Sphagnum* reestablishment of diaspores reintroduced in 1994 (Figure 8). While no significant differences were observed in the number of *Sphagnum* capitula for the different plant communities, significant differences could be detected for *Sphagnum* cover (Table 3), which suggest that the capitula were bigger or healthier when associated with one plant community than the other. A greater number of *Sphagnum* capitula was observed in the fertilized plots than in the controls (Table 3). The interaction between plant community and amendments was also too close to be significant for *Sphagnum* cover (Table 3). Figure 8 show that the best recolonization success for the 1994 reintroductions was observed when diaspores were reintroduced on the *Eriophorum angustifolium* fertilized plots (Appendix 1: Plate 11). From Figure 8, we can also see that these plots were the ones where the tallest vascular plant cover was present in 1994, and thus where the greatest protection would be offered to the diaspores. The fertilized, *E. angustifolium* plots were also the only plots where the number of capitula and the percentage of *Sphagnum* cover observed was similar between ridges and depressions, which again suggest a positive sheltering effect provided by the herbaceous plants to the diaspores.

In conclusion, the 1994 results suggest that, while fertilization can improve *Sphagnum* moss reestablishment, its indirect effect of improving the growth of companion plant species, which in turn can ensure a better protection to the reestablished diaspores against the desiccating action of wind and solar radiation, could be as important for *Sphagnum*. However, in order to benefit from the cover of companion plant species, *Sphagnum* diaspores need to be reintroduced after the herbaceous plants or shrubs have a chance to establish, unless another type of cover is provided in the mean time. Herbaceous plants such as *Eriophorum angustifolium* seem best able to quickly recolonize a site (both by vegetative reproduction and by the production of numerous seeds), especially when some nutrient amendments are provided. Furthermore, *E. angustifolium* grows well in the wet depressions where *Sphagnum* reestablishment is also favoured. Ericaceous shrubs could potentially be interesting companion species on drier sites, and it will be interesting to follow the long term development of the seedlings observed in the fertilized plots in 1994. Finally, as the number of *Sphagnum* capitula decreased between the first and the second year for the 1:100 density ratio reintroductions, it will be important to follow over the next few years the fate of *Sphagnum* plants reintroduced at a 1:20 ratio in the presence or absence of well established companion plants.

Scaling up restoration practices: The use of top spit and mulches

Scaling up restoration practices to larger areas implies that larger quantities of diaspores are needed and that the collection of the plant material need to be mechanized. The use of top spit, i.e., the surface vegetation layer that is shredded mechanically on newly exploited peatlands, has been suggested as a source of diaspores for restoration purposes (Schmilewski 1988; Famous *et al.* 1993). This surface material contains fragments of bog Sphagna, other bryophytes and vascular plants species. The use of top spit would ensure that a varied bog plant community is reestablished on the restored site, provided of course that the species represented have the potential to reestablish vegetatively from fragments.

This experiment first tested the ability of top spit material to serve as a source of diaspores for plant reestablishment on a bare peat surface. Collection and reintroduction of top spit material was done at two different time of the year, i.e., in the fall of 1993 and in the spring of 1994 to see if diaspores reintroduced in the fall could survive the winter and if they would benefit from the extended growing season they would have in comparison to the diaspores reintroduced in the subsequent spring.

Secondly, the experiment compare recolonization success of shallow top spit (first 10 cm from the surface) versus the recolonization success of top spit collected from a 0-20 cm layer. When a new peatland surface is opened to peat mining operations, the surface vegetation is usually shredded mechanically to a depth of approximately 20-30 cm. Previous laboratory and field work (Campeau and Rochefort, *in press*), have shown that only the top 10 cm of the peat material contains enough viable diaspores to be used for restoration. A previous study has also demonstrated that a thick diaspore layer will hinder recolonization success of *Sphagnum* (Quinty and Rochefort, *in press*). We thus hypothesise that, for a given ratio of surface collected to surface restored, it would be preferable to collect a thin layer of material instead of a thicker one, thus reducing the total amount of material to be spread for an equivalent quantity of diaspores. Collecting a thin (10 cm) layer of top spit may however be more complicated machinery-wise and would be advisable only if the gain in terms of recolonization success is important.

Thirdly, this experiment examines if the presence of a straw mulch cover improves the recolonization success of top spit. Results from the Maisonnette experiment and from other experiments conducted in Québec (Bastien, unpublished data; Quinty and Rochefort, *in press*), suggest that providing a physical protection to the diaspores enhance recolonization success of *Sphagnum* and other bog species. Quinty and Rochefort (*in press*) suggested that straw mulch could be used as a cover when scaling-up peatland restoration practices as it was demonstrated to be efficient at protecting diaspores while being relatively inexpensive. The use of straw mulch may, however, present some difficulties in a coastal site exposed to very windy conditions throughout the year, and would be advisable only if the gain in terms of recolonization success is significant and if no other major problems (such as weed reintroduction) are encountered.

Methods

The top spit was collected in the fall of 1993 and in the spring 1994 from an area of the Lamèque peatland that will be opened to peat mining in a near future. A vegetation survey conducted prior to top spit collection showed the presence of a variety of common bog species at the site (*Ledum groenlandicum, Kalmia angustifolia, Kalmia polifolia, Chamaedaphne calyculata, Rhododendron canadense, Gaylussacia baccata, Rubus chamaemorus, Empetrum nigrum, Vaccinium angustifolium, Vaccinium oxycoccos, Sarracenia purpurea, Sphagnum fuscum, Sphagnum capillifolium, Sphagnum magellanicum, Sphagnum flavicomans, Dicranum undulatum* and some other sparse mosses and lichens) with *S. flavicomans* being the dominant moss species.

In October 1993, the top spit material was shredded to a depth of approximately 15 - 20 cm using a rotivator (Appendix 1: Plate 12). The top spit was bagged using shovels and forks and transported to the Maisonnette peatland where it was spread by hand on a 15 m X 25 m experimental plot located on a flat surface. The ratio of surface collected to surface restored was approximately 1:15. Half of this plot was covered with straw at a density of 1 bale per 50 m^2 in early June 1994.

The second top spit reintroduction took place in early June 1994. This time, surface material at Lamèque was shredded to a depth of approximately 15-20 cm on one area, and to a depth of approximately 8-10 cm on an adjacent area. As for the fall reintroduction, the material was bagged and transported to Maisonnette to be spread by hand at a density ratio of 1:15. Three groups (blocks) of four 6 m X 6 m plots were established throughout the experimental site. One of these groups was located in an area with irregular microtopography (see previous experiment) while the other two were located on flat surfaces. One of the flat- surface blocks was located in an area that becomes fairly dry during the summer while the other was located in a wetter zone. Within each block, two out of four plots received top spit material collected from the first 10 cm of the peat column. The other two received material collected from the 0-20 cm surface vegetation layer. Two plots per block (one from each depth of top spit) were covered with straw mulch at a density of 1 bale per 50 m^2.. Straw mulch was spread by hands the same day top spit was reintroduced. Large polypropylene rope nets were placed on top of the straw to prevent it from flying away with the wind (Appendix 1: Plate 13).

In September 1994, *Sphagnum* recolonization success was estimated by counting the number of capitula in 12-16 small quadrats (30 cm x 30 cm) in each subplot. At the same time, the percentage of the peat surface covered by capitula was estimated visually. The percentage of cover of shrubs, herbaceous plants and other mosses were also estimated. The data were analysed by determining the variance using the General Linear Model (GLM) procedure of SAS (Statistical Analysis System) (SAS Institute 1988). Capitula counts data were transformed ((square-root of (x+0.5)) prior to analysis to reduce heterogeneity of variances, after being multiplied by 11 so that the number of capitula is now reported by square meter. Percentage of cover data were analysed untransformed.

Results and discussion

Effect of a straw mulch protection

The use of straw mulch significantly increased the number of Sphagnum capitula and the percentage of Sphagnum cover observed (Table 5A and 5B, Figure 9, Appendix 1: Plate 14). Qualitative observations also show that Sphagnum plants under the straw cover look generally bigger and healthier than the one without protection against wind and solar desiccation (C. Ferland, pers. obs.). The use of straw mulch also improved the reestablishment of other bryophytes and of vascular plants (Table 5C and 5D, Figure 9). This suggests that the use of a protective cover is important for plant reestablishment even in a well-rewetted site, and could likely be even more critical at drier sites.

Table 5. Analyses of variance on the effect of depth at which top spit was collected and of the use of straw mulch on *Sphagnum* , vascular plants and other moss reestablishment on bare peat at Maisonnette (density ratio of the reintroduction~1:20). Significant differences are marked in bold. Trends are underlined.

A) Number of capitula per m^{-2}, (square-root transformed) after one growing season.

Source	df	Type III SS	Mean Square	F value	Pr > F
Bloc	2	15.5	7.75	1.54	0.2879
Depth of top spit	1	6.4	6.39	1.27	0.3024
Straw mulch cover	1	233.2	233.2	46.41	**0.0005**
Depth X Cover	1	16.3	16.3	3.24	0.1219
Error	6	30.1	5.02		

B) Percentage of cover by Sphagnum after one growing season.

Source	df	Type III SS	Mean Square	F value	Pr > F
Bloc	2	1.62	0.81	2.35	0.1764
Depth of top spit	1	0.43	0.43	1.23	0.3093
Straw mulch cover	1	16.2	16.21	46.95	**0.0005**
Depth X Cover	1	0.86	0.86	2.50	0.1649
Error	6	2.07	0.35		

C) Percentage of cover by bryophytes other than Sphagnum after one growing season.

Source	df	Type III SS	Mean Square	F value	Pr > F
Bloc	2	2.73	1.36	0.37	0.7053
Depth of top spit	1	1.99	1.99	0.54	0.4903
Straw mulch cover	1	23.7	23.7	6.43	**0.0443**
Depth X Cover	1	1.82	1.82	0.49	0.5083
Error	6	22.1	3.69		

D) Percentage of cover by vascular plants after one growing season.

Source	df	Type III SS	Mean Square	F value	Pr > F
Bloc	2	0.236	0.1182	3.61	0.0936
Depth of top spit	1	0.0023	0.0277	0.07	0.7993
Straw mulch cover	1	0.2995	0.2995	9.14	**0.0233**
Depth X Cover	1	0.0003	0.0003	0.01	0.9239
Error	6	0.1966	0.0328		

Effect of top spit depth of collection

No significant differences in the number of capitula, *Sphagnum* cover, other moss cover and vascular plant cover were found in the plots receiving material from a thicker top spit layer (0-20 cm from the surface) in comparison to plots top spit from a thinner vegetation layer (Table 5A and 5B). A somewhat lower number of *Sphagnum* capitula and a lower bryophyte cover were, however, observed in the straw mulch plots receiving the 0-20 cm top spit in comparison to the ones receiving the 0-10 cm top spit (Table 5A and 5B). Quinty and Rochefort (unpublished data) showed that the detrimental effect of a thick diaspore layer on moss reestablishment was more evident after two growing seasons than after only one. Longer term monitoring of the experiment is needed to determine if the depth to which top spit is collected can affect plant reestablishment in the long run, and to which extent. Such monitoring will also be essential to assess how the diversity and plant composition of the reintroduced vegetation will compare with those of the natural area where top spit was collected.

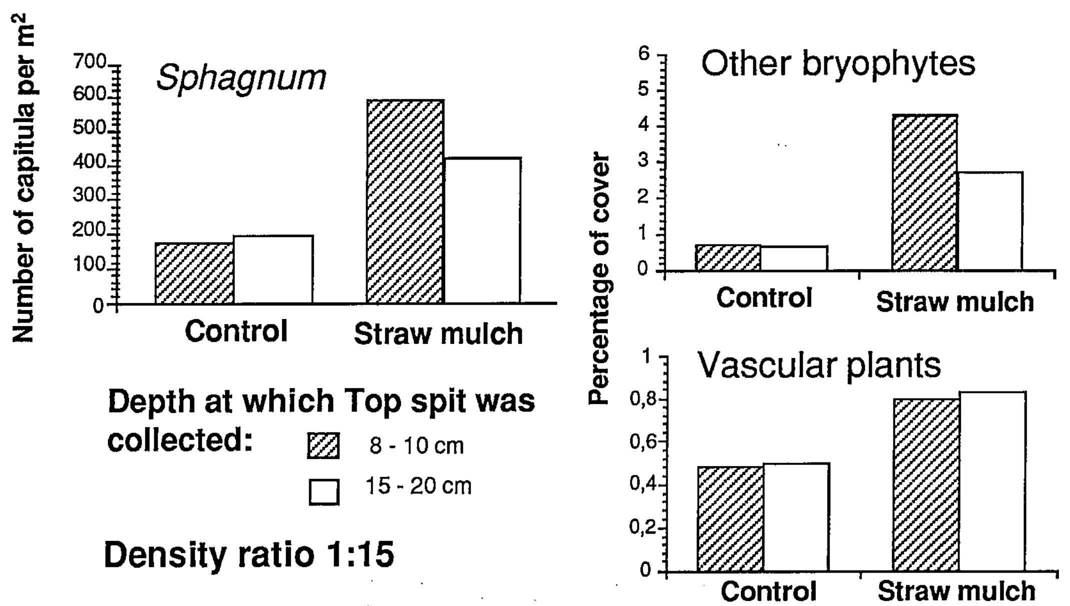

Figure 9. Effect of a straw mulch cover on plant reestablishment from top spit collected from a shallow and a thicker vegetation layer.

Timing of top spit reintroduction

Finally, for the plots where top spit was reintroduced in the fall of 1993, the average number of *Sphagnum* capitula and *Sphagnum* cover were 263 capitula per square meter and 3%, respectively, after one growing season for the plots where a straw mulch cover was provided, while it only reached 25 capitula per square meter and 0.4 % for plots without straw mulch. This data again confirm the importance of using a cover to protect the diaspores. These numbers are also lower than the corresponding values for the spring reintroduction. However, it is difficult to assess whether this difference is due to winter and early spring losses of diaspores or to the lack of protective cover in May.

SECTION B) EXPERIMENTS AT THE LAMÈQUE SITE

The 8 ha abandoned Lamèque site is part of a larger site harvested for horticultural peat by SunGro Horticulture Inc. on Ile Lamèque, N.B. Twelve 25 m x 200 m vacuum-harvested bays of the Lamèque peatland were abandoned approximately 12 to 15 years ago. All bays show a similar topography, which consists of a central dome (10-15 m wide), bordered on each side by a slope that leads into the old half-filled drainage ditch (Appendix 1: Plate 15). At the present time, both the drainage ditches and the slopes are well recolonized by peatland vegetation, while the central dome surface is bare peat. In the drainage ditches, *Sphagnum* mosses and vascular plants are present. On the slope, the vegetation is more or less developed, and is composed almost exclusively of vascular plants (*Empetrum nigrum*, *Chamaedaphne calyculata*, *Rubus chamaemorus*) and lichens.

Three hypotheses are suggested to explain the vegetation pattern observed. Firstly, low levels and large fluctuations of the water table could impede vegetation reestablishment on the domes as the drainage ditches of the Lamèque site were not blocked when peat mining operations stopped. Second, the peat surface of the central domes may be nutrient or metal enriched to a level that is detrimental or toxic to vegetation reestablishment. Finally, the winter snow cover on the central domes may be too thin to efficiently protect diaspores and seedlings against frost-burn.

Methods

Water wells were installed on the dome and in one for the ditches of four bays at Lamèque and were used to monitor water table level and fluctuations in 1994. The wells are made of 5 cm diameter PVC pipes. In the fall of 1993, eight water surface samples were collected from pits located near water wells. The last water sample was taken from a dome in September 1994 for metal analysis. Water samples were analysed at the Peat Research and Development Centre Inc., in Shippagan. Observations on the thickness of the snow cover at the site were made in February 1994 and January 1995.

In August 1993, approximately 2500 black spruce seedlings were transplanted with a 2 m spacing on the bays equipped with water wells. Survival and establishment of these transplants will be followed through time according to their position (dome, slope, etc.) on the bays.

Finally, bioassays were conducted from March 1994 to October 1994 at Laval University using *Ledum groenlandicum* seeds. These assays compare germination, survival, and growth rate between seeds placed on horticultural peat and on peat from residual peatlands. Peat from the central domes of Lamèque and from another abandoned peatland (Pigeon Hill) was included in this bioassay. The peat was mixed with sand in a proportion of 3:1. Only four seedlings were kept in each pot after germination. The pots were watered three times a week with a modified and diluted Rudolph nutrient solution (Campeau and Rochefort *in press*). They were also fertilized monthly with a 20-20-20 fertilizer. The glass greenhouse where the bioassays took place was subjected to natural light during the summer and to natural light supplemented with 400 W sodium lamps from September on. The photoperiod was adjusted to 14 hours starting in September 1994. Seedling length measurements were taken after 15 and 32 weeks.

Results and discussion

Water table level and fluctuations

As can be expected, the water table level was much lower and more variable under the central domes than in the ditches, especially at the end of the summer (Figure 10). The values observed under the domes were also lower than those observed at the Maisonnette experimental site for the same year (Figure 3). Schouwenaars (1988) suggest that a groundwater level of ca 40 cm below surface during the vegetative season would hinder vegetation reestablishment on bare peat surfaces.

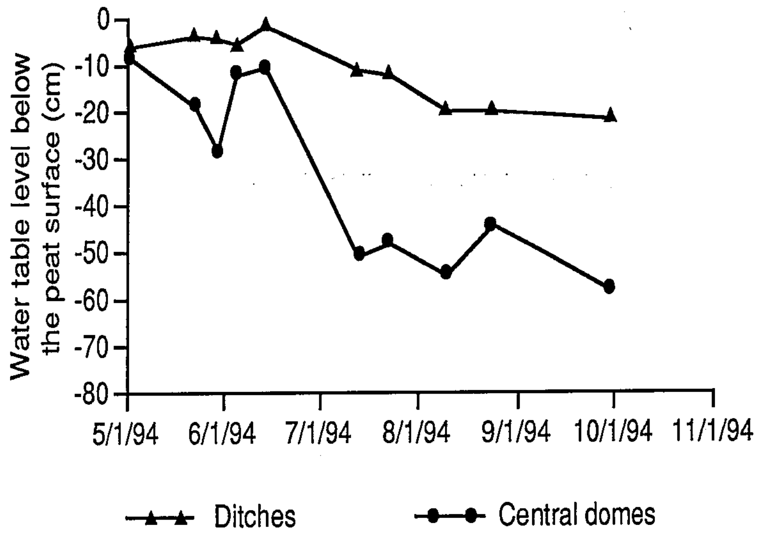

Figure 10. Water table level and fluctuations at the Lamèque experimental site in 1994. N=4 for the ditches and for the central domes.

Metal and nutrient toxicity

N and P values observed at Lamèque are similar to those recorded at Maisonnette and show no extra nutrient enrichment (Table 6 and Table 1), despite that the former site was abandoned much longer ago than the latter. Cations, Cl, SO_4 and conductivity values are, however, somewhat higher at Lamèque than at Maisonnette. Levels of certain metals (Cu and Pb) observed at Lamèque compare with values observed in natural bogs by other authors (Hemond 1980, Baxter *et al.* 1991). In contrast, Fe and Mn show higher values at Lamèque than in natural bogs (Baxter *et al.* 1991, Wieder *et al.* 1984).

Winter damage effect

The February 1994 snow survey showed that, while the ditches were under a snow cover 35 cm to 60 cm deep, domes had very little accumulation of snow (0 cm to 20 cm). In general, the limit of the snow pack corresponded roughly to the limit of the actual vegetation. In January 1995, however, both the domes and ditches were generally well covered with snow (J.Y. Daigle, pers. comm.). So it could be that the low winter precipitation years are too harsh for the vegetation that may have established in years with good snow cover, and that a dieback then occurs. This hypothesis seems to be confirmed by the presence of dead *Eriophorum* sp. tussocks on some domes (L. Rochefort, pers. obs.)

Table 6. Water chemistry values for vacuum-harvested bays at Lamèque that were abandoned 12-15 years ago. Samples for pH, conductivity, cations and N and P were taken in the fall of 1993 (n=4 for domes and for ditches). One sample was taken in September 1994 and was analysed for metals. Units: Conductivity: µS at 20°C, corrected for pH according to Sjörs 1950. Others: mg/L

	Central Domes	Ditches
pH	3.5 - 4.2	3.7 - 3.9
Conductivity	33 - 215	58 - 144
Cations:		
Ca	0.9 - 4.2	1.2 - 1.8
Mg	1.6 - 8.9	2.1 - 2.8
K	0.2 - 1.0	0.07 - 1.09
Na	4.5 - 20.8	7.8 - 13.4
Cl	11 - 68	1 - 4
SO_4	0.9 - 13.9	17 - 36
NH_4-N	< 0.28 - 2.66	< 0.28 - 3.04
NO_3-N	< 0.005	< 0.005
P total	< 0.01 - 0.012	< 0.01
Metals		
Al	< 0.1	
Cu	< 0.006	
Fe	1.14	
Mn	2.44	
Pb	< 0.03	
Cd	< 0.009	
Zn	0.015	
Ni	< 0.01	
Cr	< 0.03	

Qualitative observations made in the fall of 1994 suggest that black spruce seedlings planted in 1993 survived better on the slope than on the central domes (C. Ferland, pers. obs.). Bioassays with *Ledum groenlandicum* showed a similar germination success and growth rate of seedlings on post-harvested site peat than on horticultural peat.

All these results suggest that physical conditions (i.e. the absence of snow cover in certain years and the low water table under the central domes), more than chemical conditions, limit vegetation reestablishment at Lamèque.

SECTION C) FIELD AND GREENHOUSE WORK ON VASCULAR PLANT PROPAGATION

Vascular plants are an important part of peatland vegetation and are also important in restoration as they can provide a physical protection to the *Sphagnum* diaspores and, eventually, to the newly established *Sphagnum* carpet. The use of top spit (which includes fragments of mosses and vascular plants) seems so far one of the best approachs to initiate vegetation reestablishment on bare peat surfaces. However, it is likely that not all the species present in a natural bog will reestablish well from top spit. Likewise, we may want, in some cases, to favour a faster rate of reestablishment for certain species (the ones that can provide an adequate cover to the diaspores for example or in cases where the peat substrate needs to be rapidly stabilized). In this view, it is important to develop propagation techniques for characteristic species of peatland vascular plants. These techniques could include germination from seeds, transplantation, as well as propagation by cuttings.

In the first experiment conducted at Maisonnette, transplantation of plants from a natural area was used to reintroduced *Eriophorum angustifolium* and ericaceous shrubs on the bare peat surface. For *E. angustifolium*, this method was very effective at reestablishing a herbaceous plant cover, especially when the plots were fertilized with phosphorus. In contrast, the transplantation of shrubs had a mitigated success.

Germination trials were conducted in the laboratory with the following species: *Ledum groenlandicum, Kalmia angustifolia, Chamaedaphne calyculata, Eriophorum angustifolium* and *Scirpus cespitosus*. After 4 weeks, germination success was in the order of 85% for *E. angustifolium*, 60% for *L. groenlandicum*, 35% for *K. angustifolia*, 10% for *C. calyculata* and 2% for *S. cespitosus*. Low germination success of the last two species could possibly be improved with scarification (a treatment used to break the hardened external envelope of the seed) or with stratification (a cold treatment to remove seed dormancy)(Jaynes 1971).

Ledum groenlandicum, Kalmia angustifolia, and *Chamaedaphne calyculata* were also seeded on bare peat at Maisonnette in the spring of 1993. September 1994 observations showed that the seeds of

L. groenlandicum and *K. angustifolia* had germinated but were still at a very early stage of development (cotyledon stage). Seeds of *C. calyculata* showed little germination. In contrast, on the plots where flowering ericaceous shrubs were reintroduced in the spring of 1993, especially the fertilized ones, numerous 3-4 cm high seedlings were observed.

Little information is available on the propagation by cuttings of peatland ericaceous shrubs. In the fall of 1993, a greenhouse experiment was begun to determine which techniques currently used for the propagation of other types of shrubs could be effectively used to propagate wild Ericacea by cuttings (Ferland and Rochefort 1994). The propagation techniques used are from Dirr and Heuser (1987). Seven species of ericaceous shrubs were used for this experiment (*Ledum groenlandicum, Rhododendron canadense, Kalmia angustifolia, Kalmia polifolia, Andromeda glaucophylla, Chamaedaphne calyculata* and *Gaylussacia baccata*). The trials were conducted in collaboration with M. Antoine Boivin, teacher of horticulture at the Polyvalente de Charlesbourg highschool, and the students of his class. After six months, cuttings for most species generally failed to develop roots. The two species that did best were *L. groenlandicum* and *A. glaucophylla* with a still very low 10% success rate. Several reasons can explain this poor rooting success. First, the shrubs were collected in the fall, at a period when they normally prepare for winter dormancy. For certain species at least, spring or summer propagation by cuttings might work better. Secondly, a failure of the heating system of the greenhouse over the Christmas period in 1993 may have had an important negative impact on the cuttings. The cuttings that successfully developed roots were transplanted in the field in the spring of 1994. Their establishment success was excellent.

The results obtained so far suggest that the use of transplants and seeds are promising approaches for the propagation of ericaceous shrubs. More research is however needed to determine if ericaceous shrubs can be successfully propagated by cuttings. Other propagation methods, such as the use of rhizomes, need also to be tested. Further experiments are also needed to determine what are the optimal conditions for the establishment and growth of transplants and seedlings. The effect of phosphorus amendments and physical protections are suggested as the first variables to test.

SECTION D) RECOMMENDATIONS FOR FUTURE WORK

LONG-TERM MONITORING OF THE CURRENT STUDIES

As discussed in Section A, longer-term monitoring of the two experiments conducted at Maisonnette is needed to assess the effect of microtopography, early phosphorus amendment, plant cover, straw mulch cover and top spit use on reestablishment success of peatland vegetation. Longer-term monitoring of the snow cover, water table fluctuations, and black spruce seedlings survival and growth at Lamèque would also be important and could be accomplished concurrently to the work done at Maisonnette with a minimum of effort.

1) Long-term monitoring at Maisonnette would consist of fall vegetation measurements that would include the estimation of *Sphagnum*, other mosses and vascular plant species cover according to the methods used in 1993 and 1994. In addition, an enumeration of the species present and their relative abundance after two and three years should be done for the plots where top spit was reintroduced to compare with the vegetation present initially at the top spit collection site. This information will help assessing if the use of top spit allows for the reestablishment of a typical peatland community.

2) Water table readings should also be taken regularly (once every 2 weeks for example) to document year to year variability at the two sites.

3) A survey should also be conducted each year at the Lamèque top spit collection site (unless the area is opened for peat-harvesting) to document vegetation reestablishment.

4) Yearly monitoring of the black spruce seedling survival and growth at Lamèque and of the winter snow cover would also be important.

We suggest that, while the regular summer and winter monitoring work could be performed by locally available manpower, the annual fall vegetation surveys should be conducted by a research professional from Laval University who would also be in charge of analysing the data and writing a succinct yearly report. The fall survey (including the data to be taken at Lamèque) should take approximately 5 days for 2 persons (the research professional from Laval plus one local assistant). Two more days need to be added for transportation from Laval to Maisonnette, and the cost of transportation, lodging and food for one person need to be accounted for. Data compilation, analysis and report writing would require 10 days of work for the research professional in the first 2 years and 15 days in the third year for the final report.

POSSIBILITIES FOR FURTHER STUDIES

The Maisonnette site, with its network of boardwalks and water wells, its very wet spring and fall conditions, and its mosaic of field conditions (from very dry areas to wetter zones) is very well suited for small-scale restoration experiments where no machinery work is involved. These experiments could address further questions on the role of companion species and phosphorus amendments in peatland restoration. Propagation methods for peatland vascular plant species could also be developed and tested at Maisonnette. In the near future, we hope to recruit a graduate student to pursue experimental work at Maisonnette, possibly through a University Laval fellowship program for French students from outside the Province of Québec.

The Lamèque site is particularly well-suited for larger-scale experiments on restoration practices. The site is drier than Maisonnette and allows easy access for the machinery. Non-exploited areas in the same peatland can be used as sources of diaspores, and are readily accessible through existing roads. Moreover, the site topography (long bays with a slightly elevated centre that are bordered by ditches) is typical of abandoned vacuum-harvested sites that will need to be restored in the future. Lamèque also provides us with an opportunity to compare natural recolonization of an abandoned site with the recolonization observed when plants are actively reintroduced. Further work at Lamèque should also address the question of how to improve physical conditions at the site (snow cover and water table), while documenting the effect of such improvement on the progression of the actual vegetation. A research proposal for larger-scale restoration experiments to be conducted at Lamèque is currently in preparation.

SECTION E) RECOMMENDATIONS FOR RESTORATION PRACTICES

From the results obtained so far, we can suggest some guidelines for peatland restoration. These guidelines are derived from the results obtained in New Brunswick and from results of similar restoration experiments conducted in Québec by members of the team.

1) Drainage ditches of an abandoned site need to be blocked is order to allow a raise in the water table level and to help stabilize water table fluctuations. The reestablishment of a high water table alone is not enough, however, to result in a rapid recolonization of the site. To attain this objective, peatland vegetation needs to be actively reintroduced on the bare peat surface.

2) When appropriate conditions are provided, the use of fragments can lead to bare peat recolonization by *Sphagnum* species. The mechanically shredded surface layer of the peat column (top spit) can be used as a source of such fragments. In surplus, top spit contains seeds and fragments of other plants, ensuring that the vegetation reintroduced on the restored site will be an assemblage of typical bog species. In consequence, peat mining operations should be designed so that a portion or portions of a given exploited bog will be left untouched to ensure the availability of diaspores for the restoration of abandoned bays.

3) The ratio between the surface collected at the natural site and the surface covered at the post-harvest site should be in the order of 1:15 to 1:20 to ensure adequate recolonization of the bare peat with minimal damages to the natural site.

4) A light phosphorus amendment may help the reestablishment of plants reintroduced on bare peat. Further work is needed to determine appropriate dosage, mode of application and the long-term effect of this technique.

5) Some type of physical protection is needed to help palliate unfavourable microclimatic conditions (desiccation, wind erosion) experienced by the plant fragments reintroduced on bare peat. Increasing surface roughness on post-harvested fields can provide wetter, sheltered sites where diaspore establishment is favoured. The presence of low shrubs and herbaceous plants could also help *Sphagnum* moss reestablishment by providing shelters, but this approach implies that the vascular plants need to be well-established prior to fragment reintroduction. Finally, an artificial cover such as a straw mulch can be used successfully to protect diaspores.

Longer-term work is needed to validate some of these preliminary guidelines, to better assess the relative success and the drawbacks of the methods suggested, and to propose refinements. In any case, it is likely that restoration practices will be partly site-specific, as hydrological, topographical and vegetation conditions vary from one post-harvested surface to another.

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APPENDIX 1: PLATES

Plate 1. Example of a plot with irregular microtopography at the Maisonnette experimental site. The alternating ridges and depressions were made in the spring of 1993 by the passage of an excavator when the ground was still partly frozen.

Plate 2. Example of a plot with a smooth surface, as usually found in abandoned vacuum-harvested fields.

Plate 3. View of one of the plots where *Eriophorum angustifolium* and *Sphagnum* fragments (density ratio 1:100) were reintroduced in the spring of 1993. The picture was taken in the summer of 1993.

Plate 4. The *Sphagnum* fragments (diaspores) were spread by hand on the Maisonnette experimental plots (spring 1993).

Plate 5. The number of capitula present as well as the percentage of cover of *Sphagnum,* other mosses and vascular plants were estimated in a series of 30 cm x 30 cm quadrats for both experiments conducted at Maisonnette.

Plate 6. One growing season reestablishment of *Sphagnum* mosses, other bryophytes and vascular plant reestablishment in the depression of a plot with increased microtopography. *Sphagnum* fragments were reintroduced in the spring of 1994 at a density ratio of 1:20.

Plate 7. View of a fertilized ericaceous shrub plot with Sphagnum fragments (density ratio 1:20 in the front half of the plot, density ratio 1:100 on the other half). The shrubs were transplanted in May 1993. The picture was taken in September 1994.

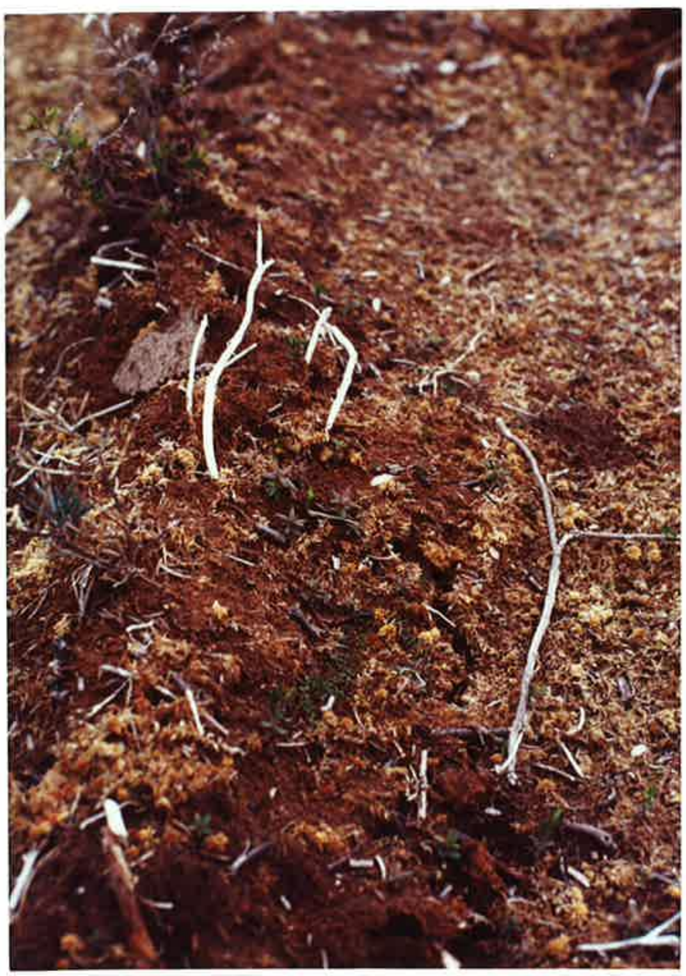

Plate 8. Seedlings observed on a fertilized plot where flowering ericaceous shrubs where reintroduced in the spring of 1993. The picture was taken in September 1994.

Plate 9. View of an unfertilized *Eriophorum angustifolium* plot with *Sphagnum* fragments (density ratio 1:20). The picture was taken in September 1994.

Plate 10. View of a fertilized *Eriophorum angustifolium* plot with *Sphagnum* fragments (density ratio 1:20). The picture was taken in September 1994. Comparison with plate 9 demonstrates the positive effect phosphorus addition had on *E. angustifolium* growth.

Plate 11. *Sphagnum* moss reestablishment under a cover of *Eriophorum angustifolium*. Sphagnum fragments were reintroduced at a density ratio of 1:20 in the spring of 1994. This picture of a depression in a fertilized *Eriophorum angustifolium* plot was taken in September 1994.

Plate 12. Collection of top spit from the Lamèque peatland in early June 1994. The surface vegetation of the peatland was shredded using a rotivator.

Plate 13. View of the Maisonnette plots where the reestablishment potential of peatland vegetation from top spit and the effect of a straw mulch cover are assessed. The picture was taken at the onset of the experiment in early June 1994.

Plate 14. One season *Sphagnum* reestablishment from top spit under a protective straw mulch cover. The picture was taken in September 1994.

Plate 15. View of a vacuum-harvested bay of the Lamèque peatland that was abandoned 12-15 years ago. While the central portion of the bay remains devoid of vegetation, the drainage ditches and slopes are recolonized by typical peatland species.