The farming of sphagnum and of aquatic and semi-aquatic plants for peatland restoration

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Summary
The cultivation of *Sphagnum* and aquatic and semi-aquatics plants in shallow basins could allow the rapid production of large quantities of material necessary for peatlands restoration. In 2004 and 2006, basins were established in old trenches of a peatland which had been exploited by the manual block-cut method in eastern Canada (New-Brunswick) in the 1940s-1960s. The objective of the farming of *Sphagnum* is to determine how environmental and biological parameters (such as fertilisation treatment and the presence of vascular plants) may promote the rapid development of a *Sphagnum* biomass. For the cultivation of aquatic and semi-aquatics plants, different approaches are being tested in wet peat-based basins.

Key index words: Peatland, Restoration, *Sphagnum* cultivation, Pools

Introduction
Different approaches in Europe (Vasander *et al.,* 2003) and North America (Rochefort *et al.,* 2003*)* have been developed to restore peatlands abandoned after peat extraction. Some of these approaches require large quantities of plant reintroduction material. However, the accessibility of *Sphagnum*, aquatic and semi-aquatics plants can be limited, as these types of plant are usually not produced commercially. Also supply of *Sphagnum* mosses can be difficult in regions where natural peatlands are scarce. Thus, the culture of these plants in shallow basins represents an interesting option by ensuring the availability of plant material.

The rapid production of large quantities of *Sphagnum* could provide the plant material necessary for peatlands restoration. In addition, it could provide a highly fibric peat moss material as an additive for horticultural substrates. It has been proposed that *Sphagnum* fibre can replace perlite in brown *Sphagnum* peat based substrates and improve low quality peat substrates. Nevertheless, little information exists about the potential to cultivate *Sphagnum* at large scale on a renewable basis in abandoned cutover peatland. Some experimental trials on abandoned peatlands showed that digging shallow basins promoted the *Sphagnum* establishment by increasing water availability (Campeau *et al.,* 2004) and limiting climatic variations. In addition, species of the Acutifolia section (particularly *Sphagnum fuscum* and *Sphagnum rubellum*) are usually used for restoration project because they show a rapid establishment rate on bare peat (Chirino *et al,.* 2006).

The cultivation of aquatic and semi-aquatic plants would provide a nice diversity of material for the restoration of pools. In natural peatlands, pools increase biodiversity. Peatland pools are a refuge for insects, birds, amphibians and host specific plant communities. In Canadian restored peatlands where artificial pools were created, Fontaine *et al.,* (2007) showed that species associated with natural pools were still absent six years after restoration when left to be spontaneously recolonised. Consequently, introduction of plants specific to pools in restored sites is necessary. As the extent of plant communities around natural pools is limited, we need alternative sources of plant material. The cultivation of species such as yellow pond lily, some Cyperaceae and aquatic mosses in basins would produce a range of plants that could be reestablished on the margins of restored pools.

To answer these needs, the Peatland Ecology Research Group and its partners in the peat industry have set up an experimental station dedicated to the culture of *Sphagnum*, aquatic and semi-aquatic plants. Currently, two experiments about *Sphagnum* culture are underway. The purpose of the first experiment was to study *Sphagnum* establishment and its biomass accumulation in relation with fertilisation treatment, the presence of vascular plants and water table fluctuations. The purpose of the second experiment is to cultivate *Sphagnum* on a larger scale. In this paper, we present the results obtained after 3 years and 1 year of *Sphagnum* culture and show the different approaches used in the basins to cultivate aquatic and semi-aquatic plants common to North American mire pools.

Materials and Method

Study site

Basins were established in old trenches of a peatland which had been exploited by the manual block-cut method in eastern Canada (47°40' N; 64°43' W). The exceptional hydrological conditions of the peatland found on this site make an excellent location for the establishment of a research station. Since the end of the peat extraction activities in the 1970's, *Sphagnum* had spontaneously colonised the trenches and a new peat moss carpet reaching nearly 30 cm in height had been observed. Trenches are about one kilometre long, 15 to 20 m wide and are separated by baulks of 0.3 and 1.5 m high. Old drainage ditches were located each side of trenches. Total precipitation in this area is around 1102 mm per year with 354 cm falling as snow. Total rainfall during the growing season (May to October) was 521 mm. Mean temperature in July is around 19°C in July and -10°C in January.

Experiment 1: Factors controlling Sphagnum growth

The purpose of the first experiment started in spring 2004 was to study the processes of *Sphagnum* biomass accumulation and the environmental factors supporting a faster *Sphagnum* production. The surface of trenches were cleared and refreshed in order to prepare basins. Eight basins (5 X 15 m) were installed in the trenches with an excavator. Techniques to reintroduce *Sphagnum* in basins are similar to those proposed by Quinty and Rochefort (2003). The surface of basins was levelled manually, with an agricultural roller. The degree of the decomposition of the peat varied between H2 and H4 (according to the Von Post scale). In six basins, *Sphagnum* was introduced manually and was covered with straw mulch. Half of each basin was fertilised in spring 2005 (150 kg/ha of phosphate rock). The comparison between the fertilised and unfertilised zones will allow understanding to which extend the fertilisation is necessary to develop rapidly a *Sphagnum* carpet. Two other basins without *Sphagnum* reintroduction were also set up (named control basins). The aim of control basins is to quantify the spontaneous colonization of *Sphagnum* on bare peat surface as had occurred after the end of the block cutting extraction.

Experiment 2: Cultivate Sphagnum at a large scale

The purpose of the second experiment is to cultivate *Sphagnum* on a larger scale. Three basins of 200 X 15 m were installed in the former trenches in spring 2006. The establishment of this experiment required a series of mechanized steps and the use of different types of machineries: Step 1) Trees had to be felled and the surface of the basins was refreshed, cleaned and flattened using an excavator and a tractor with a rototiller. The deeply frozen peat layer has allowed the passage of heavy machineries in the basins. 2) *Sphagnum* fragments (diaspores) were collected from a donor site located on the experimental station 3) *Sphagnum* mosses were reintroduced in the basins. They were seeded in basins using a manure spreader equipped with a lateral discharge system. No fertilisation treatment was applied. 4) A straw mulch was applied to cover the *Sphagnum* diaspores with the aid of a lateral straw spreader. The manure and straw spreaders have placed material in basins by circulating on the baulks only, leaving the experimental parcels untouched. In experiment 1 and 2, dams were installed to control the water table level. The water table level was about -10 ± 8 cm below the soil surface in both experiments during the summer, except during snow melt or intense rainfall events where the water level was above ground. Moreover, *Sphagnum* was reintroduced with a ratio of 1:12. Around 3000 kg/ha of straw was also applied on the *Sphagnum*. Straw mulch creates an air layer that induces cooler daytime temperature, higher relative humidity around plant fragments and maintains a high water level. In the text, we refer to a small scale factor experiment set up in 2004 versus the large scale experiment established in 2006.

Measurements

Plant cover

The percentage of plant cover was evaluated in both the small scale factor experiment and the large scale experiment. For the small scale factor experiment, the vegetation surveys were done in autumn 2005, 2006 and 2007. Surveys were done only in autumn 2007 for the large scale experiment. We noted the cover of plant groups, such as *Sphagnum*, other bryophytes, mushrooms and vascular plants in quadrats along transects. For both experiments, each transect was approximately 15 m long. Six transects per basin were set for the small scale factor experiment. At each meter along transects, we estimated the species cover using 25 x 25 quadrats (576 quadrats in total). For large scale experiment, 16 transects by basin were installed and quadrats were positioned every 1.5 m (336 quadrats in total). In particular years, it was not possible to perform the survey in all quadrats depending on hydrologic conditions, mainly when the water level was above ground.

Plant biomass

Plant biomass was harvested in autumn 2007. For the two experiments, plant biomass was collected in 20 quadrats of 25 x 25 cm distributed randomly among the basins. In laboratory, species were divided by functional groups, dried at 60 °C and weighted. These functional groups are: *Sphagnum*, other bryophytes, ericaceous shrubs and other vascular plants. All averages presented in this proceeding are accompanied by their standard error.

Results

Plant cover

In 2007, bryophytes (*Sphagnum* and other bryophytes compiled together) covered about 90 % of basins in the small scale factor experiment (Fig 1). The fertilisation treatments had no effect on *Sphagnum* cover but promoted the establishment of other bryophytes, especially *Polytrichum strictum* and *Dicranella cerviculata*. The most dominant *Sphagnum* species were *Sphagnum* belonging to the section Acutifolia (53 %; *Sphagnum rubellum*, *Sphagnum flavicomans* and *Sphagnum fuscum*. *Sphagnum magellanicum* (30 % ±10) and *Sphagnum* from section Cuspidata (5 % ± 5) were also present.

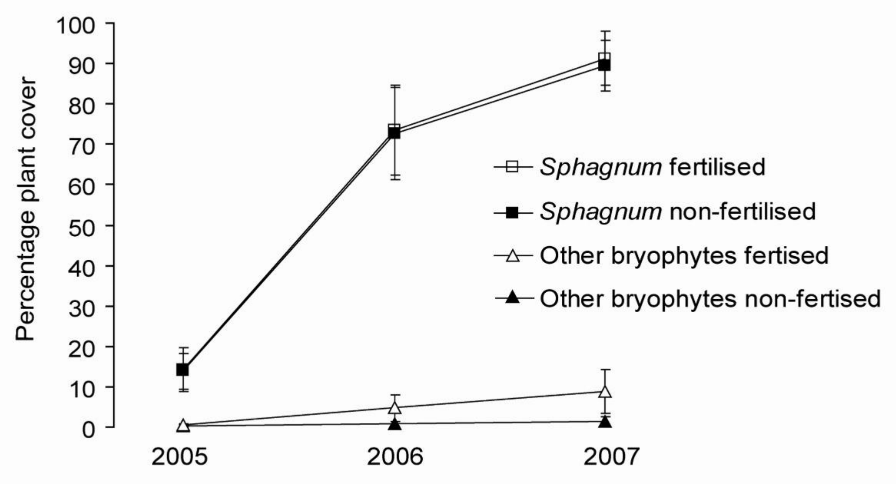

Figure 1. Percentage covers of Sphagnum and other bryophytes in six basins of the *Sphagnum* cultivation experimental station (means ± SE; small scale factor experiment). The basins were installed in spring 2004. Fertilised treatment was applied on half of each basin in spring 2005.

Control basins were colonised spontaneously by plants. The cover of other bryophytes in 2007 reached 42 % ± 25 with fertilisation treatment compared to 2 % ± 5 without fertilisation. Similarly, *Sphagnum* establishment was higher with fertilisation (12 % ± 9) than without (5 % ± 4).The high percentage of other bryophytes in fertilised zones is associated with the rapid establishment of *Dicanella cerviculata.*

The *Sphagnum* establishment rate between the two experiments was similar. Although these experiments were not started at the same time (in 2004 for small scale factor experiment and in 2006 for large scale experiment), plant coverage estimated after one year was similar. *Sphagnum* cover was around 14 % ± 5 in the small scale factor experiment and around 12 % ± 13 in the larger scale experiment. Note that standard error associated with the means is twice as high for the larger scale experiment.

Vascular plants also colonised the basins of the *Sphagnum* experimental station. The most common species were *Chamedaphnea calyculata*, *Vaccinium oxycoccos*, *Drosera rotundifolia*, *Eriophorium angustifolium* and *Eriophorium vaginatum, var. spissum*. These species occupied a small cover proportion (less than 6%) but were frequently observed in both experiments. No link has been observed so far between fertilisation treatment and the abundance of vascular plants.

Plant biomass

The biomass values demonstrate a rapid development of a *Sphagnum* carpet in the two experiments (Table 1). The fertilisation had no effect on the biomass accumulation, except in the case of other bryophytes. The total weight obtained for 2004-2007 for the small scale factor experiment has been divided by 3 to get an average weight for one year (2007). In term of peat moss biomass, accumulation ranged from 34 to 101 g/m^2 in the first year of establishment.

Table 1. Weight dry biomass of the principal functional groups presents in the Sphagnum culture experiments (g/m2; means ± SE).

	Biomass accumulated over 3 years (2004-2007)		Biomass accumulated over 1 year (2007 only)		
	Small scale factor experiment		Small scale factor experiment		Large scale experiment
	No fertilisation	With fertilisation	No fertilisation	With fertilisation	No fertilisation
Sphagnum	303 (12)	287 (30)	101	96	34 (17)
Other bryophytes	1 (0,7)	24 (17)	0,3	8	0,8 (0,2)
Ericaceous	38 (28)	20 (3)	13	7	12 (3)
Other vascular plants	8 (4)	7 (4)	3	2	3 (2)

Discussion/Conclusion

Plant cover

Sphagnum establishment

Sphagnum colonised quickly the surface of the basins. According to Chirino *et al.,* (2006) *Sphagnum* cover after reintroduction on bare peat varied between 20 and 50 % comparatively to 90 % in *Sphagnum* basins. Environmental conditions in the basins and species assemblage explained this rapid establishment. First, *Sphagnum* growth is not limited by water availability because the water table is close to the soil surface. In addition, the presence of baulks on each side of trenches creates a humid microclimate and limits peat erosion by wind. The straw mulch also increased humidity around *Sphagnum* fragments. Secondly, the *Sphagnum* mix introduced in basins was mostly composed by *Sphagnum* species with the highest establishment potential in order to create a moss carpet. These species, *Sphagnum rubellum* and *Sphagnum fuscum,* are also the species presenting the highest cover on established surfaces.

Fertilisation treatment did not promote *Sphagnum* establishment in basins. In restored peatlands, it was demonstrated that phosphorus fertilisation increases the development and spreading of mosses, such as *Polytrichum strictum* (Groeneveld *et al.,* 2007). In *Sphagnum* basins, phosphorus fertilisation is not a key factor because *Sphagnum* establishment is not promoted by the presence of acrocarpous mosses. In contrast, fertilisation treatment increased *Sphagnum* colonisation in control basins. The rapid establishment of mosses reduces peat instability caused by water movement on bare peat surface and frost heaving. Frost heaving is associated with freeze and thaw cycle action on the peat surface and consequently loosens the first centimetres of peat (Quinty, and Rochefort 2003).

Vascular plants

It is not yet known whether the presence of vascular plants in the basins is beneficial or not within a *Sphagnum* cultivation system. Vascular plants compete with *Sphagnum* for the resources, such as water and indeed, an abundance of vascular plants in basins will lower the water table. However, vascular plants create a shade and wind breaker effects on *Sphagnum* and thus limit their desiccation. Furthermore, roots and stems of vascular plants provide a physical support for *Sphagnum* growth (Malmer *et al.,* 1994). For example, in a restored site, the relation between *Sphagnum* and vascular vegetation productivity increased, resulting in the accumulation of over 10 cm of new growth of moss (PERG, unpublished data).The presence of vascular plants could also affect the decomposition rate of new *Sphagnum* cultivated in basins. The suppression of vascular plants can also be difficult and expensive, either chemically, mechanically or manually. The vascular plants that have colonised basins are typical peatland plants, some with a well-developed root system and most are either known as being very resistant to control (*Kalmia angustifolia* L., *Eriophorum* spp.) or readily propagated by vegetative fragments (*Chamaedaphne calyculata*). Further research will enable the relevance of vascular plants in the context of *Sphagnum* cultivation to be determined.

Plant biomass

The good accumulation of plant biomass in the small scale factor experiment demonstrates that environmental conditions in the basins support a good *Sphagnum* development. Over the next few years, we will follow the accumulation of the *Sphagnum* biomass. We will analyse the annual *Sphagnum* production and decomposition rate to determine after how many years *Sphagnum* peak potential is obtained and would result in best harvests of fibre. We will carry out this monitoring by taking into account weather and hydrological conditions. In addition, the monitoring of vegetation cover and plant biomass in the next few years will be undertaken to confirm the preliminary results presented in these proceedings.

The use of Sphagnum grown in basins for other purposes

The fast establishment of *Sphagnum* carpet and the good accumulation of biomass in basins show that it is possible to cultivate the *Sphagnum* in abandoned block-cut peatlands. The setting up of these two experimental sites within the Shippagan research station allows us to define which techniques and machineries are most adapted for the management of *Sphagnum* cultivation in basins. The next steps of this project are to adapt the cultivation methods developed to obtain good quality *Sphagnum* material for peatland restoration projects or for the development of growing substrates. It is possible that cultivation techniques and cultivation period will differ in regard of the ultimate uses of *Sphagnum*. For example, the presence of vascular plants will permit the return to a greater variety of peatland plants in restored sites. In contrast, the presence of other materials (such as litter of vascular plants) with *Sphagnum* fibres could interfere with the manufacture of growing substrates by peat companies. The choice of species cultivated could also be different. *Sphagnum* mosses of Acutifolia section are usually used for restoration projects while *Sphagnum* of Palustria section are mostly preferred for the manufacture of horticultural substrates. The use of *Sphagnum* of Acutifolia section from the experimental station will probably increase the success of the restoration in abandoned cutover peatlands. We have already started an experiment to determine if the cultivated *Sphagnum* could replace the *Sphagnum* originating from natural peatlands in restoration projects. The culture of *Sphagnum* from section Palustria requires new approaches to favour their establishment considering that these species present a faster development rate when they are reintroduced with other *Sphagnum* species (Chirino et al., 2006). In this context, new basins with the aim to develop pure carpets of *Sphagnum* from Palustria section will be put in place in summer 2008.

Future researches: the cultivation of aquatic and semi-aquatic plants

Pools are high spots for biodiversity in natural peatlands. Yet, we have showed that plant species strictly or preferentially found in and around natural pools do not colonize spontaneously pools artificially created in restored peatlands. Active introduction is thus needed. We have initiated a basin project to develop our expertise in the cultivation of species associated with natural pools. These plants could be used for restoring artificial pool margins. Former experiments showed that it is possible to reintroduce *Sphagnum* commonly found along mire pools on the edges of created pools (Fontaine *et al.,* in preparation). However, the typical vascular plants associated with pool margins show a very low rate of establishment. Other experiments have been recently initiated in a greenhouse for identifying the conditions promoting seed germination and establishment for these particular species. The targeted species include Cyperaceae (*Carex paupercula*, *Carex limosa*, *Carex oligosperma*, *Carex pauciflora* and *Rhynchospora alba*), *Scheuchzeriaceae* (*Scheuchzeria palustris*) and small vascular plants (*Drosera intermedia* and *Utricularia cornuta*). Two growing factors are being tested: 1) water level (-10 cm, 0 cm, +10 cm) and 2) three different substrates commonly found on natural pools margins in mires or in restored peatlands (*Sphagnum*, *Cladopodiella fluitans* and bare peat).

We initiated a field basin project during the summer of 2007. Basins characterized by the same three types of substrates being tested in the greenhouse experiment were set up for simulating different pool margins. More precisely, the three substrates are 1) *Sphagnum fallax* and *S. cuspidatum* mat, 2) *Cladopodiella fluitans* mat, a liverwort commonly found around pools, and 3) a substrate of bare peat similar to the edges of created pools. In summer 2008, seeds, seedlings and rhizomes of vascular species will be introduced on these substrates. We will follow the germination rate and seedling growth as well as physical parameters such as water table level and peat moisture content. Although these first basin trials are being conducted on a small scale, other larger basins will be put in place over the next several years.

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