Effect of repeated mowing to reduce graminoid plant cover on the moss carpet at a *Sphagnum* farm in North America

M. Guêné-Nanchen, R. Pouliot, S. Hugron and L. Rochefort

Peatland Ecology Research Group (PERG), Centre for Northern Studies (CEN), Université Laval, Québec, Canada

SUMMARY

Sphagnum farming is defined as the sustainable production of non-decomposed *Sphagnum* biomass on a cyclical and renewable basis. In this article, the influence and necessity of mowing graminoid plants to optimise *Sphagnum* growth in *Sphagnum* farming basins are examined. Repeated mowing was applied to reduce graminoid plant cover at two different stages of the production cycle (one-year-old and seven-year-old *Sphagnum* moss carpet at the beginning of the experiment) at an experimental *Sphagnum* farm in eastern Canada. *Sphagnum* growth (cover, biomass, moss layer thickness) was measured after three years of mowing. In addition, a greenhouse experiment was carried out to determine whether there is a threshold for graminoid plant cover beyond which mowing becomes necessary. *Sphagnum* cover and biomass were not affected by repeated mowing, even if mowing reduced the cover of graminoid plants. Thus, it appears that mowing is unnecessary if the dominant vascular species is a graminoid plant such as *Eriophorum angustifolium*, which accumulates minimal amounts of litter. Furthermore, high cover of *Eriophorum angustifolium* (up to 85 %) did not affect *Sphagnum* cover in a density-controlled greenhouse experiment. When the specific goal is *Sphagnum* fibre production, decisions about control of graminoid plants should be made after considering the cover, life form and litter accumulation potentials of the dominant graminoid species involved.

KEY WORDS: *Eriophorum angustifolium*, paludiculture, peatland, sedge control, *Sphagnum* fibre production

INTRODUCTION

Sphagnum farming is the sustainable production of non-decomposed *Sphagnum* fibre on a cyclical and renewable basis, i.e. it can be produced over repeated production cycles and it can replenish itself over time. As the market for *Sphagnum* fibre expands (Zegers *et al.* 2006), the sustainable production of *Sphagnum* biomass will become increasingly important to reduce human pressure on the natural bogs where *Sphagnum* fibre is usually harvested (Díaz & Silva 2012). *Sphagnum* fibre can be substituted for industrially extracted peat, perlite or vermiculite in peat-based horticultural substrates without impeding plant growth and even increasing it in some cases (e.g. Emmel 2008, Reinikainen *et al.* 2012, Jobin *et al.* 2014, Aubé *et al.* 2015), thus minimising the carbon footprint of peat-based growing media. *Sphagnum* farming ensures more responsible management of peatlands and more sustainable horticulture (Joosten & Clarke 2002, Caron & Rochefort 2013).

Despite these numerous benefits and the growing interest of the peat industry in cultivating *Sphagnum* mosses, research on *Sphagnum* farming is less than two decades old (Gaudig *et al.* 2014). A previous study by Pouliot *et al.* (2015) demonstrated that optimising the water supply to *Sphagnum* mosses is critical for maximising yields in large-scale *Sphagnum* farms. Other factors that can influence *Sphagnum* biomass accumulation are the interactions between *Sphagnum* and other plants (other *Sphagnum* species, other mosses, and vascular plants). When *Sphagnum* farming sites are established, graminoid plants and ericaceous species can be introduced (as seeds, rhizomes *etc*.) along with the *Sphagnum* diaspores or recruited naturally *via* seed rain or animal movements. Therefore, the presence of vascular plants is inevitable in large-scale outdoor farms.

Significant cover of *Juncus effusus* L. has been observed in *Sphagnum* farming basins in Germany (Gaudig & Krebs 2016, Gaudig *et al*. 2017) and is regularly mown to keep graminoid plant cover below 20–30 %, but this is done as a precautionary measure without formal evaluation of any effects. Temmink *et al*. (2017) also mowed vascular plants to prevent competition with *Sphagnum* mosses but did not evaluate the effects of mowing. In Canada, vascular plants are present at all of the *Sphagnum* farming stations, but their cover does not generally exceed 25 % (L. Rochefort personal observation). Vascular plant cover in the first years following initiation of *Sphagnum* farms is dominated by fast-growing graminoids (e.g. *Eriophorum* spp., *Carex* spp., *Scirpus* spp.) while the cover of ericaceous shrubs remains low. Therefore, we focus here on the effect of controlling graminoid plant density on *Sphagnum* biomass accumulation.

The presence of graminoid plants could benefit *Sphagnum* farming by improving microclimate (e.g. by reducing daily range of air humidity, increasing relative air humidity, moderating the light environment; Tuittila *et al.* 2000, Bergamini *et al.* 2001, Pouliot *et al.* 2011). Graminoid plants can also increase the upward growth of *Sphagnum* moss when its density is moderate (around 50 %), by serving as 'scaffolding' (Malmer *et al.* 1994, Pouliot *et al.* 2011). However, Pouliot *et al.* (2011) also found that a very dense cover of vascular plants tends to reduce biomass accumulation because the *Sphagnum* mosses become more etiolated and 'fluffy', and grow in less dense communities. In addition, various experiments have demonstrated that the interception of light by vascular plants reduces *Sphagnum* growth when the photosynthetically active radiation (PAR) is reduced by at least 50 % (Clymo & Hayward 1982, Hayward & Clymo 1983). On the other hand, it is known that bryophytes generally have low compensation points (between 40 and 70 µmol m^{-2} s^{-1}), which allows them to tolerate low light conditions (Collins 1976). However, depending on the graminoid species present (especially their density and/or litter deposition), graminoid plants could have a negative effect on *Sphagnum* biomass accumulation overall by competing with *Sphagnum* growth and by lowering the substrate quality (Facelli & Pickett 1991, PERG unpublished data). In the context of *Sphagnum* farming, whatever final use is intended for the *Sphagnum* fibres, the issue of whether graminoid plants increase *Sphagnum* biomass accumulation or impede its growth needs to be addressed. In other words, is it necessary to control graminoid density?

The general goals for this study were to evaluate the effect of reducing graminoid plant cover by repeated mowing and to determine if there is a threshold above which graminoid plants should be controlled in a *Sphagnum* farming system. More specifically, we examined the effect of graminoid plant cover and density on *Sphagnum* cover, moss layer thickness and biomass accumulation in: 1) a *Sphagnum* farming station where repeated mowing reduced graminoid plant cover; and 2) a greenhouse experiment where a *Sphagnum* carpet was established under different densities of graminoid plants. We hypothesised that, even if mowing reduced graminoid plant cover, it would not be necessary at the *Sphagnum* farm because graminoid cover was already relatively low, but a threshold should be observed in the greenhouse.

METHODS

Mowing at a *Sphagnum* farming station

Study site

This study was conducted at an experimental *Sphagnum* farm on a cutover bog in eastern Canada (47° 40' N, 64° 43' W). Mean annual temperature is 4.8 °C and mean annual precipitation is 1077 mm, of which 70 % falls as rain (seasonal distribution of rainfall = 27 % in spring, 34 % in summer, 29 % in autumn, 10 % in winter) (Environment Canada 2015). Peat extraction was carried out from 1941 to 1971, using the block-cut method, and the resulting topography of baulks and trenches is still present. A complete description of the site is available in Pouliot *et al.* (2015).

From the different *Sphagnum* farming production cycles, moss carpets that were installed in two different years (2006 and 2012) were chosen to allow comparison of two contrasting developmental stages: 1) a seven-year-old (7 yr old) pre-established moss carpet; and 2) a one-year-old (1 yr old) moss carpet still in its establishment phase. These were located in adjacent *Sphagnum* basins within the same trench (see Figure 1A). In both production cycles, *Sphagnum* mosses (mainly *Sphagnum fuscum* (Schimp.) H. Klinggr., *S. rubellum* Wilson, *S. flavicomans* (Cardot) Warnst. and *S. magellanicum* Brid.) were re-introduced using an adaptation of the Moss Layer Transfer Technique (Graf *et al.* 2012). *Sphagnum* fragments (diaspores) were obtained from a natural peatland by shredding the uppermost 10 cm of vegetation, then spread onto bare beat at the *Sphagnum* farming site. Ditches were cleaned to a depth of approximately 30 cm. A wooden dam was installed to retain water in the basins over summer and allow discharge of surplus water from snowmelt in spring. Over time, with the establishment of *Sphagnum* mosses, the ditches slowly re-filled and became inactive (Figure 1). Mean water table levels were -4.6 cm for the 7 yr old moss carpet and -15.5 cm for the 1 yr old moss carpet (calculated from Table 2 in Pouliot *et al.* 2015). *Sphagnum* cover at the beginning of the experiment was ~ 90 % in the 7 yr old moss carpet and ~ 60 % in the 1 yr old stand, the majority of it being *S. rubellum* (Pouliot *et al.* 2012). At the same time, many graminoid plants (~ 40 % cover) were observed in the 7 yr old vegetation and few (~ 1 % cover) in the 1 yr old *Sphagnum* carpet. The 7 yr old graminoid plant cover was dominated by *Eriophorum angustifolium* Honck. with 1 % of *Eriophorum vaginatum* L. and 3 % of ericaceous species. The same species were observed in the 1 yr old moss carpet, but all with cover < 1 %

(PERG unpublished data). Because it was considered highly likely that graminoid plants would disperse from one of the 7 yr old basins into the 1 yr old production cycle, precautionary mowing of the 1 yr old basin was included in its management regime. This provided an opportunity to test whether a control method should be applied directly after site installation or as a corrective measure.

Experimental design

The effect on moss carpet development of mowing (main plot) and proximity to the edge of the culture basin (sub-plot) was investigated using a split-block design replicated 3 times. The different 1 yr old and 7 yr old production basins were divided into three blocks. The 7 yr old block size was 115 m × 15 m and the 1 yr old block size was 17 m × 15 m. Each of

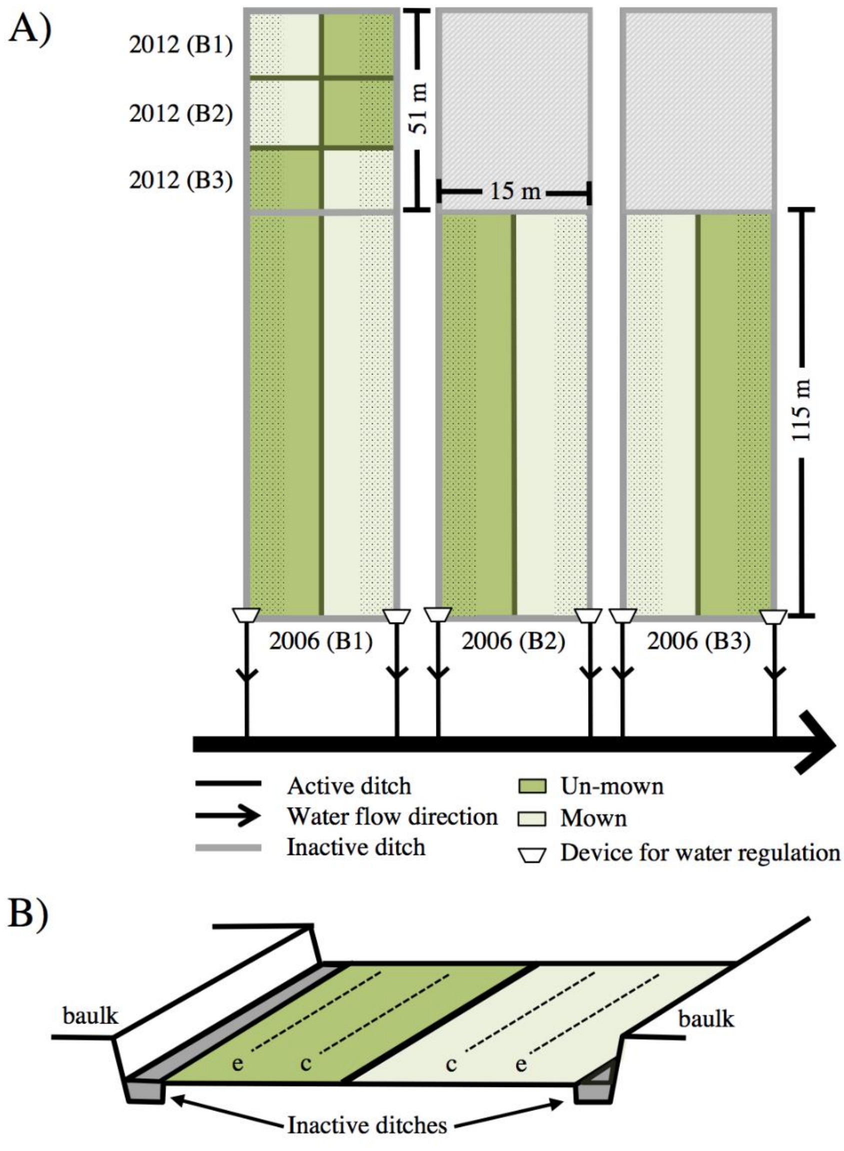

Figure 1. A) Production cycle, block disposition (B1, B2, B3 = block (replica)) and treatment disposition (stippled = edge, unshaded = centre) in the *Sphagnum* farming basins (hatched area is not part of the experiment) (2012 = 1 yr old production cycle and 2006 = 7 yr old production cycle). B) Example of the treatment disposition for one block with the mowing treatments (un-mown or mown) and the sub-treatments (e = edge, c = centre). Dashed lines indicate the disposition of vegetation transects. The particular topography of trenches and baulks created by the block-cut peat extraction method is represented here. Inactive ditches were the old ditches used by the block-cut extraction that were re-dug to a depth of 30 cm during *Sphagnum* farming site installation. Over time, they re-filled with *Sphagnum* and peat. Devices for water regulation were wooden dams placed during site installation. This Figure is not to scale.

these blocks was divided lengthwise and one side was randomly chosen to be mown three times each growing season during three consecutive years (2013, 2014 and 2015) while the other side was not mown (Figure 1A). Mowing was carried out with a weed trimmer because this is a simple and efficient control method that does not disturb the physical integrity of the *Sphagnum* carpet. Weed trimmer operatives wore snowshoes to minimise the impact of trampling. Mowing was done in June (just after graminoid plant investment for flower production), in July, and in late August (at the end of the growing season for graminoid plants in this climatic region).

Vegetation survey

After three years of mowing treatments, vegetation surveys were performed on one transect disposed lengthwise *per* sub-plot. The transects were 95 and 14 metres long for 7 yr old and 1 yr old cycles respectively, and positioned in the centres of the sub-plots. Transect position (basin edge or centre) was used as two sub-treatments to verify whether an edge effect (Figure 1B) was caused by the presence of the ~ 1.5 m wide baulks and various plants colonising them (which were cut in the third year of treatments). *Sphagnum* cover, biomass and moss layer thickness were measured. To assess the efficiency of the mowing method, cover values for graminoid plants, litter and ericaceous species were also determined (Table 1).

After three years, graminoid plant cover differed significantly between the un-mown (22–34 %) and mown (4–14 %) treatments ($CI_{95\%}$) (see Table 2 for all t and p values) and graminoid litter cover was reduced from 6–7 % to 3–4 % ($CI_{95\%}$) in the 7 yr old cycle. For the 1 yr old cycle, only graminoid plant cover exhibited a significant decrease with mowing, from 5–11 % to 2–3 %. Ericaceous species cover was ~ 1 % lower on the mown side for both production cycles.

Greenhouse experiment

Experimental design

This experiment was conducted in the greenhouse complex at Université Laval using mesocosms. The greenhouse conditions were set at 22 °C / 50 % RH during the day and 18 °C / 85 % RH during the night. The mesocosms were plastic containers measuring 61 × 41 × 42 cm (length × width × height) which were filled with rewetted horticultural peat (mean peat pH = 3.77 ± 0.03 SE). Each mesocosm accommodated two experimental units (EUs) with different treatments.

The experiment was implemented as a completely randomised design where five densities of *E. angustifolium* (0, 2, 4, 6 or 8 stems) were planted in each EU, and each EU was repeated 12 times. Individual stems of *E. angustifolium* were harvested on a post-extracted bog near Rivière-du-Loup, Québec (47° 50' N, 69° 27' W) and planted in the mesocosms in the following days. *Sphagnum* moss (*S. rubellum*) was collected from a natural peatland near Québec City (46° 39' N, 71° 19' W) and stored

Table 1. Number of samples (n) for each variable measured *per* sub-plot in the *Sphagnum* farm experiment for each production cycle and a description of the methodology.

Variables measured		n		Methodology
		7 yrs	1 yr	
Cover (%)	*Sphagnum* Graminoid plants Graminoid litter Ericaceous species	9	2	Estimated visually in rectangular 1 m × 5 m quadrats placed systematically along each transect.
Thickness (cm)	*Sphagnum*	46	6	Measured every 2 metres on each transect.
Biomass (g m^{-2})	*Sphagnum*	5	2	Measured in 25 cm × 25 cm quadrats placed systematically along each transect where all vegetation above the peat surface was collected. *Sphagnum* fibres were separated from other plant material, dried at 70 ºC and weighed.

at 4 °C for one week before introduction to the mesocosms. *S. rubellum* was chosen because it was dominant in the field experiment and is often used in *Sphagnum* farms. The *Sphagnum* was spread immediately after the *E. angustifolium* was planted, as fragments ~5 cm long with capitula, on the peat surface in the mesocosms at a ratio of 1:5 (meaning that moss collected from 1 m² of natural mire was spread over 5 m² of mesocosm surface). The *Sphagnum* fragments formed a carpet about 1 cm thick covering all of the peat surface. The water level in each mesocosm was maintained independently, between 20 and 25 cm below the peat surface, by a system of perforated pipes and drains. Twice a week, the mesocosms were watered with rainwater until water escaped by the drainage holes. Between waterings they were lightly misted to keep the moss carpet humid.

Measurements

After six months of growth, cover values for *Sphagnum* mosses and *E. angustifolium* were visually estimated by vertical projection in each EU. By visually estimating the *E. angustifolium* cover, its impact on the adjacent EU was considered because, if a leaf covered part of the inventory quadrat, it was included in the estimation no matter where it was rooted. *Sphagnum* moss carpet thickness (distance from the moss surface to the peat surface) was measured at ten points placed systematically within each EU, and *Sphagnum* capitula were counted in two 30 cm² circular samples placed systematically within each EU. Finally, *Sphagnum* biomass accumulated during the experiment was harvested for each EU, dried at 70 ºC and weighed (including the material used for the capitulum count). The amount of *Sphagnum* moss initially spread was the same in all treatments (weighed before spreading). The initial *Sphagnum* cover, biomass, *Sphagnum* moss layer thickness and number of capitula were all assumed to be zero. As new capitula grow on *Sphagnum* stem fragments, the initial number of capitula was negligible and the final *Sphagnum* cover and thickness arose from new capitula. As part of the initial material would have decomposed during the experiment, the initial weight of *Sphagnum* moss was not deducted from the final *Sphagnum* biomass. Thus, final *Sphagnum* biomass may have been slightly overestimated, but the effect was similar for all EUs.

Statistical analysis

For the *Sphagnum* farm experiment, two-way ANOVAs were performed to evaluate the effect of mowing (main plot) and transect position (sub-plot) on development of the *Sphagnum* carpet. Error terms were adjusted to take into consideration that randomisation is not complete in sub-plots (split-block design). The variables analysed were: mean *Sphagnum* moss cover, thickness and biomass. Following the ANOVAs, protected Fisher’s LSDs were run. Analyses were performed separately for the 7 yr old cycle and the 1 yr old cycle. The MIXED procedure of the SAS software was used (SAS Statistical System Software, v. 9.2, SAS Institute Inc., Cary, NC, USA). If needed, the GROUP statement of the function REPEATED was used to model variance and ensure homogeneity and normality of variances. Degrees of freedom were adjusted accordingly and the best model was selected by using the Akaike Information Criterion (AIC). Confidence intervals of 95 % are used to illustrate significant differences between treatments in Figure 2.

Table 2. Mean cover of graminoid plants, graminoid litter and ericaceous species ± CI (95 %) after three years of mowing for un-mown and mown treatments. Significant differences are shown in **bold** type (p-value < 0.05) (Paired t-test[1], α = 0.05).

	Treatments	Un-mown	Mown	df	t	p
7 yrs	Graminoid plant cover (%)	28 ± 6	9 ± 5	5	4.34	**0.007**
	Graminoid litter cover (%)	6 ± 0.5	3 ± 0.5	5	13.84	**> 0.001**
	Ericaceous species cover (%)	2 ± 0.5	1 ± 0.5	5	2.81	**0.009**
1 yr	Graminoid plant cover (%)	8 ± 3	2 ± 0.5	5	4.25	**0.008**
	Graminoid litter cover (%)	2 ± 3	Presence	5	1.43	0.09
	Ericaceous species cover (%)	2 ± 1	1 ± 0.2	5	2.32	**0.021**

[1] Paired t-tests (where the mown edge (or centre) of one basin is compared with the un-mown edge (or centre) of the same basin) were performed to evaluate the effect of mowing on graminoid plants, graminoid plant litter and ericaceous species. Paired t-tests were realised with R software (version 3.3.1).

For the greenhouse experiment, linear regressions were run to quantify the relationships between *Sphagnum* moss metrics (cover, moss layer thickness, capitulum density and biomass) and *E. angustifolium* cover values. Means *per* EU were used for moss layer thickness and capitulum density. Because of fungal infections, 14 EU (of 60) were not considered in the analyses, meaning that 46 EU were kept for the regressions. R software (R Development Core Team 2016) was used to perform these analyses.

RESULTS

Mowing at a *Sphagnum* farming station

After three years of mowing, *Sphagnum* cover and biomass in the pre-established moss carpet (7 yr old cycle) were not significantly different between mowing treatments (UM = un-mown, M = mown), regardless of position within the basin (c = centre, e = edge) (Figure 2; no significant interaction between factors; see Appendix for F and p-values). Cover and biomass accumulation hardly differed between the mowing treatments (for *Sphagnum* cover, $CI_{95\%}$ = 92–99 % (UM), 95–100 % (M); for biomass accumulation, $CI_{95\%}$ = 991–1462 g m^{-2} (UM), 995–1477 g m^{-2} (M)). However, *Sphagnum* carpet thickness was significantly greater in the un-mown treatment ($CI_{95\%}$ = 26.9–29.9 cm (UM), 22.8–25.5 cm (M)). There were only small differences between centre and edge of the basin for all of these factors (for *Sphagnum* cover, $CI_{95\%}$ = 91–99 % (c), 96–100 % (e); for biomass accumulation, $CI_{95\%}$ = 967–1463 g m^{-2} (c), 1024–1472 g m^{-2} (e); and for *Sphagnum* carpet thickness, $CI_{95\%}$ = 24.4–27.4 cm (c), 25.2–28.0 cm (e)).

In the establishing *Sphagnum* carpet (1 yr old cycle), *Sphagnum* cover and moss layer thickness were significantly higher in the 'edge' sub-plots (for *Sphagnum* cover, $CI_{95\%}$ = 64–82 % (c), 90–96 % (e); for *Sphagnum* carpet thickness, $CI_{95\%}$ = 1.8–2.7 cm (c), 3.1–4.3 cm (e)). According to the confidence intervals, there also seemed to be a tendency towards higher biomass accumulation at the basin edge ($CI_{95\%}$ = 200–568 g m^{-2} (c), 462–825 g m^{-2} (e)), but the p-value was high (p = 0.246). Mowing did not significantly affect *Sphagnum* cover or biomass

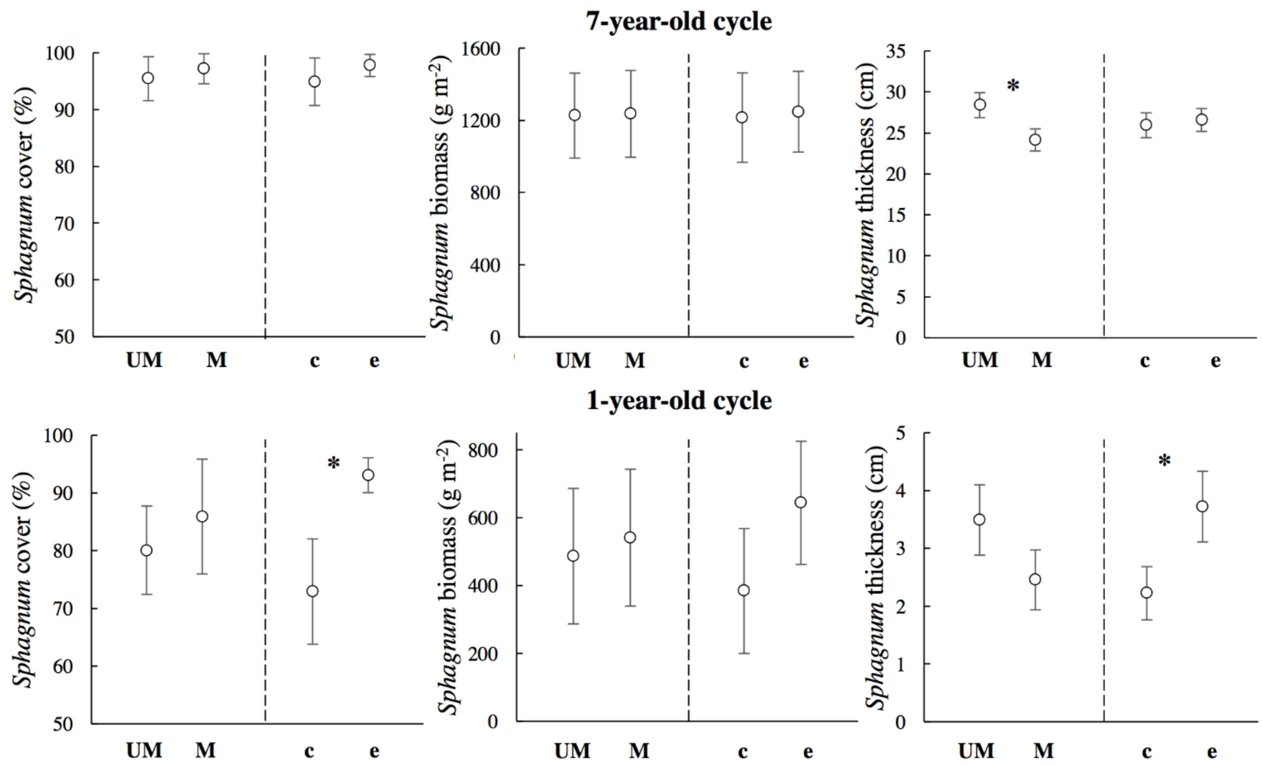

Figure 2. Means ± CI (95 %) for *Sphagnum* moss cover, moss layer thickness and biomass according to mowing treatment (UM = un-mown or M = mown) and transect position (c = centre or e = edge) for both production cycles (simple effects). An asterisk (*) indicates a significant difference between treatments (p-value < 0.05) (LSD protected, α = 0.05). There was no significant interaction between factors (mowing and transect position). Production cycles were analysed separately.

(for *Sphagnum* cover, $CI_{95\%} = 72–88$ % (UM), 76–96 % (M); for biomass accumulation, $CI_{95\%} = 287–686$ g m^{-2} (UM), 339–743 g m^{-2} (M). Even though a tendency towards thicker moss layer on the un-mown sides of the plots was observed, no significant difference was found (for *Sphagnum* carpet thickness, $CI_{95\%} = 2.9–4.1$ cm (UM), 1.9–3.0 cm (M).

Greenhouse experiment

After six months of growth in a greenhouse, the different planting densities of *E. angustifolium* resulted in cover values ranging from 0 to 85 %. Except for *Sphagnum* carpet thickness, negative linear relations were found between *Sphagnum* growth variables and *E. angustifolium* cover (Figure 3). The regressions explained 18–45 % of the variance (adjusted R^2; Figure 3). The highest cover of *E. angustifolium* (85 %) induced reductions in *Sphagnum* cover, density and biomass of 14, 37 and 18 %, respectively, relative to the values when *E. angustifolium* was absent (equations; Figure 3).

DISCUSSION

Effect of mowing

In the *Sphagnum* farming basins studied, the effect of reducing graminoid plant cover by repeated mowing was not detectable in our measurements of *Sphagnum* moss production (cover and biomass accumulation), whether the *Sphagnum* carpet was pre-established (7 yr old cycle) or still establishing (1 yr old cycle). However, it was possible to observe the 'scaffolding effect', where the increase of graminoid plant cover promotes the elongation of *Sphagnum* fibres (Malmer *et al.* 1994, Pouliot *et al.* 2011), (only) when the *Sphagnum* carpets were pre-established (7 yr old cycle). Indeed, *Sphagnum* moss carpets were thicker in the un-mown treatments for the 7 yr old cycle. However, the increased fibre length in the 7 yr old cycle did not translate into an increase in biomass accumulation, indicating that the *Sphagnum* stems are probably etiolated and fluffy. The shade caused by graminoid plant cover reduced the accessibility of

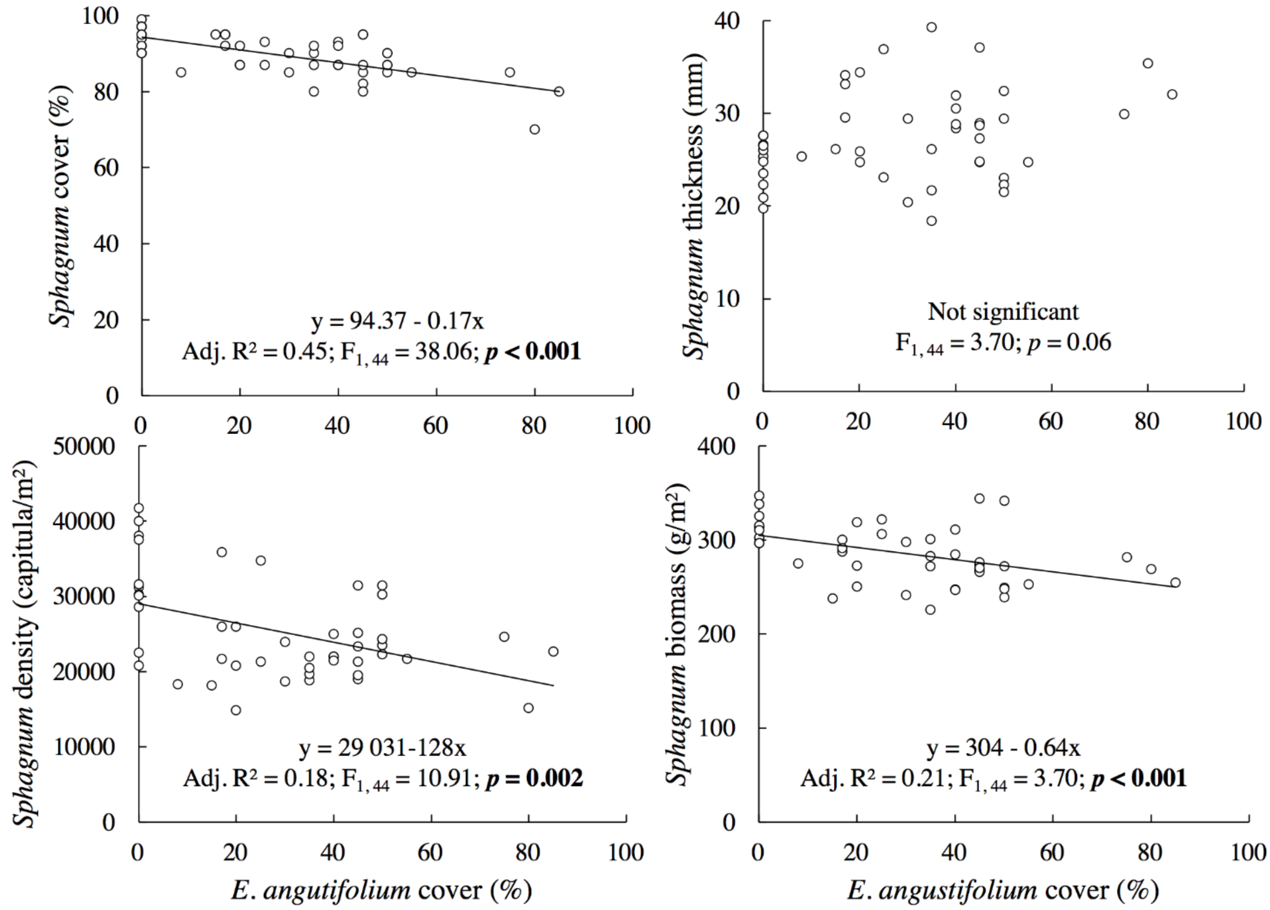

Figure 3. Relations between *Sphagnum* moss growth metrics (cover, carpet thickness, capitulum density and biomass) and *Eriophorum angustifolium* cover for the greenhouse experiment. Each point represents a value for an individual experimental unit (n = 46).

light for *Sphagnum* mosses and could have caused fibre etiolation (Heijmans *et al.* 2002, Pouliot *et al.* 2011). Another hypothesis is that fibres on the un-mown side were not etiolated, but it was rather the repeated trampling with snowshoes during mowing (three times *per* year for three years) that compressed the *Sphagnum* moss carpet on the mown side. The greenhouse experiment supports the latter hypothesis since no relation was found between *Sphagnum* moss elongation (moss layer thickness) and increasing *E. angustifolium* cover. But the reduction of the thickness on the mown side is probably not entirely an artefact of trampling by snowshoes, because it was not found in the 1 yr old cycle. Our inability to detect the effect of graminoid plants on *Sphagnum* carpet thickness in the 1 yr old cycle is probably due to low number of samples or high variations because the *Sphagnum* carpet was still establishing.

Edge effect

In relation to the basin edge effect, the field experiment showed that the presence of wetter conditions on the edges of the basins positively affected the *Sphagnum* moss cover and thickness in the 1 yr old cycle. Wet conditions were probably caused by collapsed drainage ditches blocking drainage, as well as the shade created by the baulks (Figure 1B). Well rewetted conditions were found to be a driver for better *Sphagnum* establishment and biomass accumulation at the basin scale (one basin compared to another one) within this same experimental *Sphagnum* farm (Pouliot *et al.* 2015). In this study, the same tendency could also be observed at a smaller scale, within the basin itself, for the basins with *Sphagnum* mosses in the process of establishment. However, this tendency seems to decrease over time as *Sphagnum* mosses establish, because there was no effect of basin edge for the pre-established 7-year-old *Sphagnum* carpet.

Need for mowing

Overall, the difference in *Sphagnum* accumulation between mown and un-mown treatments was negligible. Even if mowing tended to increase *Sphagnum* cover and biomass in the 1 yr old cycle, the range of increase was very low (7 % for cover and 10 % for biomass). For practical and economic considerations, mowing is probably not necessary. This recommendation is, however, specific to sites dominated by *E. angustifolium*. Indeed, in our study, *E. angustifolium* cover as high as 34 % had no detectable effect on the production of *Sphagnum* mosses in the field experiment. The greenhouse experiment showed that increasing *E. angustifolium* cover to higher levels could impede development of the *Sphagnum* moss carpet, but the magnitude of the decrease was small (14 % for cover and 18 % for biomass). Pouliot *et al.* (2011) demonstrated that *E. angustifolium* cover around 50 % did not significantly impact the *Sphagnum* moss carpet, and 100 % cover induced only a 21% loss in frequency and a 35 % loss in biomass if compared to a carpet without *E. angustifolium*. Heijmans *et al.* (2002) speculated that at least 60 % cover of *E. angustifolium* was needed to impede *Sphagnum* moss growth, but this threshold was not empirically tested by the researchers. Consequently, we believe that any investment in controlling *E. angustifolium* at a *Sphagnum* farm would probably not be justifiable in terms of gains in biomass, but a cost-benefit analysis studying this aspect would be necessary.

Importance of site-specific conditions

Nevertheless, mowing may be necessary when the dominant graminoid species present is not *E. angustifolium*. Some sedges are not rhizomatous and tend to grow in tussocks, a life form that can compete with *Sphagnum* moss for space. It is the case for *Eriophorum vaginatum*, which is regarded as an invasive species in unrestored peatlands (Lavoie *et al.* 2003, 2005). Under a complete (100 %) cover of that graminoid plant, Pouliot *et al.* (2011) observed that *Sphagnum* frequency was 42 % lower if the dominant species was *E. vaginatum* rather than *E. angustifolium*, but no significant decrease in biomass was observed. However, tussock cover of at least 50 % is generally needed to significantly affect development of the *Sphagnum* moss carpet (Hogg *et al.* 1995 for *Molinia* spp., Pouliot *et al.* 2011 for *E. vaginatum*). Apart from life form, other factors should be taken into account when one considers controlling the density of vascular plants in a *Sphagnum* farm. For instance, according to Malmer *et al.* (1994), the decrease of *Sphagnum* moss production observed with the presence of graminoid plants is the result of above-ground litter accumulation on the moss carpet rather than the effect of shading caused by the vascular plant itself. For example, a low cover of *Carex aquatilis* Wahlenb. negatively affected *Sphagnum* moss production, probably because this plant produces substantial amounts of litter (~ 50 % litter cover with 25 % cover of *C. aquatilis*; M. Guêné-Nanchen, unpublished data). Compared to *C. aquatilis*, *E. angustifolium* (another rhizomatous plant) is known to produce low amounts of annual litter (Phillips 1954, Heijmans *et al.* 2002). Indeed, litter cover generally did not exceed 7 % in the studied *Sphagnum* farming basins, even if plant cover reached 34 %. Also, site-specific factors such as water table level should be considered; for example, in this *Sphagnum* farm, drier conditions promote *E. vaginatum* whereas wetter conditions promote *E. angustifolium*. *Sphagnum* farming stations established on richer peat could be colonised by *Carex* and *Scirpus* species. Therefore, recommendations for graminoid plant control in *Sphagnum farm*s should be made according to the dominant graminoid plant present: its cover, its life form, its litter production, its invasive potential and the conditions on the site.

Practical considerations

Depending on the *Sphagnum* farming site, mowing might not be needed to maximise biomass accumulation, but it may be considered for other reasons. For example, vascular plants can impede mechanical *Sphagnum* fibre harvesting by blocking the machinery mechanisms and a control method may be necessary to facilitate harvesting. The end use of the fibres may also influence the decision to control vascular plants. If *Sphagnum* fibres are destined to be used as fibres for specialised horticultural substrates such as orchid propagation, vascular plants might need to be eradicated to minimise the risks of contamination by seeds. However, if cultivated *Sphagnum* mosses are intended to be used as diaspores for ecological restoration projects, the presence of vascular plants is not a concern and could even allow for the return of typical peatland vascular plants. Different studies have shown that graminoid plant cover generally declines spontaneously after 6–8 years in post-regenerating block-cut peatlands (field observations in Salonen 1990, Robert *et al.* 1999) and restored peatlands (from 80 % to 50 %) (D'Astous *et al.* 2013, Rochefort *et al.* 2013). This phenomenon was observed in the oldest cycle at the *Sphagnum* farm studied here, where graminoid plant cover naturally decreased between the beginning and the end of the experiment (from 7 to 10 years) from around 40 % to 28 % in the un-mown side (PERG unpublished data). If *Sphagnum* mosses grow fast enough to allow harvesting within a five-year cycle, control methods maybe needed. However, if production cycles are longer, it would be possible to wait for the decrease of graminoid plants through spontaneous succession and the self-engineering of *Sphagnum* behaviour (Van Breemen 1995). Moreover, graminoid plant cover in the studied *Sphagnum* farming station remained low after seven growing seasons and were lower than in restored peatlands (Rochefort *et al.* 2013, Pouliot *et al.* 2015), adding yet another argument for site-specific decision-making for vascular plant control. Thus, ultimately, the need for control of vascular plants in *Sphagnum* farming basins is determined by the life forms of the vascular species in combination with logistical constraints linked to harvesting and the specific use of the *Sphagnum* fibres.

CONCLUSION

The improvement of growth conditions will continue to be a major concern in *Sphagnum* farming research. This study is the first of its kind to make recommendations for graminoid plant control and to study its effect on the structure of the *Sphagnum* carpets. For this particular *Sphagnum* farming site, located in the maritime provinces of Canada, control of graminoid plants is not deemed necessary to improve *Sphagnum* productivity regardless of the age of the *Sphagnum* carpet. However, this recommendation cannot be applied to all *Sphagnum* farming sites, and is limited to graminoid plants with similar growth habits to *E. angustifolium* (individual stems, spreading by rhizomes and producing minimal amounts of litter). The decision to control the density of vascular plants will be specific to each *Sphagnum* farming station and recommendations must be made in light of the dominant graminoid plant species present in culture basins. The graminoid species cover, life form, litter accumulation and potential for invasion are factors that should be considered when deciding whether or not to cut graminoid plants. Moreover, this decision should be made according to the intended final use of the *Sphagnum* fibres. Therefore, we suggest that further studies should be conducted with other graminoid plants or dominant vascular plants, and in *Sphagnum* farming stations in different climates. Moreover, the effect of mowing on increasing vegetative reproduction by rhizomes in graminoid plants should also be evaluated.

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Author for correspondence: Professor Line Rochefort, Department of Plant Sciences, Université Laval, 2425, rue de l’Agriculture, Québec City, Québec, G1V 0A6, Canada
Tel: 1-418-656-2131 ext 3595; Fax: 1-418-656-7856; E-mail: line.rochefort@fsaa.ulaval.ca

Appendix

ANOVA in a split-block design was used to evaluate the effect of mowing (main treatment) and transect position (sub-treatment) on mean *Sphagnum* moss cover (9 measures for the 7 yr old cycle and 2 measures for the 1 yr old cycle), thickness (46 measures per transect for 7 yr old cycle and 6 measures for 1 yr old cycle) and biomass (5 samples per transect for 7 yr old cycle and 2 samples for 1 yr old cycle) for both production cycles. Significant differences are bolded (LSD protected, α = 0.05).

***Sphagnum* moss cover**

Production cycle		**7 yrs**			**1 yr**	
Variation sources	df	F	p	df	F	p
Block	2			2		
Mowing	1	0.82	0.417	1	0.87	0.377
Error main treatment	2			2		
Transect	1	2.09	0.222	1	**10.44**	**0.012**
Error sub-treatment	2			2		
Mowing x Transect	1	0.46	0.536	1	NA[1]	NA[1]
Error interaction	2			2		
Total	11			11		

***Sphagnum* moss thickness**

Production cycle		**7 yrs**			**1 yr**	
Variation sources	df	F	p	df	F	p
Block	2			2		
Mowing	1	**9.16**	**0.023**	1	1.86	0.245
Error main treatment	2			2		
Transect	1	0.00	0.958	1	**53.66**	**0.002**
Error sub-treatment	2			2		
Mowing x Transect	1	0.28	0.619	1	0.12	0.746
Error interaction	2			2		
Total	11			11		

***Sphagnum* moss biomass**

Production cycle		**7 yrs**			**1 yr**	
Variation sources	df	F	p	df	F	p
Block	2			2		
Mowing	1	0.75	0.455	1	0.02	0.9057
Error main treatment	2			2		
Transect	1	1.91	0.257	1	1.91	0.246
Error sub-treatment	2			2		
Mowing x Transect	1	12.08	0.0601	1	0.50	0.523
Error interaction	2			2		
Total	11			11		

[1] It was not possible to calculate F and p-values because a linear combination of covariance parameters was compounded with the residual variance.