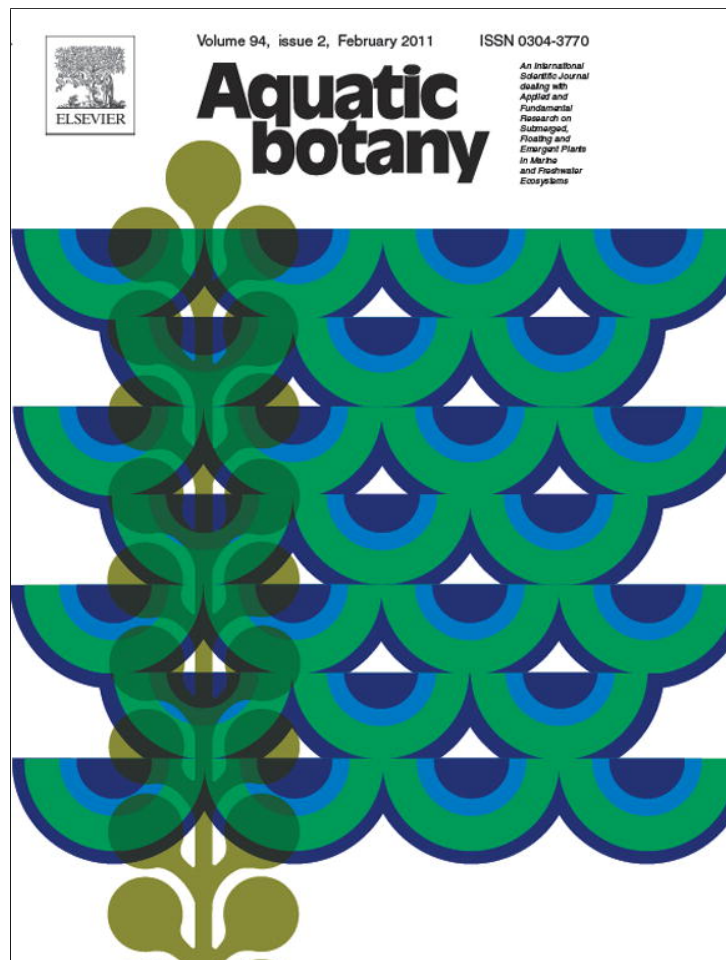


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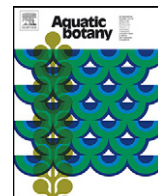
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Short communication

Restoration of pool margin communities in cutover peatlands

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ABSTRACT

Two experiments were conducted for developing restoration techniques for pool margin communities in cutover peatlands. We first aimed to measure the regeneration potential of a typical edge pool liverwort, *Cladopodiella fluitans* (Nees) H. Buch. We introduced *C. fluitans* in floating baskets in a restored peatland. We tested three fragment sizes (patches of 2 cm², stretched patches and shredded fine fragments of 0.1–1 mm), two introduction densities (ratio between surface of collected areas and surface of restored areas of 1:5 and 1:10) as well as the effect of a straw mulch. After two years, the percentage covers of *C. fluitans* were five times larger in experimental units protected with straw than in those without protection. Yet, the fragment sizes and the densities tested had no effect on the regeneration of the liverwort. The second experiment aimed to test a moss layer transfer approach to restore plant diversity around pool margins. We tested four communities, dominated by (1) *Sphagnum cuspidatum* Hoffman, (2) *Sphagnum fallax* (H. Klinggraff) H. Klinggraff, (3) *Sphagnum papillosum* Linberg as well as (4) a mixed community composed of equal quantities of *C. fluitans*, *S. cuspidatum* and *S. papillosum*. We introduced plant material in two density ratios (1:5 and 1:10). *Sphagnum* mosses did colonize pool margins, and showed even more than 60% cover for some treatments after three growing seasons, but the recovery of the introduced vascular plants remained below 5% for most species. The establishment of pool vascular species thus seems to be more intricate than for bryophytes and specific introduction techniques might be needed.

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1. Introduction

Although pools are known to significantly increase biodiversity in natural peatlands (Lindsay et al., 1985; Guinan et al., 1998; Poulin et al., 2002; Fontaine et al., 2007), attempts to re-establish their associated plant species assemblages along created pools in restored peatlands remain scarce. In bogs, pools are often characterized by open habitats dominated by liverworts and by wet *Sphagnum* species of the section *Cuspidata* and *Subsecunda*. In association with these substrates, one finds a diversity of vascular plants which do not occur in the other more abundant peatland habitats (Fontaine et al., 2007). Among others, *Cladopodiella fluitans* (Nees) H. Buch is a common liverwort around pools found in strict association with the uncommon and sporadically distributed species *Utricularia cornuta* Michx. Yet, we are aware of no trials for testing restoration techniques for this liverwort. In this study, we designed one experiment to test the regeneration potential of *C. fluitans* in restored peatlands.

For *Sphagnum* dominated communities, the so called moss layer transfer approach developed in North America has been proved

to be successful for dry residual peat surfaces but has never been used for wetter pool edges. This approach consists in transferring the upper vegetation layer from a natural donor site (i.e. the first 5–10 cm) over a 10–15 times larger area in a residual peatland (Rochefort and Lode, 2006). Not only *Sphagnum* fragments are thus transferred but also all plant propagules occurring in this upper vegetation layer (fruits, seeds, rhizomes, roots, etc.), which lead to the recovery of typical plant communities found in natural bogs (Isselin-Nondedeu et al., 2007). On the contrary, introducing plants as delimited plugs (in small patches with original soil) have proved unsuccessful for peatland restoration since they do not spread over bare peat surfaces in cut-over sites (Rochefort, personal observations). Yet, the few trials for restoring pool margins focused on transferring vegetation plugs, without success (Mazerolle et al., 2006). We thus conducted a second experiment to test whether the moss layer transfer approach could be used successfully for restoring pool margin communities.

2. Methods

2.1. Restored site description

Experiments were carried out from 2005 to 2007 at a restored peatland in central Québec (48°47'N, 72°10'W), eastern Canada.

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The 3.5 km² cut-over site was restored between 2000 and 2003 in the middle of an ombrotrophic peatland of 43 km². The moss layer transfer approach (Rocheffort and Lode, 2006) developed in Canada was used to restore the site, with no attention paid to recreate pools. To study the regeneration potential of *C. fluitans*, we recreated water saturated peat surfaces by filling floating baskets with peat and placing the baskets in former ditches filled all year long with water. This experiment will be referred to as the “*Cladopodiella fluitans* regeneration experiment”. Former drainage ditches with gently sloping bare peat surfaces were used as a proxy for pools in order to study the regeneration success of wetter plant communities usually found along pool margins in natural peatlands, hereafter named the “pool margin communities experiment”. Mean water pH of experimental ditches was 3.3 (± 0.7) whereas it varied between 3.8 (± 0.5) and 4 (± 0.3) in pools of natural donor sites where plant material was collected. Mean annual temperature is 2.3°C, which varies from -16°C in January to 18°C in July (Environment Canada, 2006).

2.2. Experimental designs and data sampling

2.2.1. *C. fluitans* regeneration

For studying the regeneration potential of *C. fluitans*, we collected plant material from several floating mats within a poor fen remnant, some 250 km from the experimental site. At the experimental site, we tested the three following plant density ratio: 1:8, 1:4 and 1:2. The 1:8 ratio meaning for example that 1 m² of collected surface area was spread over 8 m² of restored surface area. We tested three different sizes of *C. fluitans* fragments: (1) patches of 1 cm \times 2 cm with a thickness of 0.5 cm, (2) same as in 1 but stretched by hand to untangle *C. fluitans* carpet, and (3) fine shredded fragments (0.1–1 mm) as obtained by shredding *C. fluitans* with a food processor. Finally, we assessed the influence of a protective cover by adding a straw mulch to some plots. The treatments were not tested as a full factorial experiment because of the large number of experimental units needed for testing all combinations of treatments. We chose to focus on specific combinations of treatments which we judged more relevant for a first study on the regeneration capacity of *C. fluitans*. The 10 treatments constituted an incomplete factorial experiment and were randomly distributed among four ditches (blocks).

Unmixed *C. fluitans* carpets were collected with a knife at the donor site and *C. fluitans* fragments were then introduced at the experimental site in plastic baskets (36 cm \times 29 cm \times 14 cm depth) filled with *in situ* peat. Foam floats were used to keep their surface leveled with water. The baskets were perforated to keep the peat permanently saturated and a fine meshed screen confined peat within baskets. After two growing seasons, the cover of *C. fluitans* was evaluated from 10 randomly chosen sub-quadrats out of 25 (4 cm \times 5 cm) delineated within each basket. The randomization was done a new for each experimental basket. The cover of *C. fluitans* and bare peat was visually estimated to the nearest 5% in each small sub-quadrat.

2.2.2. Pool margin communities

We tested whether the moss layer transfer technique could be used for restoring pool communities. Plant material was collected from two nearby natural bogs. Four pool communities were tested. They were dominated by: (1) *S. cuspidatum* Hoffman, (2) *S. fallax* (H. Klinggraff) H. Klinggraff, (3) *S. papillosum* Lindberg, and (4) a mixed community composed of equal quantities of the following three species: *C. fluitans*, *S. cuspidatum* and *S. papillosum*. One or few vascular species could be dominant. We tested also two introduction densities (1:5 and 1:10 ratios, i.e. area of collected material over restored area). The nine treatments (two

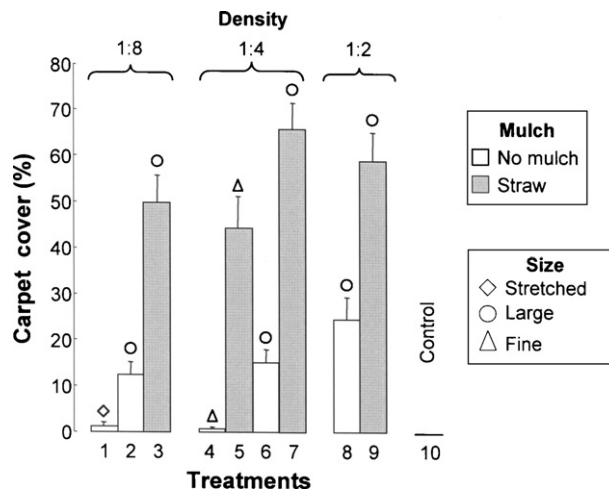


Fig. 1. Effect of density of introduced plant material, fragment size and straw mulch on the regeneration of *Cladopodiella fluitans* after two growing seasons. Bars indicate standard errors ($n=4$). Treatments are as follow: (1) density^a 1:8, stretched fragments^b, no mulch; (2) density 1:8, large fragments^c, no mulch; (3) density 1:8, large fragments, with mulch; (4) density 1:4, fine fragments, no straw; (5) density 1:4, fine fragments^d, with straw; (6) density 1:4, large fragments, no straw; (7) density 1:4, large fragments, with straw; (8) density 1:2, large fragments, no straw; (9) density 1:2, large fragments, with straw; (10) control without introduction. ^aRatio between surface of collected areas and surface of restored areas. ^bHand stretched entangled patches (2 cm²) of *C. fluitans*. ^cPatches of *C. fluitans* of 2 cm². ^d*C. fluitans* shredded with a food processor (0.1–1 mm fragments).

densities \times 4 communities + 1 control without introduction) constituted an incomplete factorial experiment and were randomly distributed among four blocks. Two blocks were in individual ditches whereas the two other blocks were 100 m apart in the same ditch.

At donor sites, we harvested by hand only the upper layer (10 cm) of the vegetation, including bryophyte and vascular plant species in each community, after evaluating the percent cover for all species. Collecting only the top surface allows a faster recovery of donor sites since living plant material is left *in situ* (Rocheffort and Campeau, 2002). At the experimental site, the plant material was spread homogeneously by hand (1 m \times 1.5 m) within each plot. The control plots did not receive any plant fragments to evaluate spontaneous colonization. For all treatments, a mulch of about 20 cm thick of well structured straw was manually spread on the introduced plant material to protect it from desiccation. We assessed plant establishment by estimating the percentage cover of moss and vascular plant species from six quadrats of 25 cm \times 25 cm systematically located within each 1.5 m² plot after three growing seasons (a buffer of about 20 cm was kept around and in between quadrats). The percent cover was evaluated to the nearest 1% when the plant species occupied between 0 and 10% of the sampled quadrat and to the nearest 10% when it occupied between 11 and 100% of the sampled quadrat. This common approach was used since it is easier to give precise visual estimates when the plant cover is low (e.g. it is easier to tell the difference between 5 and 8% than between 23 and 26%).

2.3. Statistical analyses

For the *C. fluitans* regeneration experiment, the effect of treatments on *C. fluitans* cover was tested with an ANOVA in a completely randomized block design followed by a series of planned comparisons (nine *a priori* contrasts), testing the effect of either mulch, fragment size or plant density reintroduction. For the pool margin communities experiment, the effect of treatments on plant establishment was estimated by performing a two-way ANOVA

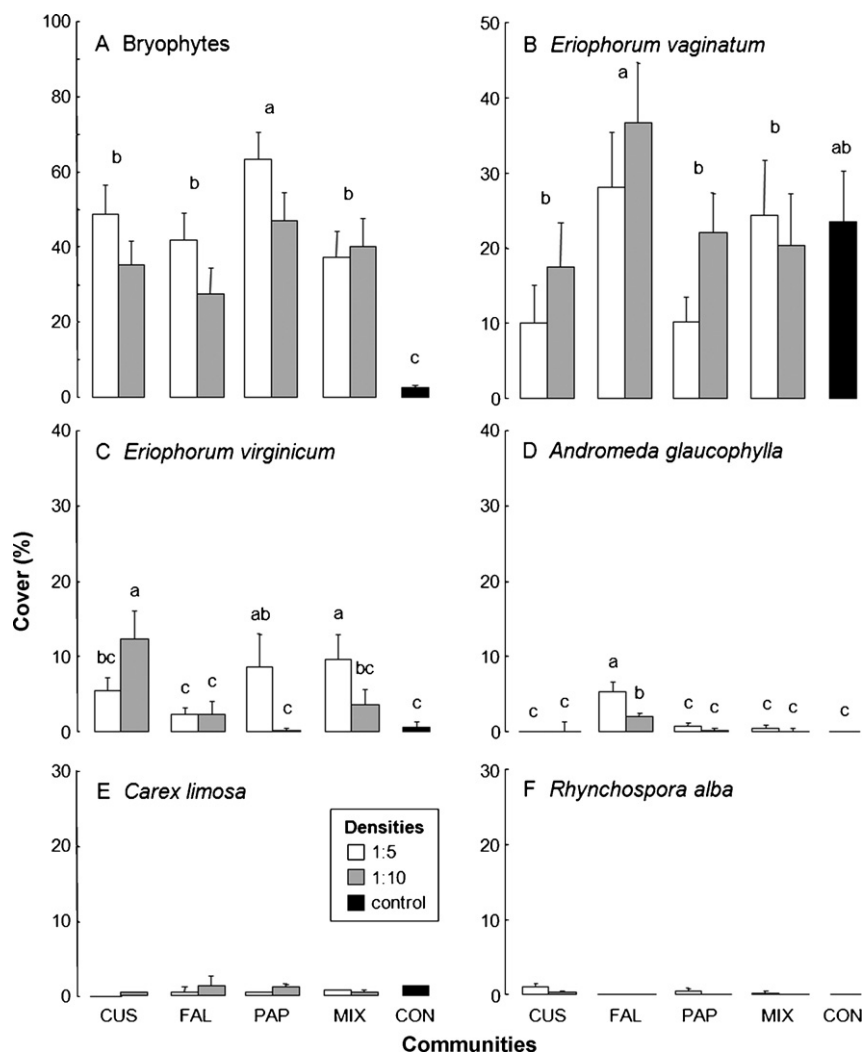


Fig. 2. Effect of introduction densities and community types on plant establishment after three growing seasons. The horizontal axis represents the four community types that were tested: CUS = *Sphagnum cuspidatum*, FAL = *Sphagnum fallax*, PAP = *Sphagnum papillosum*, MIX = mixed community composed of equal quantities of the following three species: *Cladopodiella fluitans*, *S. cuspidatum* and *S. papillosum* (see Table 1 for a complete description of the communities), as well as a control without introduction (CON). Bryophytes include *Cladopodiella fluitans*, *S. cuspidatum*, *S. fallax*, and *S. papillosum*. For bryophytes and *E. vaginatum*, letters refer to significant differences between communities regardless of the density, revealed by a protected LSD test. When no interaction was found, density was in fact significant for bryophytes only ($F=6.59$; $P=0.02$). There was a significant interaction between density and community type for *E. virginicum* ($F=6.37$; $P=0.003$) and *A. glaucophylla* ($F=5.91$; $P=0.004$). Significant differences between individual treatments according to LSMEANS comparison are shown by letters. No difference was found between treatments for *Carex limosa* and *Rhynchospora alba* ($P \geq 0.5$). Bars indicate standard errors ($n=4$).

for a randomized complete block design. Multiple comparison tests were used to locate differences between treatments of each main effect, once shown significant (protected LSD). When the density \times community interaction was shown significant, the SLICE option of GLM in combination with LSMEANS comparison option (protected LSD) was used to detect the overall effect of a factor within each level of the other factor. All the analyses were conducted using the GLM procedure of SAS Software (SAS Institute, 2003).

3. Results

3.1. *C. fluitans* regeneration

C. fluitans did not colonize bare peat when no fragment was added to the experimental floating peat surfaces (Fig. 1; contrast control vs other treatments: $F=6.28$, $P=0.02$). Yet, when fragments were introduced, they spread more when protected by a straw mulch (Fig. 1; contrast straw 1:4 fine (treatment 5) vs no straw 1:4 fine (treatment 4): $F=6.73$, $P=0.02$; contrast straw large (treat-

ments 3, 7, 9) vs no straw large (treatments 2, 6, 8), $F=19.53$, $P<0.01$). More precisely, treatments with straw had a mean percent cover of 55% while treatments without straw, excluding the control, had a mean percent cover of 11%. The size of fragments and their introduction density had no effect on the regeneration of *C. fluitans* (P varied between 0.15 and 0.98 for the six contrasts used).

3.2. Pool margin communities

After three years, bryophyte covers for all communities were much higher in the experimental plots (43%) than in the control plots where no introduction was done (2%; Fig. 2A). Introducing plant material with a higher density ratio proved slightly beneficial for bryophytes ($F=6.59$; $P=0.02$): with initial density ratio of 1:5, the final percentage cover was 1.3 times higher (48% cover) than with the initial density ratio of 1:10 (37% cover; Fig. 2A). The community dominated by *S. papillosum* established better than all the others (Fig. 2A). Analysing the outcome composition of the mixed community, we did observed the following: (1) the plots became

dominated by *S. papillosum* covering twice more surface area than when reintroduced as an unmixed community, (2) the cover of *S. cuspidatum* was 20 times lower when introduced in a mixed community rather than in an unmixed community, and (3) *C. fluitans* did not succeed to establish (Fig. 3).

Vascular plants that were introduced had <5% cover after three years, except *Eriophorum virginicum* L. which reached $12 \pm 3\%$ cover in the *S. cuspidatum* community (Fig. 2C). Even though *Eriophorum vaginatum* L. was not part of the introduced plant material (Table 1), it invaded all communities in experimental plots with a mean percent cover between $10 \pm 6\%$ and $37 \pm 16\%$ (Fig. 2B). *Andromeda glaucophylla* Link. established best in the *S. fallax* community, especially with a higher initial density ratio (Fig. 2D). Yet, its cover was low ($5 \pm 0.3\%$) despite a high initial cover at the donor site ($28 \pm 12\%$, see Table 1). *Carex limosa* L. and *Rhynchospora alba* (L.) Vahl. did not establish well; there was no difference between their mean percent cover in the control vs reintroduced communities (Fig. 2E and F).

4. Discussion

4.1. *C. fluitans* regeneration

Our study shows that *C. fluitans* is able to regenerate in a restored site when the peat surface is continually kept moist. Yet, straw mulch seems essential to the liverwort development. It is possible that *C. fluitans* may have benefited from nutrient leaching from straw mulch, but only *K* lixiviates from straw have been shown significant for peatland bryophytes (Rochefort, unpublished data). Even if peat substrate was permanently wet in our experiment, the liverwort may also have benefited from improved moisture conditions at the interface soil–atmosphere as shown beneficial for other mosses (Price et al., 1998). Yet, we think *C. fluitans* may use straw mainly as a substrate for growth. Reintroduction by patches of *C. fluitans* protected with straw covered two times more surfaces after two growing seasons than originally. Yet, it did not grow directly on bare peat between patches but instead extended mainly on straw fragments. Straw thus seems to provide a suitable structural substrate for the growth and expansion of *C. fluitans* mats. The density and the fragment size had no effect on the regeneration of *C. fluitans*. Lower densities should be favored for restoring pool margins since areas dominated by *C. fluitans* mats in natural peatlands are restricted. For introducing *C. fluitans* directly on pool margins of restored sites, fine shredded fragments may produce a more uniform mat since they are easier to apply homogeneously. It remains that restoring unmixed *C. fluitans* carpets should be favored since it did not establish when introduced simultaneously with *Sphagnum*. Further research is needed to test whether *C. fluitans* is able to maintain itself beside *Sphagnum* carpets on pool margins of restored peatland.

Table 1

Mean percentage cover \pm SD of the species at the donor sites in the harvested quadrats for the four communities (*Cladopodiella fluitans*, *Sphagnum cuspidatum*, *Sphagnum fallax*, and *Sphagnum papillosum*) prior to harvest (2005). For botanical nomenclature, see: Ley and Crowe (1999) for *Cladopodiella fluitans*, Anderson (1990) for *Sphagna*, and Gleason and Cronquist (1991) for vascular plants.

	<i>C. fluitans</i>	<i>S. cuspidatum</i>	<i>S. fallax</i>	<i>S. papillosum</i>
<i>Cladopodiella fluitans</i> (Nees) H. Buch	100	0	0	0
<i>Sphagnum cuspidatum</i> Hoffman	0	99 ± 2	0	0
<i>Sphagnum fallax</i> (H. Klinggraff) H. Klinggraff	0	0	98 ± 4	0
<i>Sphagnum papillosum</i> Lindberg	0	0	0	99 ± 1
<i>Andromeda glaucophylla</i> Link.	0	0	28 ± 12	7 ± 1
<i>Carex limosa</i> L.	28 ± 18	44 ± 2	16 ± 19	20 ± 16
<i>Chamaedaphne calyculata</i> (L.) Moench.	1 ± 1	1 ± 2	7 ± 9	2 ± 2
<i>Eriophorum virginicum</i> L.	0	24 ± 20	0	6 ± 6
<i>Rhynchospora alba</i> (L.) Vahl.	0	14 ± 16	0	4 ± 5
<i>Vaccinium oxycoccos</i> L.	2	4 ± 3	3 ± 4	3 ± 2

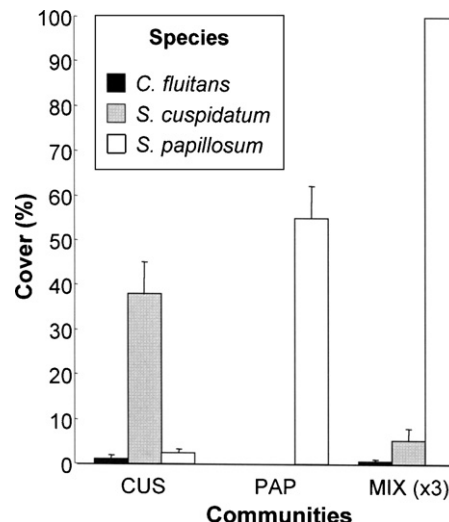


Fig. 3. Establishment of *Cladopodiella fluitans*, *Sphagnum cuspidatum* and *Sphagnum papillosum* in the *S. cuspidatum* (CUS) and *S. papillosum* (PAP) dominated communities as well as in the mixed community (MIX, see Table 1), after three growing seasons. Mean covers have been multiplied by three for the species composing the mixed community to correspond to the same initial cover as for the CUS and PAP communities, facilitating direct comparison of establishment success between mixed and unmixed *Sphagnum* species dominated communities. Bars indicate standard errors ($n=4$). The two introduction densities (1:5 and 1:10) were averaged here.

4.2. Pool margin communities

The *Sphagnum* moss layer transfer approach with wet bog communities was successful in revegetating *Sphagnum* carpets along pool margins, where a cover of 50% was reached after three growing seasons. The tested *Sphagnum* had similar establishment success than the other species used for restoring drier peat field surfaces, which reach 65% cover within 6–9 years post-restoration (Peatland Ecology Research Group, unpublished data). *S. papillosum* was the most successful species, especially when introduced simultaneously with *S. cuspidatum* where it grew twice as much as in the unmixed community. The benefit of growing peat mosses of the taxonomic section *Sphagnum* (ca *S. magellanicum* or *S. papillosum*) on substrate conditioned with species of the taxonomic section *Cuspidata* has been shown in the context of *Sphagnum* fibers farming for optimizing biomass production (Picard, 2010). In fact, species of the section *Sphagnum* are not efficient in transporting water by capillarity and may benefit from the neighboring presence of individuals from the section *Cuspidata* which adhere better to the substrate and may act as a substrate conditioner on residual peat. This may also apply to pool margin which may sporadically experience drought during the summers.

Despite successful establishment for *Sphagnum* mosses, vascular plants were still scarce in experimental plots, even after three growing seasons. Their establishment from seed germination may have been impeded by the reduced light intensity (Kettenring et al., 2006), but rhizomes were also part of the reintroduced material. It may also only be a question of time as vascular plants take six years to reach significant cover (more than 20%) on drier peat field surfaces (Isselin-Nondedeu et al., 2007). Pool vascular species may also have suffered from competition since our plots were spontaneously invaded by *E. vaginatum*. This plant is a competitive species known to be one of the few plants able to colonize vacuum mined peatlands (Lavoie et al., 2005; Poulin et al., 2005). However, a decrease in the number of *E. vaginatum* tussocks in time has been observed in abandoned peatlands (Lavoie et al., 2003, 2005) and this invasion at the pool margin might be just a transient phase in the restoration trajectory.

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