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Techniques for restoring fen vegetation on cut-away peatlands in North America

Graf, M.D.[1,2*] **& Rochefort, L.**[1,3]

[1]*Peatland Ecology Research Group and Centre d'études nordiques, Département de phytologie, Université Laval, Québec, G1K 7P4, Canada;*
[2]*Current address: Karl-Grüneklee-Str. 1, 37077 Göttingen, Germany;* [3]*E-mail line.rochefort@plg.ulaval.ca;*
[*]*Corresponding author; E-mail martha-darling.graf.1@ulaval.ca*

Abstract
Question: Which restoration measures (reintroduction techniques, reintroduction timing and fertilization) best enable the establishment of fen species on North American cut-away peatlands?
Location: Rivière-du-Loup peatland, southern Québec, Canada.
Methods: In total, eight treatments which tested a combination of two reintroduction techniques, two reintroduction timings and the use of phosphorus fertilization were tested in a field experiment within a completely randomized block design.
Results: *Sphagnum* transfer, a reintroduction technique commonly used for bog restoration in North America, was effective for establishing *Sphagnum* and *Carex* species. The hay transfer method, commonly used for fen restoration in Europe, was much less successful, probably due to questionable viability of reintroduced seeds. The treatments which included light phosphorus fertilization, had a higher *Carex* cover after three growing seasons. The timing of the reintroductions had no impact on the success of vegetation establishment. However, vegetation reintroduction should be carried out in the spring while the ground is still frozen to minimize other ecological impacts.
Conclusions: The success of the diaspore reintroduction technique on small-scale units indicates that a large-scale restoration of fens using this technique is feasible.

Keywords: *Carex*; Fertilization; Reintroduction timing; Revegetation; *Sphagnum*.

Nomenclature: Scoggan (1978) for vascular plants; Anderson (1990) for *Sphagnum*; Anderson et al. (1990) for other mosses.

Abbreviations: GLM = Generalized linear modeling.

Introduction

Research on restoring bog vegetation in North America is abundant (Price et al. 1998; Rochefort 2000; Rochefort et al. 2003; Campeau et al. 2004; Chirino et al. 2006). However, research on restoring fen vegetation has only recently begun (Cooper & MacDonald 2000; Cobbaert et al. 2004). These projects aim to restore fen vegetation on harvested peatlands. Modern harvesting techniques can lead to exposure of the underlying minerotrophic peat and mineral deposits. Such peatlands are richer in minerals and higher in pH than the pre-existing bog, thus creating conditions which are sub-optimal for bog community restoration. Restoration towards a fen including *Sphagnum* species common in moderate-rich fens is more desirable for such sites (Wind-Mulder et al. 1996).

Although much research has been conducted on fen restoration in Europe, little can be transferred to North America due to different goals, desired end-states and restoration challenges (Table 1). These dissimilarities can be attributed to differences in starting conditions, vegetation types and land-use, as well as population densities and the resulting pressure on the landscape. Due to the paucity of pristine fens in Europe, restored fens create important habitats (Kratz & Pfadenhauer 2001). Therefore, the goal of restoration projects in Europe is often high plant diversity and the successful reintroduction of rare species (Wheeler & Shaw 1995; van Duren et al.1998; Hald & Vinther 2000; Kratz & Pfadenhauer 2001; Tallowin & Smith 2001; Lamers et al. 2002). In contrast, large undisturbed fen systems are abundant in boreal North America (Zoltai & Pollet 1983; Rubec 1998; Vitt et al. 2005); therefore, the focus of restoration is on the return of the peatland's ecosystem functions (Rochefort 2000). The great majority of European projects aim to restore intensive agricultural lands to extensively managed fen meadows, not back to their undisturbed state (Rowell et al. 1985; Pfadenhauer 1994; Pfadenhauer & Klötzli 1996; Lamers et al. 2002; Jacquemart et al. 2003). The restoration of agricultural lands implies challenges (i.e. eutrophication, competition with existing plants, succession towards forest; succession towards bog due to altered hydrology) different from those in North America. Abandoned, cutover peatlands are primary succession sites which are void of vegetation and have no viable seed bank (Campbell et al. 2003). Owing to these inherent differences, fen restoration techniques which correspond with the North American context should be developed and tested.

Table 1. An overview of the differences between fen restoration in Europe and North America.

	Europe	North America
Goal	High biodiversity [a,b,c,d,e,f] Ecosystem function [b,c]	Ecosystem function [g]
Major disturbance	Intensive agriculture [a,b,c,d,e,f] Peat extraction [h,i]	Peat extraction [b]
Desired state	Semi-natural fen state (extensive agriculture) [a,b,c,d,e,f]	Natural fen state [h,i]
Problems	Eutrophication [b,c,d] Succession [a,d] Acidification [d] Existing seed bank/ vegetation [b,c,d,f] Changes in hydrology [a,b,c,d]	No seed bank [h,i] Changes in hydrology [h,i]
Techniques	Top-soil removal [c,d,f] Mowing/grazing [a,b,c,f,] Liming [d] Hay transfer [c,d,f] Rewetting/restoration of hydrology [b,c,d]	Rhizome transplants [h] *Sphagnum* transfer [i] Rewetting/restoration of hydrology [h,i]

[a] Wheeler & Shaw (1995); [b] Pfadenhauer & Klötzli (1996); [c] Kratz & Pfadenhauer (2001); [d] Lamers et al. (2002); [e] Rowell et al. (1985); [f] Patzelt et al. (2001); [g] Rochefort (2000); [h] Cooper & MacDonald (2000); [i]Cobbaert et al. (2004).

Bryophyte species are largely absent in European fen restoration projects, although they are important to species composition (Mitsch & Gosselink 2000; Succow & Joosten 2001) and function of undisturbed fen (Longton 1984; Vitt 2000). The exclusion of bryophytes from European restoration projects is probably due to a lack of donor vegetation sources and unsuitable water chemistry caused by eutrophication (H. Joosten pers. comm.). As these problems are not as extreme in North America, fen restoration techniques should include bryophytes because they may be essential in the return of the systems' peat accumulating function (Rochefort 2000).

The existing research projects on fen community restoration in North America have not been successful in introducing bryophytes (Cooper & MacDonald 2000; Cobbaert et al. 2004). Bryophytes have been, however, successfully restored on bogs using the application of donor diaspore material (Rochefort et al. 2003). This method, called the *Sphagnum* transfer method, involves collecting the first few centimeters of plant diaspores from a donor site, reintroducing these plant fragments in a 1:10 donor to recipient ratio, applying straw mulch and a light dose of phosphate fertilizer (Rochefort et al. 2003).

A European fen revegetation technique of interest for North American restoration goals is the hay transfer method (Pfadenhauer & Grootjans 1999). This technique involves mowing the donor site when the desired seeds are ripe, yet still attached to the stalks, then transferring the fen 'hay' directly onto the restoration site. This technique can only be carried out in the summer months when the seeds are ripe. The hay is spread using a donor to recipient area ratio of 1:1 to 5:1. This technique has also been shown to be effective in reintroducing bryophytes on calcareous grasslands (Jeschke & Kiehl 2006).

Using fertilization in restoration projects can have positive and harmful effects on the development of the restored site. In some cases fertilization may aid the establishment of aggressive, fast growing plants that can persist for a long time after invasion (D'Antonio & Chambers 2006). In contrast, fertilization may help recolonization in severe environments. In the case of bog restoration, a light fertilization of phosphate has been shown to increase the cover of vascular plants and pioneer mosses, which facilitate the establishment of *Sphagnum* species by stabilizing the microclimate and substrate (Salonen & Laaksonen 1994; Sliva & Pfadenhauer 1999; Groeneveld et al. 2007).

We conducted a field experiment to test vegetation reintroduction techniques which are applicable to fen restoration in North America. The goal of this experiment was to respond to the following questions: (a) which technique, *Sphagnum* transfer or hay transfer, is more effective for reintroducing fen species, (b) does phosphate fertilization increase the establishment of the reintroduced species and (c) what is the best time, early spring or mid-summer, to reintroduce species?

Material and Methods

Site description

The field experiment was carried out over three growing seasons on two areas of an abandoned, cut-away peatland (47°45' N, 69°30' W and 47°50' N 69°25' W), ca. 200 km northeast of Québec, Canada. This 15-km^2 peatland is part of a large complex of ombrotrophic bogs interspersed with *Alnus* swamps (Gauthier & Grandtner 1975) and is classified as low boreal peatland (Anon. 1988). Different sectors of the peatland were mined to their minerotrophic peat layer and were abandoned four and eight years prior to the experiment. The regional climate is characterized by cold winters and warm summers with January and July mean temperatures of – 13 °C and 18°C, respectively. The mean annual precipitation is 963 mm, of which 72% falls as rain (Anon. 2007). The pH of the restoration sectors varied from 5.0 to 5.9 and the electrical conductivity from 24 μS.cm^{-1} to 134 μS.cm^{-1} (Graf et al. 2008; Cobbaert et al. 2004).

The donor sites are ca. 25 km southwest of the restoration site. These donor sites were chosen because the environmental parameters were similar to the restoration sites. The pH values were 5.5 and 5.8 and electrical conductivities were 27 μS cm^{-1} and 40 μS cm^{-1} for the first and second donor sites, respectively (Cobbaert et al. 2004). The first donor site (47°77' N, 52°83' W) was a poor fen, dominated by *Sphagnum* species. The dominant species were (in order of decreasing dominance including all species with >2% cover): *Sphagnum centrale*, *Calamagrostis canadensis, Salix discolor, Carex brunnescens, Glyceria canadensis, Polytrichum strictum, Sphagnum fallax, Spiraea latifolia, Aulacomnium palustre, Sphagnum squarrosum, Solidago rugosa, Rubus idaeus, Alnus rugosa, Sphagnum girgensohnii* and *Carex stricta*. The second donor site (48°19' N, 52°81' W) was a moderate to rich fen, dominated by herbaceous plants, especially *Carex* species. The dominant species which had a percent cover > 2% were: *Carex rostrata, Calamagrostis canadensis, Carex utriculata, Glyceria canadensis, Sphagnum warnstorfii, Aulacomnium palustre, Warnstorfia exannulata* and *Scirpus cyperinus*. For more information on the sites see Cobbaert et al. (2004).

Experimental design

The experiment was a randomized block design with five blocks of eight treatments. The aim was to test two reintroduction techniques, two donor: recipient area ratios, two reintroduction times, two different plant communities used for donor sites, the use of straw mulch and phosphate fertilizer (Table 2). Because of the large number of tested variables, the experiment design was not factorial; we only included treatments that were logical from a restoration and ecological standpoint. Table 2 provides an overview of the different treatments.

The five blocks were located on three 30 m × 70 m areas which were scraped and leveled in the early summer of 2004 to homogenize the surface and remove any spontaneous vegetation. Each treatment was applied to 5 m × 6 m experimental units during May and early August of 2004. For the *Sphagnum* transfer method, the top 10 cm of vegetation was collected by hand, manually shredded and applied to the specified experimental units. The material for the hay transfer technique was collected by hand clipping the aerial vegetation at ground level. The straw mulch was manually applied to the corresponding experimental units to the point that the reintroduced vegetation or bare peat was completely covered. This is consistent with 3000 kg ha^{-1} recommended for bog restoration (Rochefort et al. 2003). The straw mulch exceeded the units by at least 0.5 m to minimize the border effect. A rock phosphorus fertilizer in a dose of 15 g m^{-2} (Quinty & Rochefort 2003) was applied to specified units.

Site monitoring

The regional precipitation of the three growing seasons was assessed by comparing the monthly rainfall data (Direction du suivi de l'état de l'environnement, Ministère du Développement durable, de l'Environnement et des Parcs du Québec) with 30-year mean values from nearby St. Arsène (Anon. 2007). The soil water potential was measured using tensiometers (Soil Measurement Systems, Tucson. AZ, US) on 18 experimental units (between three and four for each block) at 2 cm below the surface to characterize the water available for the bryophytes and at 10 cm below the surface to characterize the root zone for vascular plants. The water level was also measured from five wells, one located at the center of each block. The soil water potential and water levels were measured weekly during the growing season of 2004. Although positive water potentials are possible, zero was the maximum value because measurements could not be taken on flooded areas.

The establishment of the reintroduced species was assessed by visually estimating the percent cover of each species as well as total bryophytes, total *Sphagnum,* total of other mosses (mosses other than *Sphagnum*), total vascular plants, total *Carex*, total shrubs and trees and the total vegetation cover for each experimental unit. The bryophytes were estimated by noting species and percent covers observed within 20 (25 cm × 25 cm) quadrats equally spaced on each unit. The vascular plants and total vegetation were estimated using ten (50 cm × 50 cm) quadrats per unit. These vegetation surveys were carried out in September of three consecutive growing seasons (2004-2006).

Data analysis

The cover (%) of each vegetation strata, as well as the most important vegetation groups, such as *Sphagnum* and *Carex*, and the dominant species *Scirpus cyperinus* were compared among treatments using the generalized linear modeling (GLM) procedure of SAS and *a priori* contrasts (SAS Statistical System software, v. 9.1, SAS

Table 2. Treatments tested in a field experiment.

	Vegetation reintroduction	Donor: recipient ratio	Reintroduction time	Donor site	Mulch	Fertilization
1	Diaspore application	1:10	Early spring	*Sphagnum* fen	Straw	Phosphate
2	Hay transfer	1:1	Mid-summer	*Sphagnum* fen	No straw	Phosphate
3	Hay transfer	1:10	Mid-summer	*Sphagnum* fen	Straw	Phosphate
4	Hay transfer	1:1	Mid-summer	*Carex* fen	No straw	Phosphate
5	*Sphagnum* transfer	1:10	Mid-summer	*Sphagnum* fen	Straw	No phosphate
6	*Sphagnum* transfer	1:10	Mid-summer	*Sphagnum* fen	Straw	Phosphate
7	None		Mid-summer		Straw	Phosphate
8	None		Mid-summer		Straw	No phosphate

Institute Inc., Cary, NC, US). *A priori* contrasts were used because of the strong inherent structure of the treatments (Day & Quinn 1989). Contrary to *post priori* contrasts, significant contrasts can be considered even when the main treatment effect is not significant.

Seven *a priori* contrasts were designed for this experiment. The contrasts are outlined below:

1. Two reintroduction techniques in their optimal forms (optimal timing and donor: recipient ratio; Table 2, treatment 1 vs. 4)
2. Two reintroduction techniques in identical forms (treatment 3 vs. 6)
3. Two reintroduction times of *Sphagnum* transfer (treatment 1 vs. 6)
4. The effect of fertilizer for *Sphagnum* transfer (treatment 5 vs. 6)
5. The effect of the ratio used for hay transfer (treatments 2 and 4 vs. 3)
6. Two donor sites used for hay transfer (treatment 2 vs. 4)
7. All treatments where vegetation was introduced (treatments 1 through 6) vs. two control treatments (treatments 7 and 8).

Five outlier experimental units out of 40 were excluded from the analysis because these units were permanently flooded during the growing season. Because constant flooded conditions were not intended and because we did not reintroduce aquatic vegetation, these units were removed so that the analysis was not biased.

Results

Vegetation

Of the treatments tested, only the reintroduction method and fertilizer treatments showed differences in vegetation after three growing seasons. No differences in vegetation cover were detected among treatments with different donor sites, reintroduction times and donor: recipient ratios (Table 3). The *Sphagnum* transfer was a superior method for reintroducing fen vegetation, as the covers of *Sphagnum*, *Carex* and total vegetation were higher on these experimental units (Table 3 and Fig. 1, contrasts 1 and 2). When all reintroduction treatments were compared with control treatments, only *Sphagnum* cover was significantly higher (Table 3 and Fig. 1, contrast 7). The cover of *Carex* species was higher where phosphate fertilizer was used (Table 3 and Fig. 1, contrast 4). Moreover, species richness was significantly higher where vegetation had been reintroduced (24 ± 3 species per unit) than where vegetation had not been reintroduced (22 ± 2 species per unit) (Table 3).

The mean cover of herbaceous plants was similar for all treatments (ca. 30%). The covers for non-*Sphagnum* mosses, as well as the trees/shrub strata, were very low among all treatments (2% for mosses and 0.7% for trees/shrubs) and also were not different among treatments.

A closer look at species that established on the experimental units revealed that the majority were wetland species, many of which recolonized spontaneously. *Scirpus cyperinus* had the highest cover (13%) and was found on 85% of the experimental units (Table 4). When the covers of the individual species were examined according to the reintroduction method, only *Sphagnum* transfer treatments had species covers which were much higher than the control units (Table 4). The reintroduced species which proved to be the most successful in recolonizing the *Sphagnum* transfer experimental units were *Sphagnum centrale*, *Carex brunnescens, Glyceria canadensis*, *Sphagnum fallax* and *Viola palustris* (Table 4).

Environmental conditions

The first growing season (2004) was wetter than normal. The recorded precipitation was higher than the

Table 3. ANOVAs and *a priory* contrasts for a field experiment testing the effect of two reintroduction techniques, two reintroduction times, the use of phosphate fertilizer, two donor: recipient area ratios and two donor sites on vegetation cover of various groups. Significant *P*-values ($\alpha < 0.05$) are in bold. The numbers signify contrasts described in the text; contrasts which were significantly different are shown in Fig. 1.

Source	df	*Sphagnum* spp. (log (x+1)) F	*P*	*Carex* spp. (log (x+1)) F	*P*	*Scirpus cyperinus* F	*P*	Herbaceous plants F	*P*	Total vegetation F	*P*	Species richness F	*P*
Blocks	4												
Treatments	7	64.35	**< 0.0001**	3.79	**0.007**	1.71	0.16	0.75	0.64	3.01	**0.02**	1.43	0.24
Contrasts:													
1. Reintroduction method (optimal timing and ratio)	1	149.68	**< 0.0001**	13.59	**0.001**	4.08	**0.05**	0.01	0.91	7.78	**0.01**	0.01	0.93
2. Reintroduction method (identical timing and ratio)	1	85.59	**< 0.0001**	6.76	**0.02**	0.25	0.62	1.66	0.21	7.65	**0.01**	1.46	0.24
3. Reintroduction timing	1	1.74	0.2006	0.09	0.76	2.37	0.14	0.39	0.54	0.00	0.97	2.57	0.12
4. Fertilizer	1	3.15	0.09	4.45	**0.05**	0.75	0.39	2.81	0.11	0.41	0.53	0.04	0.84
5. Ratio of hay transfer	1	0.00	0.99	0.11	0.74	0.23	0.64	0.14	0.72	0.04	0.84	0.04	0.83
6. Hay transfer sites	1	0.91	0.35	0.07	0.79	0.28	0.60	0.35	0.56	0.01	0.91	0.29	0.59
7. Control	1	93.37	**< 0.0001**	1.02	0.32	4.05	**0.05**	1.19	0.29	0.70	0.41	4.37	**0.05**
Error	23												
Total	34												

30-year means for the months of June, July, August and September (Anon. 2007). The month of August was exceptionally wet with a total precipitation of 186 mm, which is almost double the mean of 98 mm. As the first growing season is critical to *Sphagnum* regeneration (Chirino et al. 2006), the wet 2004 season was a good premise for the successful establishment of the *Sphagnum* species. The second growing season (2005) was drier than normal with a long dry period in August and the third growing season was average with precipitation evenly spread out throughout the season (Anon. 2007).

The water level and water potential data from the first growing season show that hydrological conditions varied among blocks (Table 5). They ranged from near constant inundation (block A) to drier conditions (block C and D). The highest *Sphagnum* cover (31% ± 14) was observed for block B where the water level was just below the surface (Table 5).

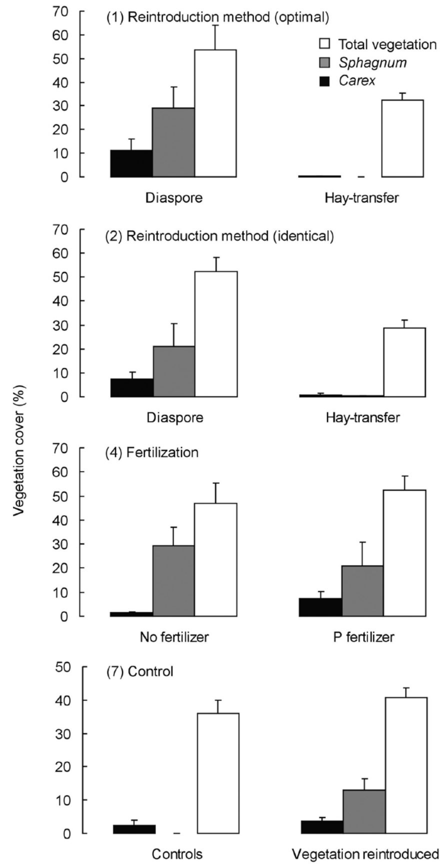

Fig. 1. Cover % of *Carex*, *Sphagnum* and total vegetation for the treatments where the contrasts were significantly different ($\alpha < 0.05$). 1, 2, 4 and 7 are the graphic representations of the contrast analyses (Table 3). Contrast 1, 'Reintroduction method (optimal)' compares a spring introduction of the *Sphagnum* transfer method in a 1:10 ratio with a summer introduction of the hay transfer method in a 1:1 ratio. Contrast 2, 'Reintroduction method (identical)' compares the same reintroduction methods where the reintroduction timing and ratio are identical. Contrast 4 compares *Sphagnum* transfer method treatments which were fertilized with P with those which were not and contrast 7 compares treatments where vegetation was introduced with control treatments.

Discussion

Reintroduction techniques

It was not surprising that *Sphagnum* cover, and consequently total vegetation cover, were significantly higher on *Sphagnum* transfer units because only this technique included large amounts of *Sphagnum* fragments. However, it was surprising that *Carex* percentages were higher on *Sphagnum* transfer units than hay transfer units (Fig. 1, Graph A). The donor material for the hay transfer treatments came from a site where *Carex* was dominant and donor to recipient ratio ten times higher than that used for the *Sphagnum* transfer treatments.

Carex species are notorious for being problematic in restoration efforts (Galatowitsch & van der Valk 1996; Pfadenhauer & Grootjans 1999; van der Valk et al. 1999; Cooper & MacDonald 2000; Patzelt et al. 2001). Seed viability proved to be a major impediment to the establishment of *Carex* species in prairie potholes (van der Valk et al. 1999). Under controlled conditions, Patzelt et al. (2001) found that *Carex* species showed some of the lowest germination rates found for fen species. Restoration methods which reintroduce rhizomes, not seeds, have shown higher *Carex* establishment (Cooper & MacDonald 2000). The *Sphagnum* transfer method included *Carex* rhizomes which could explain a higher establishment rate, despite a much lower quantity of reintroduced *Carex* material.

The hay transfer technique on our experimental units proved far less successful for reintroducing fen species than was observed in European experiments (Patzelt et al. 2001; Tallowin & Smith 2001). Patzelt et al. (2001) found that 70% of the donor species were transferred using the hay transfer method. In contrast to our experiment, they introduced seed material from four different donor sites which increased their chances of having viable seeds.

The hay transfer method is highly adapted to European fen management strategies which require mowing to prevent succession to shrub land and eventually forests (Table 1; Rowell et al. 1985; Jacquemart et al. 2003). Conversely, in North America, fen preservation does not require mowing. Additionally, the intact hydrology of North American fens would require specialized equipment for large scale mowing in the summer when the seeds are mature. Due to the unpredictability of the germination of the introduced seeds and the logistical challenges of this technique, it seems the *Sphagnum* transfer method is more appropriate to the North American context.

Table 4. The frequency, mean total cover of species across all experimental units, provenance and mean cover for units from each reintroduction technique category. The twenty-five most frequent species are shown. The frequency was computed by dividing the number of units where the species was present by the total number of experimental units ($n = 35$).

Species	Frequency (%)	Mean total cover (%)	Provenance		Cover (%) for treatments		
			Donor sites	Spontaneous	Diaspore	Hay transfer	Controls
Scirpus cyperinus	85	13.00	X	X	9.1	15.3	15.0
Solidago graminifolia	62	2.84	X	X	2.4	3.7	2.4
Agrostis scabra	60	1.38		X	1.0	1.7	1.4
Spiraea latifolia	52	0.49	X	X	0.5	0.5	0.4
Dicranella cerviculata	36	0.76		X	0.2	1.6	0.4
Sphagnum centrale	35	7.72	X		21.4	0.2	0.04
Juncus brevicaudatus	34	1.83		X	0.9	0.9	4.2
Polytrichum strictum	31	0.43	X	X	0.5	0.5	0.3
Pohlia nutans	28	0.45	X	X	0.6	0.4	0.2
Lycopus uniflorus	25	1.87		X	0.3	1.0	2.9
Juncus effusus	25	0.55		X	2.0	1.0	0.4
Epilobium leptophyllum	24	0.52		X	0.5	0.4	0.3
Calamagrostis canadensis	23	0.43	X	X	0.6	0.6	0.4
Carex brunnescens	23	1.89	X		5.1	0.2	0.06
Viola palustris	21	0.41	X		1.1	0.1	0.02
Triadenum fraseri	20	0.25		X	0.2	0.2	0.3
Glyceria canadensis	18	1.09	X		2.7	0.3	0.01
Aulacomnium palustre	17	0.21	X		0.2	0.3	0.1
Solidago rugosa	16	0.27		X	0.2	0.2	0.5
Eriophorum spissum	15	0.26		X	0.7	1.3	0.4
Juncus bufonius	13	1.04		X	0.1	0.3	1.2
Equisetum arvense	12	0.83		X	0.3	0.5	1.5
Carex bebbii	12	0.42		X	1.0	0.2	0.4
Salix discolor	11	0.16	X	X	0.3	0.1	0.06
Sphagnum fallax	11	0.11	X		1.4	0.02	0.01

Preventive control

The dominance of *Scirpus cyperinus* on our experimental units is not a local phenomenon. This species has been observed on 50% of quadrats sampled from 17 abandoned, vacuum harvested fens across Canada (Graf et al. 2008). Yet, it is not known whether it should be considered an invasive species, a species that out-competes more desirable species or co-opts the direction of the post-disturbance succession (D'Antonio & Chambers 2006). Perhaps *S. cyperinus* is a desirable species which increases species diversity due to an increased microtopography created by the tussock structure (Peach & Zedler 2006). A dense *Scirpus* cover improved the regeneration of introduced fen bryophytes (Graf & Rochefort in press).

Fertilization

Fertilization proved to be effective in increasing the percentage of *Carex* species. Fertilization is known to increase vascular plant cover in bog restoration (Rochefort et al. 2003). As vascular plants are an important component of fen systems, using fertilizer should greatly improve the establishment of reintroduced species. Interestingly, no improvement could be discerned for the total herbaceous plant cover for treatments that included fertilizer. This field experiment used the same dose as is used for bog restoration. More research is needed to see if fen vegetation re-establishment could be improved with a different fertilization mix and/or dose.

Reintroduction timing

Even though there were no differences between the vegetation cover for the spring and summer reintroduction times, the logistics of the *Sphagnum* transfer method make a summer reintroduction more costly and damaging to the system. The best option to reduce the disturbance to the donor and restoration sites is to do the majority of the machine work in the early spring when the peatlands are still frozen or have just begun to thaw (Quinty & Rochefort 2003).

Table 5. Water level, soil-water potential at –2 cm and –10 cm for each experimental block during the first growing season (2004).

Block	Water level (cm)			Water potential –2 cm (mbars)			Water potential –10 cm (mbars)		
	Mean (± SD)	Max	Min	Mean (± SD)	Max	Min	Mean (± SD)	Max	Min
A	5 (±13)	23	– 15	– 1 (±2)	0	– 5	0 (±0)	0	0
B	– 5 (±12)	11	– 27	– 6 (±9)	0	– 23	– 6 (±9)	0	– 23
C	– 29 (±14)	– 1	– 41	– 29 (±24)	– 4	– 75	– 13 (±18)	0	– 53
D	– 39 (±12)	– 16	– 68	– 44 (±35)	– 10	– 110	– 38 (±41)	0	– 104
E	– 30 (±17)	– 5	– 64	– 16 (±13)	– 3	– 45	– 9 (±16)	0	– 36

Environmental conditions

Small changes in hydrology have a profound effect on bryophytes because they capture water mainly through capillary movement and do not have the means to actively extract water from their environment (Rydin & Jeglum 2006). The highest *Sphagnum* covers were observed for units where the mean soil water potential was just below 0, a fact which has been confirmed in greenhouse experiments (Graf & Rochefort in press). Additionally, prolonged flooding had a disastrous effect on the establishment of these species. Although greenhouse experiments showed that continuous flooding does not impede *Sphagnum* regeneration (Rochefort et al. 2002), physical disturbances in the field, such as erosion and sedimentation, often have a negative effect on regeneration (Quinty & Rochefort 2000).

Conclusions

Sphagnum transfer is an effective technique for restoring fen vegetation. After three years *Sphagnum* cover was similar to those observed on undisturbed fens with similar conditions in North America (Graf et al. 2008). In contrast, the cover of *Carex* species on the experimental restoration units was much lower than those observed in undisturbed fens (Graf et al. 2008). However, *Carex* species did establish successfully and perhaps their cover will increase through time with clonal growth.

The success of the *Sphagnum* transfer method at the small scales demonstrates a need for a large-scale restoration. Using a combinatorial experiment (Naeem 2006), the effect of the dominant species on the ecosystem function of the fen could be tested.

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