WETLANDS, Vol. 17, No. 4, December 1997, pp. 513–517

FIELD EXPERIMENT OF *SPHAGNUM* REINTRODUCTION ON A DRY ABANDONED PEATLAND IN EASTERN CANADA

Jean-Luc Bugnon[1], Line Rochefort[1,3] and Jonathan S. Price[2]
[1] *Université Laval*
Centre d'Études Nordiques and
Département de Phytologie
Faculté des Sciences de l'Agriculture et de l'Alimentation
Ste-Foy, Québec, Canada G1K 7P4
E-mail: Line.Rochefort@plg.ulaval.ca

[2] *University of Waterloo*
Department of Geography
Wetlands Research Center
Waterloo, Ontario Canada N2L 3G1

[3] *Author to whom correspondence should be addressed.*

Abstract: Early attempts at peatland restoration have been aimed mostly at rewetting the peat, which alone has proven inadequate to ensure good regeneration of *Sphagnum* mosses. *Sphagnum* mosses can be actively reintroduced by scattering *Sphagnum* fragments (diaspores) on bare peat surfaces and by sheltering them against desiccation. The present study aims at refining the restoration techniques to reintroduce *Sphagnum* where the surface conditions of cutover peatlands are too harsh for natural *Sphagnum* establishment. The objective is to increase local moisture conditions of the peat by reprofiling the surface to invert the camber created during drainage operations. *Sphagnum* diaspores were spread in the concavity. Reprofiling fields increased *Sphagnum* establishment compared to control sites. The addition of two plastic sheets on the edge of the field reduced evaporation and directed precipitation towards the middle of the field. When they were combined with reprofiling, there was a further increase in the establishment success of *Sphagnum*.

Key Words: reprofiling, restoration techniques, rewetting, *Sphagnum* establishment, water management

INTRODUCTION

The natural revegetation of abandoned peatlands does not have the attributes of natural bog vegetation and sometimes does not occur at all (Salonen 1987, Famous et al. 1991, Lavoie and Rochefort 1996). Natural revegetation of *Sphagnum,* the dominant peat-forming vegetation in bogs, has rarely been observed in rewetted bogs (Poschlod 1992) due to persistantly harsh hydrologic and microclimatic conditions (Price 1996). Early attempts at peatland restoration have focused on restoring the wet conditions typical of undisturbed peatlands by damming the drainage ditches, building embankments, and creating water reservoirs (Nick 1984, Eggelsmann 1988, Schouwenaars 1988, Meade 1992, Roderfeld 1993, Wheeler and Shaw 1995, LaRose et al. 1997). Until recently, peatland restoration has relied mostly on active water management practices but little on plant reintroduction (Wheeler and Shaw 1995). As natural regeneration of the moss layer in peat-harvested sites does not occur readily (at least in the time range of 25 years; Famous et al. 1991), attempts to actively reintroduce *Sphagnum* are warranted. Sphagna have a great power of regeneration and are able to reproduce vegetatively from almost any distinct part of the plant (including leaf, branch, and stem fragments; Poschlod and Pfadenhauer 1989, Rochefort et al. 1995). Subsequent studies demonstrated that a moss cover can be re-established by scattering such *Sphagnum* parts (diaspores) onto a peat surface (Rochefort and Campeau 1997). However, moss establishment is significantly better if a protective cover, such as a straw mulch, is applied on top of the diaspores (Quinty and Rochefort 1997, Rochefort and Campeau 1997). Alternatively, *Sphagnum* establishment success can also be improved by reintroducing Sphagna in association with shelter plants (Ferland and Rochefort 1997). These methods of plant reintroduction reduce evaporation from *Sphagnum* diaspores and the peat substrate and result in more favorable, humid, growing conditions at the air-peat interface (J.Price pers. com.). In a similar way, irrigation systems have been tested to increase humidity at the diaspore level (Rochefort and Bastien 1998). Irrigation favored *Sphagnum* establishment but to a lesser extent than the two previous methods. The impact of water droplets on the peat substrate displaced and/or buried the newly introduced *Sphagnum* diaspores.

Generally, *Sphagnum* regeneration/restoration success is related to the depth of the water table below the peat surface (Money 1995, Rochefort et al. 1995, Rochefort and Bastien 1998, Campeau and Rochefort 1996). Schouwenaars (1988) suggested that the water table should be no more than 40 cm below the peat surface if good *Sphagnum* regeneration is to be attained. However, Price (1996) indicated that soil moisture and soil tension conditions are more relevant for *Sphagnum* establishment than the water-table position. This is partly confirmed by Quinty and Rochefort (1997), who succeeded in re-establishing a *Sphagnum* cover when the water table fluctuated between −50 and −70 cm over several summers. Success here was attributed to the presence of a mulch that increased surface soil moisture. The long-term viability of the newly formed moss layer, however, remains to be seen for time spans greater than four years.

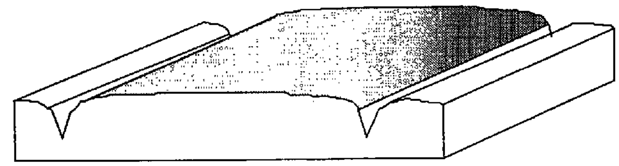
In this study, we attempted to reintroduce common peat-accumulating *Sphagnum* species on a very dry abandoned peatland where former drainage ditches had been filled three years before the experiment. Given that the only input of water to a bog is by direct precipitation, we needed to find ways to concentrate the rain water into local zones where *Sphagnum* diaspores could be reintroduced. In the peat industry, particularly when peat is harvested by the vacuum technique, the fields are shaped in a convex cross-sectional form to promote drainage toward the ditches. We hypothesized that if the convex form was inverted to produce a V shape, like a funnel, the peat substrate in the center of the field would be at a lower elevation with respect to the water table and would become relatively more humid than the surrounding areas. Furthermore, higher humidity of the peat substrate in the middle of the field could be attained if evaporation from the peat was reduced. This reduction can be achieved by adding an evaporation barrier (plastic sheets) on the elevated sections on the V shapes reprofiled fields. Additionally, this design will concentrate runoff from the plastic sheets toward the middle of the field.

METHODS

Study Site

The experiment was conducted at the St-Modeste peatland near Rivière-du-Loup, Québec, Canada (48°51′42″N, 69°27′12″W). Mean January and July temperatures are −12.1°C and 17.8°C, respectively, with mean total annual precipitation of 924 mm, of which 672 mm fall as rain (Environment Canada 1993). The peatland is located in the low boreal wetland zone and can be classified as a raised bog (NWWG 1987). The site was harvested for horticultural peat moss by the vacuum harvesting technique. An area of 16 fields (30-m wide by 350-m long) were exploited for approximately 25 years and then abandoned in 1987. The thickness of the residual organic layer is over 1 m deep. Drainage ditches were filled in 1992. Eight years after harvesting operations ceased, the vegetation cover is still very poor. Bare peat has been colonized only by a few shrubs (*Vaccinium sp.*, *Kalmia angustifolium* L., *Chamaedaphne calyculata* (L.) Moench) and a few *Betula alleghaniensis* Britton and *B. papyrifera* Marsh., which together represent less than a 1% cover over the total abandoned area.

A) Typical abandoned field profile



B) Experimental reprofiling

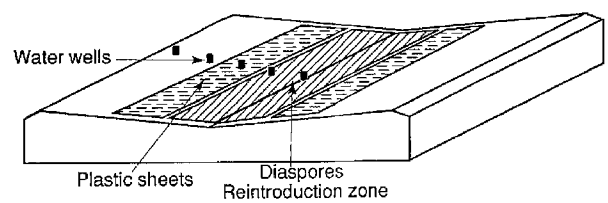


Figure 1. Typical abandoned vacuum post-harvested peat fields (A) before experimental reprofiling and in a wide V shape (B).

Rewetting Strategy

To create a peat substrate with better local moisture conditions, the exploited fields were re-shaped with a bulldozer to invert the cambered form into a wide V shape. After reprofiling the fields, the height difference from the edge to the middle of the field was approximately 1 m, representing a local slope of 0.03%. A second treatment consisted of adding a polyethylene sheet 10-m long and 5-m wide, on each external edge of the V, parallel to the ditch relicts. Each treatment was compared to a control site that was only flattened to reproduce the effect of the bulldozer passage (Figure 1).

Water-table depth was measured in dip wells oriented perpendicular to the ditch relicts (Figure 1). At the control site, only one dip well was used, assuming that the water table followed the plane topography. Volumetric soil moisture was measured at three locations in each experimental unit on three separate occasions, two days following a rain event. Samples were oven-dried at 65°C for five days to determine the volumetric moisture content. To minimize heterogeneity of variance of the moisture content data, an arcsin transformation ($\arcsin(\sqrt{(x/100)})$) was conducted on the original data.

Experimental Design

The experiment was carried out in a factorial split-plot design. Nine experimental units of 8 m × 8 m were delimited in the middle of the abandoned peat fields and clustered in three blocks. The blocks were scattered throughout the experimental area (17 ha). On each block, two experimental units were reprofiled in a concave form (see details below) and one flattened to be used as a control. The treatments were effected from early May 1995 and continued until the end of September for a total 181 growing days. The *Sphagnum* moss material that was reintroduced was collected in early May in nearby natural sites. The species used for the experiment were *Sphagnum angustifolium* (C. jens.) ex Russ, *S. capillifolium* (Ehrh.) Hedw., *S. magellanicum* Brid., *S. fuscum* (Schimp.) Klinggr., *S. fallax* (Klinggr.) Klinggr., *S. pulchrum* (Lindb. ex Braithw.), and *S. riparium* Ångstr. The selection of species collected from different ecological niche (pool, lawn, and hummock species) was justified by the fact that it was difficult to predict the hydrologic conditions in the middle of the V shape. Each species was collected by hand, in a pure species carpet, to a depth of 10 cm, which constitutes the most viable material (Campeau and Rochefort 1996). They were mixed and scattered by hand without any cutting of the *Sphagnum* fibers. *Sphagnum* material was introduced on area basis, to each experimental unit. In this experiment, each experimental unit of 8 m × 8 m received moss extracted from an equivalent area of 50 cm × 50 cm by species for a total of 2 m^2 for a ratio of 1 m^2 of living material for 30 m^2 of bare peat. *Sphagnum fallax* was applied 100 cm × 50 cm to balance the design.

The reintroduced *Sphagnum* mosses were covered with a straw mulch to reduce evapotranspiration. One bale of straw was used for each main plot, representing an approximative density of 1500 kg/ha (Quinty and Rochefort 1997).

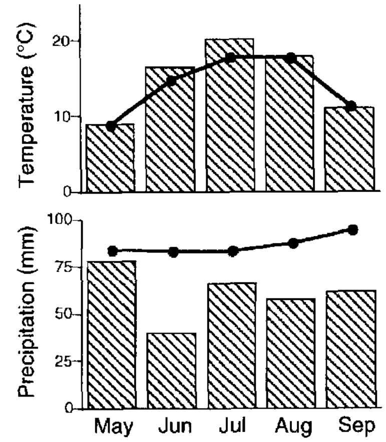


Figure 2. Climatic data for Rivière-du-Loup for the period May to September. Thirty-year normals (1961–1990) (lines) compared to the 1995 season (bars). Environment Canada (1993) and data from Ministère de l'Environnement et Faune du Québec for the summer 1995.

Plant Establishment Performance

To evaluate plant-establishment performance, 240 quadrats (20 cm × 20 cm) were placed on six equidistant lines along the humidity gradients for each experimental unit. In each quadrat, every capitulum (the head of the *Sphagnum* shoot) was counted. Originally, it was planned to evaluate the performance of each species, but after only one growing season, it was really difficult to segragate the regenerating diaspores, so no count per species was made. To reduce variance heterogeneity, the data were square-root transformed ($\sqrt{(n+0.5)}$). Statistical analyses were made with the GLM procedure of SAS (SAS Institute 1990). A Waller-Duncan comparison test was applied to determine the difference in the levels factor (Steel and Torie 1980). ANCOVA analysis was done by SYSTAT Software, 5.02 (Systat Inc. 1991).

RESULTS AND DISCUSSION

Hydrologic and Climatic Conditions of the 1995 Growing Season

The 1995 season was drier than normal, with total rainfall during the growing season (May to September) of 309 mm compared to the normal 447 mm (Figure 2). The dry weather during the summer of 1995 provided severe conditions to test the effectiveness of the experimental design. The water table in 7 out of 8 dip wells over the abandoned area remained 60 cm below the peat surface from July to October 1995 (LeQuéré, unpublished data).

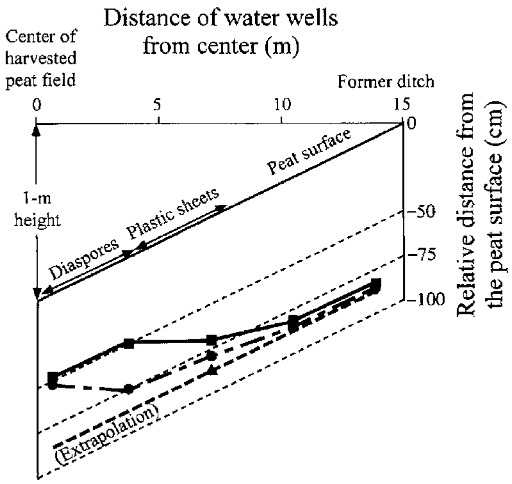


Figure 3. Relative distance from the peat surface (cm) for the water table for each treatment; square is profiled with plastic sheets, circle is profiled only, and triangle is the horizontal profile.

Rewetting Strategy

A markedly lower position with respect to the water-table position resulted from reprofiling the surface of the peat field, in the zone where the *Sphagnum* were reintroduced (Figure 3). The average water-table depth at the control site was −80 cm, compared to an average of −50 cm and −60 cm in the central zones of the profiled field with and without plastic sheets, respectively.

The plastic sheets had a twofold effect: 1) they reduced the evaporative losses from the covered portion, and 2) they directed surface flow toward the central zone, thus keeping it wetter. This may significantly increase the area compatible with *Sphagnum* regeneration (Heathwaite 1995).

There was a significant difference between the average volumetric soil moisture ($F = 61.9$; $P < 0.001$), for the profiled field with the plastic sheets (83%), profiled only (80%), and horizontal profile treatment (73%) (Figure 4). These moisture contents were relatively high compared to those reported by Price (1997) for cutover peat, in which saturation occurred at about 85% volumetric soil moisture. Price (1997) suggested that moisture contents in this range do not impose soil water-tension limitations to *Sphagnum* diaspores. While there was a general relationship between water-table depth and soil moisture demonstrated by our data, Price (1997) found that the nature of this relationship varied widely for peat of different bulk density.

Sphagnum Establishment Success

Sphagnum survival was directly related to the greater soil moisture and closer proximity to the water table

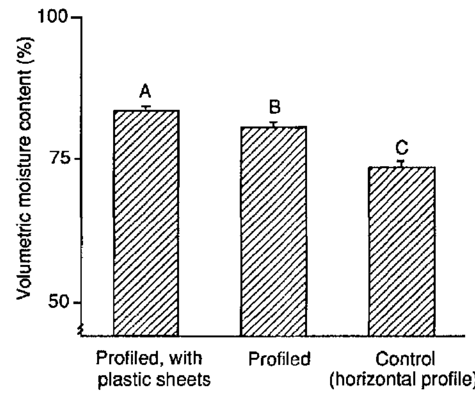


Figure 4. Average moisture content of surface peat of the re-profiled field treatments. Oneway ANOVA $F = 61.95$; $P < 0.001$; Waller-Duncan comparison tests are represented by different letters (alpha = 0.05).

induced by re-profiling the fields (Figure 5). *Sphagnum* establishment was greater when plastic sheets were used in combination with profiling (629 capitula/m^2) compared to profiling only (469 capitula/m^2) or the control site (146 capitula/m^2) ($F = 63.6$; $P < 0.001$). *Sphagnum* establishment success relative to moisture gradients in abandoned peatlands was also reported by Money (1995). Rochefort et al. (1995) and Campeau and Rochefort (1996) further demonstrated, in a greenhouse setting, that *Sphagnum* regrowth increased when the water table was high. Evidence of the relationship between soil moisture and *Sphagnum* re-establishment is provided in Figure 5. The number of capitula increased toward the center of the profiled fields, especially when plastic sheets were used, corresponding to the increased moisture content of the peat.

CONCLUSION

This experiment shows that it is possible to improve local moisture conditions on a cutover peatland in a

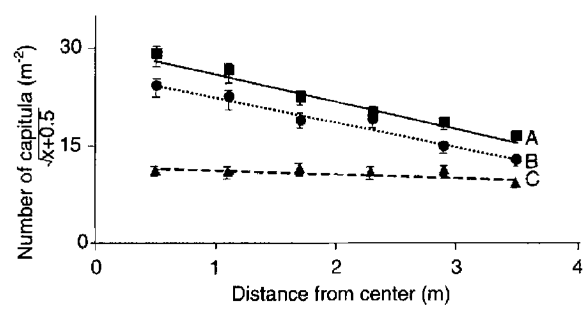


Figure 5. Average number of capitula/m^2 along the moisture gradient represented by the distance (m) of the sample point from the middle of the experimental profiled fields; square is profiled with plastic sheets, circle is profiled only, and triangle is the horizontal profile. ANCOVA analysis results are represented by different letters (alpha = 0.05).

manner that can improve re-establishment of *Sphagnum.* Reprofiling abandoned peat fields to invert the crowned slope brought the peat in closer proximity to the water table in the area where diaspores were reintroduced. The addition of two plastic sheets on the edge of the reprofiled field further increased soil moisture in that area. The reprofiling technique increased the establishment success of *Sphagnum* diaspores compared to a horizontal profile. Since blocking the drainage ditches is often insufficient to restore proper hydrologic conditions conductive to recolonization of *Sphagnum* mosses, profiling seems to partly compensate the problem of restoring the water table.

ACKNOWLEDGMENTS

This study was supported financially by the Natural Sciences and Engineering Research Council of Canada (grant OGP0138097 to LR) and grants from projects of exchange at the university level (Ontario-Québec) and Coopération Québec-Provinces canadiennes to JP and LR. Tourbière Premier CDN of Rivière-du-Loup made our work possible by providing unlimited access to the experimental site and by reprofiling the peat fields. We thank Dominique LeQuéré of Tourbière Premier CDN for her presence and her technical support and Suzanne Campeau for her advice on statistical and experimental design. Finally, we thank Julien Beaulieu, Sophie Bouchard, Marie-Noelle Croteau, and Nathalie Poirier, who aided in the progress of this experiment.

LITERATURE CITED

Campeau, S. and L. Rochefort. 1996. *Sphagnum* regeneration on bare peat surfaces: Field and greenhouse experiments. Journal of Applied Ecology 33:599–608.

Eggelsmann, R. R. F. 1988. Rewetting for protection and renaturation/regeneration of peatland after or without peat winning. p. 251–260. *In* Proceedings VIII International Peat Congress, Section III. St-Petersbourg, Russia.

Environnement Canada. 1993. Canadian climats normals 1961–1990: Québec. Atmospherics Environment Service. Ottawa, Ontario, Canada.

Famous, N. C., M. Spencer, and H. Nilsson. 1991. Revegetation patterns in harvested peatlands in central and eastern North America. p. 48–66. *In* Proceedings of the International Peat Symposium. Duluth, MN, USA.

Ferland, C. and L. Rochefort. 1997. Restoration techniques for *Sphagnum*-dominated peatlands. Canadian Journal of Botany 75: 1110–1118.

Heathwaite, L. 1995. Problems in the hydrological management of cutover raised mires, with special reference of Thornes Moors, South Yorkshire. p. 315–329. *In* B. D. Wheeler, S. C. Shaw, W. J. Fojt, and R. A. Robertson (eds.) Restoration of Temperate Wetlands. John Wiley & Sons, Ltd., New York, NY, USA.

LaRose, S., J. S. Price, and L. Rochefort. 1997. Rewetting of cutover peatland: hydrologic assesment. Wetlands 17: 416–423.

Lavoie, C. and L. Rochefort. 1996. The natural revegetation of a harvested peatland in southern Québec: A spatial and dendroecological analysis. Écoscience 3:101–111.

LeQuéré, D. 1995. Unpublished data. Personal communication, Premier Tech Ltd, 454, chemin Témiscouata, C.P. 2600, Rivière-du-Loup, Québec, Canada. G5R 4C9.

Meade, R. 1992. Some early changes following the rewetting of a vegetated cutover peatland surface at Danes Moss, Cheshire, UK, and their relevance to conservation management. Biological Conservation 61:31–40.

Money, R. P. 1995. Re-establishment of a *Sphagnum*-dominated flora on cut-over lowland raised bogs. p. 405–422. *In* B. D. Wheeler, S. C. Shaw, W. J. Fojt, and R. A. Robertson (eds.) Restoration of Temperate Wetlands. John Wiley & Sons, Ltd., New York, NY, USA.

(NWWG) National Wetlands Working Group. 1987. Wetlands of Canada. Canada Committee on Ecological Land Classification, Canadian Wildlife Service, Environment Canada, Ecological land classification Series No. 24. Ottawa, Ontario, Canada.

Nick, K.-J. 1984. Measures and changes of success for the regeneration of bogs after the complete industrial cutting of peat. p. 331–338. *In* Proceedings VII International Peat Congress vol. 1. Dublin, Ireland.

Poschlod, P. 1992. Development of vegetation in peat-mined areas in some bogs in the foothills of the Alps. p. 287–290. *In* O. M. Braggs, P. D. Hulme, H. A. P. Ingram, and R. A. Robertson (eds.) Ecosystems and Man: An Impact Assessment. Department of Biological Sciences, University of Dundee, Dundee, Scotland.

Poschlod, P. and J. Pfadenhaeur. 1989. Regeneration of vegetative parts of peat mosses—A comparative study of nine *Sphagnum* species. Telma 19:77–88.

Price, J. S. 1996. Hydrology and microclimate of a partly restored cutover bog, Québec. Hydrological Processes 10:1263–1272.

Price, J. S. 1997. Soil moisture, water tension, and water table relationships in a managed cutover bog. Journal of Hydrology 201: (in press).

Quinty, F. and L. Rochefort. 1997. Plant reintroduction on a harvested peat bog. p. 133–146. *In* C. C. Trettin, M. F. Jurgensen, D. F. Grigal, M. R. Gale, and J. K. Jeglum (eds.) Northern Forested Wetlands: Ecology and Management. Lewis Publishers, New York, NY, USA.

Rochefort, L. and D. F. Bastien. 1998. Réintroduction de sphaignes dans une tourbière exploitée: évaluation de divers moyens de protection contre la dessication. Ecoscience 5: (in press).

Rochefort, L. and S. Campeau. 1997. Rehabilitation work on post-harvested Bogs in South Eastern Canada. p. 287–294. *In* L. Parkyn, R. E. Stoneman, and H. A. P. Ingram (eds.) Conserving Peatlands. CAB International, Wallingford, UK.

Rochefort, L., R. Gauthier, and D. LeQuéré. 1995. *Sphagnum* regeneration—toward an optimisation of bog restoration. p. 423–434. *In* B. D. Wheeler, S. C. Shaw, W. J. Fojt, and R. A. Robertson (eds.) Restoration of Temperate Wetlands. John Wiley & Sons, Ltd., New York, NY, USA.

Roderfeld, H. 1993. Raised bog regeneration after peat harvesting in North-West Germany. SUO 44(2):43–51.

Salonen, V. 1987. Revegetation of an area of Mustasuo-mire after clearing for peat harvesting. SUO 38(1):1–3.

SAS Institute. 1988. SAS/STAT® User's guide, version 6.03 edition. Cary, NC, USA.

Schouwenaars, J. M. 1988. The impact of water management upon groundwater fluctuations in a disturbed bog relict. Agricultural Water Management 14:439–449.

Steel, R. G. D. and J. H. Torie. 1980. Principles and Procedures of Statistics.—A Biometrical Approach, 2nd edition. McGraw-Hill, New York, NY, USA.

Systat Software Inc. 1991. Systat, version 5.02. Copyright, 1991, Systat Inc. Evanston, IL, USA.

Wheeler, B. D. and S. C. Shaw. 1995. Restoration of damaged peatlands. Department of the Environment. University of Sheffield, London, UK.

Manuscript received 21 April 1997; revision received 18 July 1997; accepted 4 August 1997.