Extended abstract No. 259

SECONDARY SUCCESSION IN ABANDONED BLOCK-CUT PEATLANDS

González E[1*]
Poulin M[1,2]
Rochefort L[1]

[1]Peatland Ecology Research Group, 2425, rue de l'Agriculture, Université Laval, Québec, Québec, G1V 0A6, Canada. Telephone number: 1-418-656-2131 (7058)
[2]Quebec Centre for Biodiversity Science (QCBS), 1205 Dr. Penfield Avenue, McGill University, Montreal, Québec, H3A 1B1, Canada
*corresponding author: eduardo.gonzalez-sargas.1@ulaval.ca / edusargas@hotmail.com

SUMMARY

In 2005-2006, five abandoned block-cut peatlands of Eastern Canada, whose vegetation had been surveyed in 1994-1997, were revisited to examine whether the trajectories of the plant communities were converging or diverging among and within peatlands. Ordination techniques were used to separate 166 observation sites (2 sampling campaigns x 83 trenches left by the block-cut activities) in the 5 peatlands along two main gradients: dry-to-wet and open-to-forested. Results showed that the tendency of trenches was to diverge with time along the first gradient and to converge to more forested sites along the second gradient. Thus, sites which need active intervention to Ensure the return of the peat accumulation function could be identified.

KEYWORDS: spontaneous revegetation, abandoned exploited bogs, trench, autogenic processes

INTRODUCTION

Once abandoned, mined peat surfaces are barely re-colonized by plants which face harsh environmental conditions such as altered hydrology (Price *et al.*, 2003; Price and Whitehead, 2004), wind erosion, frost heaving (Campbell *et al.*, 2002; Groeneveld and Rochefort, 2002), and unsuitable physical properties of the residual peat surface (Wind-Mulder *et al.*, 1996; Price and Whitehead, 2001). *Sphagnum* mosses are among the least successful plants to re-colonize abandoned peatlands, which may counteract the peat accumulating process associated with their presence in peatlands.

However, some vascular and non-vascular plant species are able to colonize abandoned peat fields, especially after the traditional block-cut method compared to vacuum industrial mining (Girard *et al.*, 2002). Despite some spontaneous re-colonization in block-cut peatlands, species composition and cover differ notably from that found in undisturbed systems (Konvalinkova and Prach, 2010), even 50 years after abandonment (Soro *et al*., 1999), and may be in fact very variable at a regional scale (Poulin *et al*., 2005). This is usually a consequence of the drainage works that were performed, which remain partially and not-uniformly active decades after

abandonment (Van Seters and Price, 2000). With abandoned block-cut sites not returning to one resembling the pre-exploitation state, their contribution to the ecological functions of carbon accumulation and preservation of regional diversity is jeopardized.
In 1994, 1995, and 1997, a large-scale survey of abandoned peatlands was conducted throughout the provinces of Québec and New Brunswick (Poulin *et al.*, 2005), two of the primary peat-producing regions of the world. By that date, sites had been abandoned for ~25 years and were already revegetated. We revisited the block cut sites 10 years later in 2005-2006 to answer the following questions. Once abandoned block-cut peatlands have been already colonized: 1) How do their plant succession trajectories evolve? 2) Do plant assemblages converge or diverge among and within peatlands with time? It was expected that the answer to these questions could help to identify sites which need active intervention to insure the return of the key ecological function of peat accumulation and to preserve biodiversity in bogs.

MATERIALS AND METHODS

Study area

The study was carried out in 5 peatlands located in the Eastern Canadian provinces of Quebec and New Brunswick (Fig 1). Quebec and New Brunswick are the two main Canadian provinces extracting peat for horticultural purposes.

The 5 surveyed peatlands were totally or partially exploited by the block-cut method before being abandoned for spontaneous revegetation. The block-cut method leaves a characteristic topography of alternating trenches and baulks. However, the experimental unit of this survey was the trench. Baulks were discarded from the survey because previous studies have shown that *Sphagnum* is mostly absent and water table levels much deeper than in the adjacent trenches (Poulin *et al.* 2005). We thus assumed that plant communities in baulks would not evolve to those typical of peatland without human intervention.

Sampling campaigns

During the period 1994-1997 (~25 years after their abandonment), a broad vegetation survey of the 5 peatlands was carried out. The number of trenches to be surveyed was chosen as a function of the peatland size (n = 83, Fig. 1).

We conducted detailed species relevés in the 83 trenches using a systematic point sampling design (Bonham, 1989). Ten equidistant transects were established across each trench, where all species including mosses, liverworts, lichens and vascular plants touching a vertical rod were recorded on ten equidistant positions. Species counts over the 100 pinpoints were the occurrence frequency of a species at each trench.

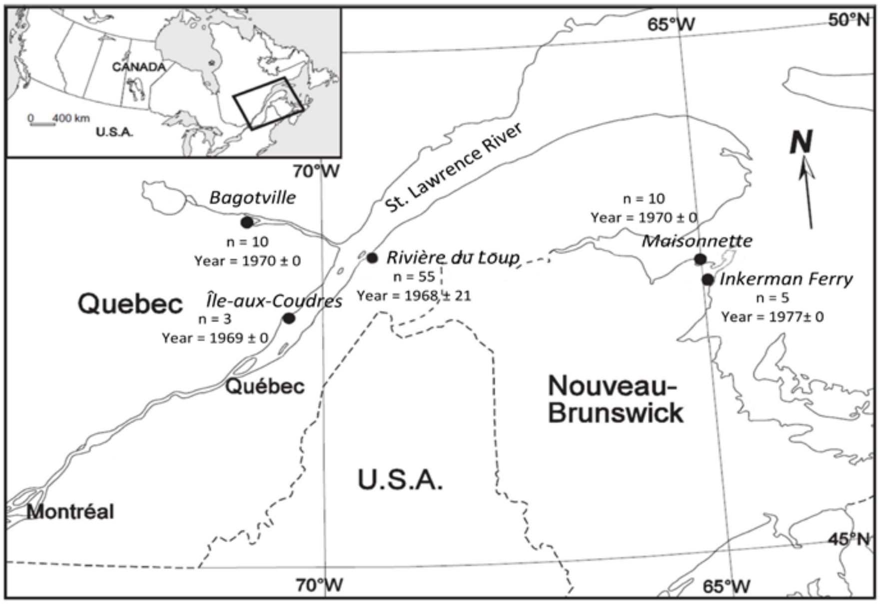

Fig. 1. Location of the 5 abandoned block-cut mined peatlands in the Eastern Canadian provinces of Québec and New Brunswick. The number (n) of trenches surveyed and their median ± range of their year of abandonment are also shown.

In order to compare the successional trajectories of the vegetation, the trenches were revisited 10 years later and the vegetation composition was surveyed again in a second sampling campaign (2005-2006) with the same sampling design as the former one. Therefore, the total number of observations of our vegetation dataset was 166 (i.e., 83 trenches x 2 sampling campaigns). Additionally during this second sampling campaign, the thickness of the *Sphagnum* fiber accumulated since abandonment was measured at the central pinpoint of transects 2, 5 and 9 of each trench.

Data processing and statistical analyses

We used ordination methods to assess the degree of differentiation among the plant assemblages in the peatlands and their successional trajectories. Before looking at plant composition trajectories among peatlands and trenches, the effect of time since abandonment was partialled out running a RDA on Hellinger's transformed data. A principal components analysis (PCA) was then carried out on the residuals of the RDA. The PCA revealed the major community gradients within the vegetation and reflected the temporal evolution of plant communities in the trenches along those gradients. The scores of the trenches on the selected axes of the PCA (sites scores) were then compared between peatlands within the same sampling campaign by means of non-parametric Mann-Whitney tests for two groups of independent samples; and within the same peatland between the two sampling campaigns using non-parametric Wilcoxon matched-pairs signed-ranks tests. Finally, the capacity of peatlands to accumulate new *Sphagnum* fibre along the ecological gradients was assessed by adjusting different functions to the mean of the *Sphagnum* fiber thickness measurements at each trench (dependent variable) and the sites scores of the PCA axes with an ecological meaning (independent variables).

Ordinations were carried out using R (version 2.14.0) software (R Development Core Team 2011), more precisely the vegan (Oksanen *et al*., 2011) and ade4 (Dray and Dufour, 2007) packages. SPSS v 13.0 was used to run the Mann-Whitney and Wilcoxon tests.

RESULTS

Ordination of peatlands

A total of 121 plant species were identified in the 83 trenches of the 5 peatlands, after being surveyed twice. Removal of infrequent species (i.e., occurring in less than 5% of the trenches) resulted in a total of 76 species for inclusion in the ordination analyses. The year of abandonment explained 9% of the variability among the sites (RDA; permutation test, 9999 runs, $F = 16.739$, $P < 0.001$). The first two axes of the subsequent PCA carried out on the residuals of the RDA explained 23 and 12% of their variability, respectively. Axis 1 separated the peatland of Rivière du Loup from the peatlands of Maisonnette, Inkerman Ferry and Bagotville (as confirmed by Mann Whitney tests on their PC1 scores) along what it seemed a dry to wet gradient (Fig. 2). The species associated to the driest trenches were three ericaceous species: *Vaccinium angustifolium*, *Kalmia angustifolia* and *Rhododendron canadense* and the tree *Picea mariana*, whereas *Vaccinium oxycoccos* and three *Sphagnum* species (*S. fuscum*, *S. rubellum* and *S. magellanicum*) dominated the wettest part of the gradient. In addition, the centroid of *Sphagnum* species was clearly separated from the centroids of ericaceous and tree species. Axis 2 seemed to separate peatlands along an open (negative PC2 scores) to forested (positive PC2 scores) gradient. Three trees (*Picea mariana*, *Larix laricina* and *Betula papyrifera*) and one shrub (*Ilex mucronata*) were the most positively loaded, whereas the ericaceous shrubs *Kalmia angustifolia* and *Chamaedaphne calyculata*, the lichens *Cladonia* spp. and the moss *Mylia anomala* had the most negative PC2 values. The centroids of trees and ericaceous were on opposite sides, the latter group in co-occurrence with lichens. Mann Whitney tests carried out to compare the PC2 scores between peatlands showed that Axis 2 separated well the forested Bagotville and Rivière du Loup in 2005-2006 from the open Maisonnette and Inkerman Ferry sites.

Evolution of the peatland plant communities

Overall, the heterogeneity of plant assemblages increased between trenches from the first field campaign to the second one, as shown by the higher standard errors observed for almost all peatlands in the site scores means of both PCA axes (Fig. 2). However, Wilcoxon tests performed within the same peatland between the two sampling campaigns (see arrows in Fig. 2) showed that two peatlands (Bagotville and Île-aux-Coudres) remained stable in terms of vegetation composition during the time-lag of 10 years between the two surveys. On the other hand, when peatlands significantly evolved, they did it differently. That is, the plant community in Rivière du

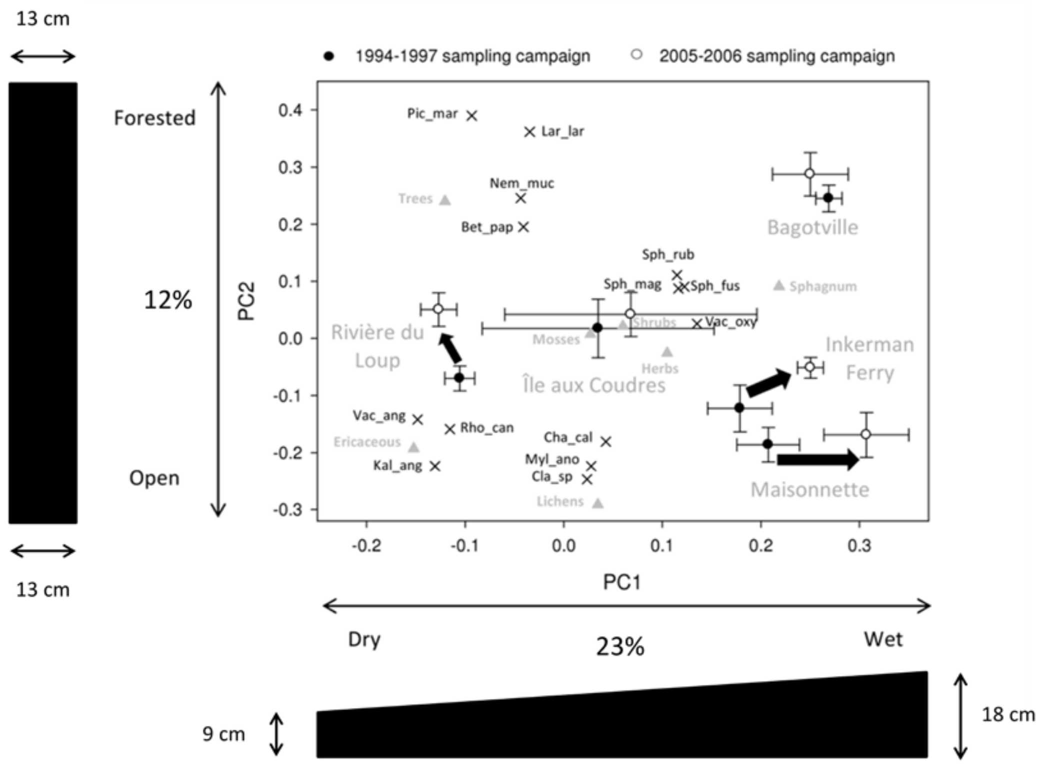

Fig. 2. Two first axes of a PCA ordination of a plant species occurrence matrix (abandonment year previously removed by RDA on Hellinger's transformed data, see text) built from 166 observations (83 trenches x 2 sampling campaigns) in 5 abandoned block-cut milled peatlands of Eastern Canada. To improve visual clarity of the PCA diagram, we draw only the centroids (site scores means) of each peatland at each one of the two sampling campaigns (filled circles = 1994-1997, open circles = 2005-2006) and the ±1 standard error of the means. For the same reason, only the species with the highest scores are depicted. The species scores on the first axis were scaled by multiplying by 1/3 and the centroids (species scores means) for each vegetation strata were scaled by multiplying by 5/2. Arrows indicate that site scores between the two sampling campaigns at a given peatland were significantly different (Wilcoxon tests, $P < 0.05$). Rivière du Loup: $P_{PC1} = 0.056$, $P_{PC2} < 0.001$; Maisonnette: $P_{PC1} = 0.012$; Inkerman Ferry: $P_{PC1} = 0.043$, $P_{PC2} = 0.043$. Note that if the test was only significant for one of the axes, the arrow was drawn perpendicular to the one with no significance ($P > 0.05$). The thickness of the new *Sphagnum* fiber accumulated since abandonment is also shown as a function of the site scores (second sampling campaign only) of each axis.

Loup moved towards one characterising a drier and more forested peatland, the one in Maisonnette tended to become typical of wetter environments, and Inkerman Ferry of wetter and more forested sites.

Sphagnum fiber accumulation

The range of variability in *Sphagnum* fiber accumulation among trenches was 0 - 30 cm, meaning that some trenches accumulated up to ~ 1 cm y^{-1}. A significant positive linear relationship was found between the thickness of the new *Sphagnum* fiber accumulated and the PC1 site scores (fiber = 12.18 + 14.56 * PC1 site score, F=18.7053, d.f.=81, adj. r^2 = 0.18, P < 0.001) (Fig. 2). In other words, abandoned block-cut peatlands classified as “wet” according to the ecological gradient given by the first PCA accumulated more *Sphagnum* fiber than the “dry” ones. However, no relationship was found along the open to forest gradient represented by the second axis of the PCA (Fig. 2).

DISCUSSION

The main result of this study is that vegetation in abandoned block-cut mined peatlands evolves differently some decades after they have been spontaneously revegetated. In other words, their plant assemblages tend to diverge with time. This diversion in plant successional trends was observed both between peatlands and within peatlands (between trenches of the same peatland). On one hand, taking the ecological gradient defined by the first ordination axis as a reference, peatlands that were classified as “dry” in 1994-97 became drier in 2005-06 and those classified as “wet” became wetter (with the only exception of Bagotville). Regarding the second main ecological gradient (“open-to-forest”), the five peatlands followed the same direction towards afforestation. However, the intensity of change was different among the five studied peatlands. For example, the complex of peatlands in Rivière du Loup displayed a remarkable greater process of afforestation, a result supported by Pellerin and Lavoie (2000), who identified drainage for agriculture as the main cause of afforestation. A closer examination of the differences in plant composition of the wet open sites (especially at Inkerman-Ferry) showed that their evolution towards the positive end of the Axis 2 (*a priori* a tendency towards afforestation) was not due to an actual increase in trees but rather to a loss in the relative abundance of ericaceous species, a result following increased wetness of the site (negatively loaded in Axis 2).
Within peatlands, the diverging succession is reflected by an increased variability in the plant species composition between the trenches of the same peatland, from one sampling campaign to another in practically all cases (see errors in PCA biplot, Fig. 2).

These differences in succession patterns after abandonment might be explained by complementing hypotheses based on the relative importance of allogenic vs. autogenic processes as the drivers of succession. Thus, while it is well known that hydrological conditions (i.e., water table depths and fluctuations) and the quality and depth of the residual peat play a critical role in the establishment and development of plant communities in peatlands, including block-cut sites (Rochefort and Lode, 2006), our results would be also consistent with a succession mainly driven by plant interactions in a harsh environment such as the one that remains after mining perturbation. In this sense, we suggest that, in the absence of human intervention after abandonment, peatland hydrology could have remained rather stable in our study sites decades after mining, exerting a strong environmental filter for vegetation, which, once established, would have evolved autogenically. The high variability in plant composition and succession between the trenches of the same peatland could be explained, among other factors, by the lack of maintenance of the drainage ditches that were not blocked after the exploitation and remained active. The progressive collapse of the abandoned ditches may have caused subsequent local variations of the hydrology among trenches within each peatland, with critical effects on the vegetation structure and dynamics. This hypothesis does not exclude the existence of stochastic patterns in plant establishment and plant interactions as other sources of variability.

Regardless of their causes, the different trajectories reported here give clues to identify sites which need active intervention to insure the return of the key ecological function of peat accumulation in bogs and to detect trends that may be important to achieve the goal of biodiversity conservation. For example, the complex of peatlands of Rivière du Loup seemed to have a trajectory that will poorly contribute to the conservation of regional biodiversity (diversity was the lowest among the 5 peatlands, data not shown) and carbon accumulation function of peatlands (lowest *Sphagnum* fiber accumulation, Fig. 3a). Therefore, intervention is highly recommended. In fact, some pilot restoration measures such as the blocking of former drainage ditches have been already carried out in one of the Rivière du Loup peatlands, with promising results on the improvement of the site hydrology, more favourable to *Sphagnum* recolonization (Ketcheson and Price, In Press). Our results suggest that similar measures were applied also to other trenches with negative trajectories on our PC1 axis (i.e., becoming "drier").

Finally, it is worth to mention that working at the trench level is appropriate for such prospective study, but a smaller spatial scale should be considered when assessing finer vegetation patterns. Working at the trench level removes the variability in plant composition associated to microtopography, which strongly determines key hydrologic parameters for vegetation growth and survival, such as distance to the water table, soil moisture and soil water-pressure (Price and Whitehead, 2001; Price *et al.* 2003).

ACKNOWLEDGEMENTS

Financial support was provided by the Natural Sciences and Engineering Research Council of Canada, the Ministry of Natural Resources and Energy of New Brunswick, the Canadian Sphagnum Peat Moss Association and its members. Thanks are extended to all participants in the field surveys.

REFERENCES

Bonham, C.D. (1989). *Measurements for terrestrial vegetation.* John Wiley & Sons, New York.

Campbell, D.R., Lavoie, C., and Rochefort, L. (2002). Wind erosion and surface stability in abandoned milled peatlands. *Canadian Journal of Soil Science* **82**, 85-95.

Dray, S. and Dufour, A.B. (2007): The ade4 package: implementing the duality diagram for ecologists. *Journal of Statistical Software* **22**, 1-20.

Girard, M., Lavoie, C. and Thériault, M. (2002). The regeneration of a highly disturbed ecosystem: A mined peatland in southern Québec. *Ecosystems* **5**, 274-288.

Groeneveld, E. and Rochefort, L. (2002). Nursing plants in peatland restoration: on their potential use to alleviate frost heaving problems. *Suo* **53**, 73–85.

Ketchenson, S.J. and Price, J.S. (In Press). The impact of peatland restoration on the site hydrology of an abandoned block-cut bog. *Wetlands*
Konvalinkova, P. and Prach, K. (2010). Spontaneous succession of vegetation in mined peatlands: a multi-site study. *Preslia* **82**, 423-435.

Oksanen, J., Guillaume Blanchet, F., Kindt, R., Legendre, P., Minchin, P.R., O'Hara, R.B., Simpson, G.L., Solymos, P., Henry, M., Stevens, H. and Wagner, H. (2011). vegan: Community Ecology Package. R package version 2.0-2. http://CRAN.R-project.org/package=vegan

Pellerin, S. and Lavoie, C. (2000). Peatland fragments of southern Quebec: recent evolution of their vegetation structure. *Canadian Journal of Botany* **78**, 255-265.

Poulin, M., Rochefort, L., Quinty, F. and Lavoie, C. (2005). Spontaneous revegetation of mined peatlands in eastern Canada. *Canadian Journal of Botany* **83**, 539-557.

Price, J.S. and Whitehead, G.S. (2001). Developing hydrologic thresholds for *Sphagnum* recolonization on an abandoned cutover bog. *Wetlands* **21**, 32-40.

Price, J.S., Heathwaite, A.L. and Baird, A.J. (2003). Hydrological processes in abandoned and restored peatlands: An overview of management approaches. *Wetlands Ecology and Management* **11**, 65-83.

Price, J.S. and Whitehead, G.S. (2004). The influence of past and present hydrological conditions on *Sphagnum* recolonization and succession in a block-cut bog, Québec. *Hydrological Processes* **18**, 315-328.

R Development Core Team (2011). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org/.

Rochefort, L. and Lode, E. (2006). Restoration of degraded boreal peatlands. In: Wieder, R.K. & Vitt, D.H. (eds.) *Boreal peatland ecosystems*. pp. 9–24. Springer-Verlag, Berlin, DE.

Soro, A., Sundberg, S. and Rydin, H. (1999). Species diversity, niche metrics and species associations in harvested and undisturbed bogs. *Journal of Vegetation Science* **10**, 549–560.

Van Seters, T.E. and Price, J.S. (2001). The impact of peat harvesting and natural regeneration on the water balance of an abandoned cutover bog, Québec. *Hydrological Processes* **15**, 233-248.

Warnes, Gregory R. Includes R source code and/or documentation contributed by: Ben Bolker, Lodewijk Bonebakker, Robert Gentleman, Wolfgang Huber Andy Liaw, Thomas Lumley, Martin Maechler, Arni Magnusson, Steffen Moeller, Marc Schwartz and Bill Venables (2011). gplots: Various R programming tools for plotting data. R package version 2.10.1. http://CRAN.R-project.org/package=gplots

Wind-Mulder, H.L., Rochefort, L. and Vitt, D.H. (1996). Water and peat chemistry comparisons of natural and post-harvested peatlands across Canada and their relevance to peatland restoration. *Ecological Engineering* **7**, 161-181.