Groupe de recherche en écologie des tourbières / Peatland Ecology Research Group

24th PERG's Symposium / *24e Symposium du GRET*

Thursday, February 15th, 2018 / *Jeudi 15 février 2018*

Université Laval, Québec

Room 1110-1116, Paul-Comtois building / *Salle 1110-1116, pavillon Paul-Comtois*

Schedule and abstracts / *Programme et résumés*

Université Laval — University of Waterloo — McGill — Brandon University — Centre d'études nordiques

AIM OF THE SYMPOSIUM:

The annual Symposium of the Peatland Ecology Research Group (PERG) aims to present to the various stakeholders in the peat, peatland and wetland sectors of (researchers, industrial partners, ministries and municipalities, students, environmental firms of consultants, etc.) the latest developments in research projects in the restoration, management and conservation of peatlands and other wetlands.

BUT du SYMPOSIUM :

Le Symposium annuel du Groupe de recherche en écologie des tourbières (GRET) a pour but de présenter aux divers intervenants des secteurs de la tourbe, des tourbières et des milieux humides (chercheurs, partenaires industriels, ministères et municipalités, étudiants, firmes de consultants en environnement, etc.) les derniers développements réalisés dans le cadre des projets de recherche en restauration, en aménagement et en conservation des tourbières et autres milieux humides.

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24th Symposium of the Peatland Ecology Research Group

24e symposium du Groupe de recherche en écologie des tourbières

Program and Index / *Programme et index*

February 15th, 2018 / *15 février 2018*

Université Laval, Québec City, Canada

Room/*Salle* 1110-1116, building / *pavillon* Paul-Comtois,
(2425, rue de l'Agriculture, Québec, QC, G1V 0A6)

Symposium langage: mostly in English / *Langue du symposium : majoritairement en anglais*

* Indicates a student presentation (for the vote!) / * *Indique les présentations étudiantes (à considérer pour le vote!)*

Time	Speaker	Affiliation	Title	Page
8:10	Registration			
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11:10	Laurence Turmel-Courchesne*	U. Laval (Québec)	Rewetting a minerotrophic peatland after peat extraction activities: Impact on carbon exchange and vegetation	8

11:25	Pete Whittington	Brandon U. (Manitoba)	Re-contouring a cutover peatland to improve hydrological function and promote fen restoration in southeast Manitoba, Canada	9
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11:40	Paul Gaffney	U. of the Highlands and Islands (Scotland, UK)	Measuring restoration progress using pore- and surface-water chemistry across a chronosequence of formerly afforested blanket bogs	10
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13:45	Aneta Bieniada*	U. Waterloo (Ontario)	Methane fluxes at a horticulture peatland complex in Seba Beach, Alberta	12
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14:55	Coffee break and vote for the best student presentations			
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15:15	Line Rochefort, Ian Strachan, Maria Strack, Jonathan Price, Marie-Claire LeBlanc, Pete Whittington, Claude Lavoie, Sandrine Hugron, Stéphane Godbout	U. Laval and McGill U. (Québec), U. of Waterloo (Ontario), Brandon University (Manitoba)	Improving the restoration methods and assessing success: 5 years of research on peatlands restoration and management	17
16:40	Jean-Paul Doyon	*Photographe* (Québec)	*Projet de conservation de la Grande plée Bleue en photos* (in French)	n/a
16:55	Student awards / *Remise des prix étudiants*			
17:05	COCKTAIL under the theme of the "local flavors of Université Laval" (sponsored by Magellanicum Ecological Services)			

KEYNOTE SPEAKER

Sustainably managing peat forests: 15 years of a research partnership

Nicole J. Fenton[1], Y. Bergeron[1], B. Lafleur[1], D. Paré[2], N. Thiffault[2] & O. Valeria[1]

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Abstract: Peatland forestry in Canada has a long history. Large areas of our boreal forest are underlain by soils with poor drainage, and as a consequence much of our industry is based on the harvest and regeneration of these forests. However, not all peat forests are the same and society no longer allows companies and governments to completely alter landscapes with drainage as was done in the past. To ensure the sustainable management of peatland forests on the great Northern Claybelt that straddles Quebec and Ontario a research partnership has been built that includes industry and government practitioners along with researchers from universities and governments. In this presentation we will trace the evolution of the both the partnership and the research, as we explore how to manage both the trees and organic soil.

Résumé : La foresterie des tourbières forestières au Canada possède une longue histoire. De vastes zones de notre forêt boréale reposent sur des sols mal drainés, ce qui explique qu'une grande partie de notre industrie forestière concerne la récolte et la régénération de ces forêts. Cependant, les tourbières forestières ne sont pas toutes les mêmes et la société ne permet plus aux entreprises et aux gouvernements de modifier complètement, par drainage, les paysages comme cela a été fait dans le passé. Afin d'assurer la gestion durable des tourbières forestières sur la grande zone argileuse nordique qui chevauche le Québec et l'Ontario, un partenariat de recherche a été établi avec des représentants de l'industrie et du gouvernement, ainsi que des chercheurs des universités et des gouvernements. Dans cette présentation, nous allons suivre l'évolution du partenariat et de la recherche, tout en explorant comment gérer à la fois les arbres et les sols organiques.

A few words about Dr. Nicole Fenton:

Dr. Nicole Fenton is a professor in the *Institut de recherche sur les forêts* (IRF) of the Université du Québec en Abitibi-Témiscamingue (UQAT - Québec, Canada), and graduated from University of Winnipeg (B.Sc. 1998), University of New Brunswick (M.Sc. 2001) and UQAT (Ph.D. 2006). She is member of the *Centre d'études de la forêt* (CEF), a researcher of the *Chaire industrielle CRSNG-UQAT-UQAM en aménagement forestier durable* (*Chaire AFD*), and a member of the Board of Directors of the Canadian Botanical Association (CBA). She has been studying bryophyte community structure and assembly for over 15 years, specialising in boreal bryophytes. Her interest in ecosystem function has led her to examine the roles bryophytes play in boreal ecosystems, such as forested peatlands, and as a consequence she has been a leader in organizing trait based information on bryophytes of these environments.

Optimizing *Sphagnum* fibre farming: Estimating the ideal water table depth using inverse modelling

James B. Elliott & Jonathan S. Price

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Abstract: *Sphagnum* fibre farming is being considered as an alternative end of use for peatlands after they have been harvested. Similar techniques to restoration can be used for *Sphagnum* fibre farming; however variation in moisture content during early years and throughout the growing season can slow down establishment and reduce productivity. As such, sub surface irrigation has been proposed to moderate soil moisture variation in order to optimize productivity. Proposed design for sub surface irrigation control soil moisture by raising the water table, thus the soil moisture - water table relationship needs to be quantified. The purpose of this study is to create model that can accurately simulate soil moisture dynamics in the field and estimate the water table range where optimal soil moisture occurs. Hydraulic parameters were characterized by curve fitting in RETC and inverse modelling in HYDRUS 1D and were validated using soil moisture measurements from a 10 cm moss profile 2.5 and 7.5 cm below the surface over 80 days. Inverse modelling yielded more accurate parameters than curve fitting at 2.5 and 7.5 cm (RMSE 0.09 & 0.05 vs. 0.23 & 0.25 respectively). Parameters from inverse modelling represented periods of evaporation well; however soil moisture after rain events was generally under represented .Inverse modeling parameters were then used to model the water table range that corresponds with optimal soil moisture for GEP. Based on the model output, water table should be maintained between 34 – 58 cm below ground surface to optimize productivity in a 10 cm profile.

Growing cloudberry in mesic peat: The effects of P fertilization and liming on Al accumulation and growth parameters

Cultiver la chicouté sur tourbe mésique : effet de l'ajout de P et de chaux sur l'accumulation d'Al et sur les paramètres de croissance

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Abstract: Cloudberry (*Rubus chamaemorus* L.) produces fruits highly valued on the market. Cloudberry exhibits better growth on fibric than on mesic peat. We recently reported that not only low-nutrient availability but also aluminium (Al) toxicity seem to affect cloudberry growth on well-decomposed (mesic) peat. An experiment was carried out in a greenhouse to test the impact of an addition of phosphorus (P) and/or lime to neutralize Al in mesic peat and reduce its absorption by the plants. Fibric peat without fertilization (F0) was used as a control. In mesic peat, 4 treatments were applied at the time of planting: single dose of P (MP), double dose of P (M2P), single dose of P+lime (MPC), single dose of lime (MC). Cloudberry rhizomes were planted individually in pots then grown for 2 seasons in a greenhouse. Mortality rate was higher in the M2P treatment. Plants produced more leaf biomass in all the P-fertilized treatments while in the MC treatment plants had the smallest leaves. Leaves and soil were analysed for nutrients. Fertilization with P increased the foliar and soil concentration of that nutrient. MC was the only treatment in which a significant decrease in soil Al was observed, meaning that this decrease cannot be attributed to the action of P. Nonetheless, MC was the overall worst-performing treatment, which might be related to the low concentration of manganese (Mn) in the leaves. Indeed, observations in the field showed that cloudberry plants with high growth rate and yield have a high foliar concentration of Mn, by opposition to the plants that exhibit a poor performance. In conclusion, adding P to the soil for the culture of cloudberry in mesic peat had a positive effect on growth indicators, but did not alter Al concentration in the soil.

Résumé : La chicouté (*Rubus chamaemorus* L.) produit des fruits à haute valeur commerciale. Elle pousse mieux sur tourbe fibrique que sur tourbe mésique. Selon nos plus récentes recherches, la croissance sur tourbe mésique est affectée par la toxicité de l'aluminium (Al). Une expérience a donc été menée en serre afin de tester l'effet de l'ajout de phosphore (P) et/ou de chaux pour neutraliser l'Al sur tourbe mésique et réduire son absorption par les plantes. La tourbe fibrique non fertilisée a été utilisée comme témoin. Sur tourbe mésique, quatre traitements ont été appliqués : dose unique de P (MP), double dose de P (M2P), dose unique de P+chaux (MPC), dose unique de chaux (MC). Des rhizomes de chicouté ont été plantés individuellement dans des pots, puis exposés à deux saisons de croissance en serre. Le taux de mortalité était plus élevé dans le traitement M2P. Les plants ont produit plus de biomasse foliaire dans tous les traitements fertilisés au P, alors que le traitement MC avait les plus petites feuilles. La fertilisation au P a augmenté la concentration de ce nutriment dans les feuilles et dans le sol. MC est le seul traitement qui a entraîné une diminution de la concentration d'Al dans le sol, ce qui signifie que l'action du P n'en a pas été responsable. Néanmoins, le traitement MC est celui qui a le moins bien performé, ce qui pourrait être lié à la faible concentration de manganèse (Mn) dans ses feuilles. En effet, des observations sur le terrain ont montré que les plants de chicouté ayant des taux de croissance et des rendements élevés ont une concentration foliaire élevée en Mn, contrairement aux plants qui performent moins bien. En conclusion, l'ajout de P sur tourbe mésique pour la culture de la chicouté a eu un effet positif sur les indicateurs de croissance, mais n'a pas modifié la teneur du sol en Al.

POSTER SESSION

Compression of regenerated *Sphagnum* moss to increase carbon sequestration in restored cut-over peatlands

Tasha-Leigh J. Gauthier & Jonathan S. Price

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Abstract: Ten years after restoration was implemented at the Bois-des-Bel peatland (BdB) in Quebec, there was limited hydrological connectivity between the regenerated *Sphagnum* moss and the remnant cutover peat due to the formation of a capillary barrier. This resulted in lower soil water content and decreased productivity of the regenerated *Sphagnum* moss compared to a natural analogue. Previous lab and field studies have demonstrated that compression of while frozen will break the moss structure resulting in increased moisture content. This study evaluates the effects of compression and subsequent increase in moisture content on gross ecosystem productivity (GEP), and the overall impact of compression on CO_2 exchange. In January 2016 two fields at BdB were compressed using a John Deere Tractor to apply the necessary force which significantly reduced the moss height in comparison to an adjacent uncompressed field (~38%, p <0.001, Mann-Whitney Rank Sum Test). During the 2016 growing season (May-August) CO_2 flux measurements were taken using the chamber technique with clipped vasculars to characterize *Sphagnum* moss CO_2 exchange. Round collars were installed in three areas: the compressed fields (n=18), an adjacent uncompressed field (n=6), and an undisturbed area nearby (n=3). Water table and capitulum water content (fw/dw) measurements were taken in conjunction with each flux measurement. Capitulum water content over the growing season was highest in the undisturbed area, followed by the compressed fields, and the uncompressed field. Despite the increase in capitulum water content, GEP was not significantly different than the uncompressed (p <0.05, Kruskal-Wallis one way ANOVA on ranks). The compressed fields had higher respiration (p <0.05, Kruskal-Wallis one way ANOVA on ranks) causing the moss to be a slightly stronger CO_2 source vs. the uncompressed fields.

Water table dynamics in a restored peatland on a former oil well-pad

Torben R. Russo & Maria Strack

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Abstract: There are over 300,000 well-pads in Alberta, with many present in peatland ecosystems. Only a few peatland restoration trials have been completed on well-pads and very little is known about hydrological properties on these restored sites. This study was conducted on a restored well-pad near Peace River (Alberta) that was restored by burying some of the mineral fill used in well-pad construction under the peat to expose peat at the surface, followed by revegetation with moss layer transfer. Surface elevation was determined across the well-pad and the adjacent undisturbed peatland and water table was monitored between May and August. Results of water table monitoring in 2017 will be presented and future work discussed.

Is it possible to quantify a comfort water zone for *Sphagnum* cultivation?

Est-il possible d'identifier une zone hydrique de confort pour la culture de sphaigne?

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Abstract: For the design and management of *Sphagnum* farming project, groundwater analysis as a resource contributor is fundamental. However, before starting the design, it is necessary to identify the comfort hydric zone for *Sphagnum* growth. In this project, the relationship between groundwater variation and *Sphagnum* biomass production was analyzed to identify this area. For this, records of groundwater level in experimental basins were analyzed. The analyzed basins have an area of about 100 m^2, intending to produce *Sphagnum papillosum*, *S. magellanicum* and *S. rubellum*. The analysis of the water table variation was done with data from 2015 to 2017, for six basins in Saint-Modeste (Quebec) with different irrigation configurations, namely: no canal, peripheral drainage ditch, peripheral irrigation ditch and central irrigation ditch. The concept of the sum of exceedance value in excess (and deficiency) peat water was introduced to explain *Sphagnum* biomass production. For optimal *Sphagnum* biomass production, it is appropriate to establish a groundwater level around 1500 cm-day during the growing session. Groundwater level should not only be near the surface, it is also necessary to ensure the least possible variation. The introduction of these exceedance and deficiency indicators contributes to the appropriate design or even the hydric evaluation of *Sphagnum* culture basin. This analysis will be completed in a next stage of the project with the characterization of the movement of water in porous media.

Résumé : Pour la conception et la gestion de la culture de sphaigne, l'analyse des eaux souterraines en tant que contributeur de la ressource est fondamentale. Cependant, avant de commencer le design expérimental, il est nécessaire d'identifier la zone hydrique de confort pour la croissance des sphaignes. Dans ce projet, la relation entre la variation de la nappe phréatique et la production de biomasse de sphaigne a été analysée afin d'identifier cette zone en question. Pour cela, les enregistrements du niveau de nappe phréatique dans les bassins expérimentaux ont été analysés. Les bassins analysés ont une surface d'environ 100 m^2, et sont destinés à la production de *Sphagnum papillosum, S. magellanicum* et *S. rubellum.* L'analyse de la variation de la nappe phréatique a été faite avec les données de 2015 à 2017, pour six bassins à Saint-Modeste (Québec) ayant différentes configurations d'irrigation, à savoir : aucun canal, canal de drainage périphérique, canal d'irrigation périphérique et canal d'irrigation central. Le concept de la somme de la valeur de dépassement et de carence en eau a été introduit pour expliquer la production de biomasse de sphaigne. Pour la production optimale de biomasse de sphaigne, il est convenable d'établir un niveau autour de 1 500 cm-jour pendant la saison de croissance. En d'autres termes, il faut garantir non seulement un niveau près de la surface, mais assurer le moins de variation possible. L'introduction de ces indicateurs de dépassement/carence permettra de poursuivre la conception ou même l'évaluation hydrique des cultures de sphaigne. Cette analyse sera complétée dans une prochaine étape du projet avec la caractérisation du mouvement des fluides en milieux poreux.

The impact of competition and allelopathy on the niche differentiation of the hollow species and the hummock species in peatlands

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Abstract: In contrast to resource competition, allelopathy, one kind of plant-plant interactions, is currently less well studied. Here, we address hypotheses about the role of allelopathy, the same as resource competition, as a driver of impacting the growth and inducing niche differentiation dynamics. Growth and interaction abilities of a hollow (*Sphagnum fallax*) and a hummock species (*Sphagnum magellanicum*) were evaluated under four backgrounds of plant-plant interactions with high or low water table level condition: 1) a control, growing alone; 2) allelopathy (A) + competition (C), *S. magellanicum* and *S. fallax* growing together; 3) competition (C), two species growing together but activated carbon being added below neighbor capitulum to reduce allelopathy; 4) allelopathy (A), estimating by C + A and by subtracting C. After 12 months of experimentation in the field, under the condition of high water table level, relative neighbor effect (RNE) was weak between them. *Sphagnum fallax* had the high advantage of height growth if it's biomass production was same as that of *Sphagnum magellanicum*. The Overall Phenotypic Responses of *S. magellanicum* was much wider than that of *S. fallax* when the water level decreased, suggesting that the physiological and growth plasticity of *S. fallax* is much weaker than that of *S. magellanicum*. RNE_A shows that the hollow species *S. fallax* was inhibited by allelopathy (not competition) of the hummock species *S. magellanicum*. And in *S. magellanicum*, a decrease in plant growth and an increase in release of phenolics (potential allelochemicals) were observed and there was a significant negative correlation between them in the C treatment. RNE_A and RNE_C for height increment of *S. magellanicum* also slightly negatively correlated. *Sphagnum fallax* showed a similar trend, biomass production negatively relating with phenolic production, but no significant negative correlation between them was observed.

This study suggests that *Sphagnum* competitive advantage comes from the two aspects of resource competition and allelopathy and that the trade-off between plant growth and the release of phenolics was species and resource conditions dependent. The ability of resource competition and allelopathy of the two species were changed along the water table level gradient.

Key words: *Sphagnum fallax*, *S. magellanicum*, allelopathy, resource competition, niche differentiation

FEN SESSION

Regeneration of fen true moss species: Implication for future restoration project

La régénération des vraies mousses de fen : les implications pour des projets de restauration futurs

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Abstract: Peatland restoration towards a fen ecosystem has been the subject of a recent interest in the scientific community in Canada. The first large-scale fen restoration using the Moss Layer Transfer Technique (MLTT) in Canada couldn't restore the moss layer typical of fen. There is few information on the ecology of fen true mosses, the main component of the fen moss layer, that can be used in a restoration context. The goal of this study is to create the basic information on what can influence the regeneration of mosses in a restoration context. This project contains two main parts: factors that were tested in controlled environment and factors tested in a realistic environment; the latter of which used the information obtain in the first part as a backbone for its realization. The first experiment showed that fen true moss regeneration capacity decreased as the distance with the apex increases. Both the fragmentation and fertilization experiment increase regeneration of moss in a controlled environment but varied in effect in the field sometime being effective, detrimental or having no effect. Liming affected positively only one species significantly. The nursing plant experiment had no effect to the target mosses in any of the treatment. Some species of mosses consistently produce higher cover and a higher number of innovations during the field experiment than others. Mosses forming small hills tend to regenerate better than the ones growing in depression when applied on the field.

Résumé : La restauration de tourbière vers un écosystème de fen est le sujet d'un intérêt récent chez la communauté scientifique canadienne. La première restauration à grande échelle utilisant la méthode de transfert du tapis muscinal (MTTM) au Canada n'a pas restauré la couche muscinale typique des fens. Il y a peu d'information sur l'écologie des vraies mousses de fen, composantes principales des tapis muscinaux des fens. Le but de cette étude est de créer l'information de base nécessaire à la compréhension de la régénération des mousses de fen dans un contexte de restauration. Ce projet fut conçu en deux parties, les facteurs testés dans un environnement contrôlé et les facteurs testés en condition réelle; les informations issues de la première partie furent utilisées pour la réalisation de la deuxième partie. La première expérience a prouvé que plus les fragments des vraies mousses de fen sont pris loin de l'apex, moins ils se régénèrent. La fragmentation et la fertilisation ont augmenté la régénération des mousses dans un environnement contrôlé, mais ont eu des effets plus divers sur le terrain, parfois étant bénéfiques, parfois néfastes et parfois n'ayant aucun effet. Le chaulage a affecté positivement une espèce de manière significative. L'expérience des plantes compagnes n'a eu aucun effet sur les mousses cibles, dans aucun des traitements. Certaines espèces ont produit plus de couvert et plus d'innovations que d'autres, et ce, de manière consistante. Les mousses formant de buttes ont eu une meilleure régénération que celles se retrouvant dans les dépressions.

Rewetting a minerotrophic peatland after peat extraction activities: Impact on carbon exchange and vegetation

Remouillage d'une tourbière minérotrophe après extraction de tourbe : effet sur les échanges de carbone et la végétation

Laurence Turmel-Courchesne[1], Maria Strack[2] & Line Rochefort[1]

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Abstract: The Moss Layer Transfer Technique (MLTT) has been developed to restore the carbon sequestration function and typical vegetation of extracted ombrotrophic peatlands (bogs). However, peat extraction in bogs sometimes leads to uncovering the underlying sedge-peat layers with physicochemical characteristics typical of those prevailing in minerotrophic peatlands (fens). In these cases, restoring towards fen ecosystems is more appropriate. In Europe, rewetting is commonly used as a peatland restoration strategy. In Canada, where restoration goals and backgrounds differ from Europe, little is known about the potential of rewetting to promote vegetation reestablishment and carbon sequestration on peatlands with a minerotrophic residual peat layer. Yet, the first rewetting experiments on such surface suggest that it may lead to the reestablishment of high vascular plant cover. During the 2016 growing season, CO_2 and CH_4 fluxes were measured using the closed chamber technique on a rewetted vacuum-extracted peatland with minerotrophic residual peat in Manitoba. Vegetation surveys were realized in August 2016 and 2017. Data was collected on three rewetted sectors of the peatland which also received different surface preparation treatments: 1) one growing season after rewetting: surface levelled; 2) one growing season after rewetting: surface not levelled; 3) ten growing seasons after rewetting: surface levelled, on 4) a reference ecosystem (natural fen) and on 5) a non-rewetted sector. Rewetting resulted in the return of similar CO_2 uptake between the rewetted sectors and the reference ecosystem. However, one sector showed high CH_4 emissions. Environmental factors controlling CO_2 and CH_4 fluxes differed between the rewetting treatments and the reference ecosystem. Rewetting lead to the establishment of typical peatland vascular and moss species although their cover remained lower than in the reference ecosystem. Rewetting proved to be an efficient restoration technique in terms of typical peatland vegetation reestablishment and carbon sequestration. However, proper water table management is critical to avoid high methane emissions and to promote the return of an optimal vegetation structure. Considering the hydrological context of a site is also essential when deciding to rely only on rewetting to restore a site.

Résumé : La technique de transfert de la couche muscinale a été développée et utilisée avec succès pour restaurer la fonction de séquestration du carbone et la végétation typique des tourbières ombrotrophes (bogs) après extraction de tourbe horticole. Il arrive toutefois que l'extraction expose des couches de tourbe présentant des caractéristiques physicochimiques typiques des tourbières minérotrophes (fens). Il est alors plus approprié de restaurer vers un écosystème de fen plutôt que vers un bog. En Europe, la technique du remouillage est couramment utilisée comme stratégie de restauration des tourbières. Au Canada, où l'historique et les buts de restauration diffèrent de l'Europe, le potentiel de la technique de remouillage pour restaurer des fens à la suite d'activités d'extraction de tourbe est encore peu connu. Cela dit, les premiers essais de remouillage suggèrent que cette technique pourrait mener à de hauts recouvrements en espèces vasculaires. Durant la saison de croissance 2016, la technique des chambres fermées a été utilisée afin de mesurer des flux de CO_2 et de CH_4 dans une tourbière post-extraction du Manitoba présentant une tourbe résiduelle minérotrophe. Des inventaires de végétation ont également été réalisés en août 2016 et 2017. Les mesures ont été effectuées dans trois secteurs remouillés ayant subi différents types de préparation de surface : 1) une saison de croissance post-remouillage, surface non reprofilée; 2) une saison de croissance post-remouillage, surface reprofilée; 3) dix saisons de croissance post-remouillage, surface reprofilée; 4) dans un

écosystème de référence (fen naturel) et 5) dans un secteur non remouillé. Les flux de CO_2 étaient similaires entre les secteurs remouillés et l'écosystème de référence. Toutefois, l'un des secteurs remouillés a émis de grandes quantités de CH_4. Les facteurs environnementaux contrôlant les échanges de CO_2 et de CH_4 ont également différé entre les traitements de remouillage et l'écosystème de référence. Le remouillage a mené à l'établissement d'espèces vasculaires et muscinales typiques des tourbières, bien que leur recouvrement ait été inférieur à celui de l'écosystème de référence. Le remouillage s'est avéré être une méthode de restauration efficiente menant au retour de la fonction de séquestration de carbone et d'une végétation typique des fens. Néanmoins, une gestion adéquate des niveaux d'eau est cruciale pour éviter de générer de hautes émissions de CH_4 et pour promouvoir le retour d'une structure de végétation optimale. Finalement, il est indispensable de tenir compte du contexte hydrologique d'un site à restaurer lorsque l'utilisation de la seule technique de remouillage est envisagée dans un projet de restauration.

Re-contouring a cutover peatland to improve hydrological function and promote fen restoration in southeast Manitoba, Canada

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Abstract: The struggle with restoring peatlands back to functional ecosystems after extraction is that the moss cannot just simply grow back. The water level, soil water tension, and general water balance needs to be conducive to *Sphagnum* establishment. Elma North is a post-vacuum extracted peatland in southeast Manitoba, Canada, which was left for restoration after 12 years of extraction. The cutover surface was re-contoured into a grid pattern with wells and piezometer nests (N=44) installed intermittently throughout the cutover surface and in transects into the surrounding natural areas. The average 2015 water levels within the natural area and cutover grid was -46 cm and >-100 cm, respectively, while the average 2016 water levels within the natural area and cutover grid was -18 cm and -15 cm, respectively. It is of note that the average precipitation for the 2015 and 2016 study periods was 200 mm and ~140 mm more than the 30-year historical average, respectively. Intermittent measurements were taken in 2017, finding an average water level of -14 cm and 25 cm within the natural area and cutover area, respectively. The 2016 soil water tensions within the top 5 cm of the surface were -15 cm and -16 cm for the cutover section and natural area, respectively. From the 2016 results, it could be concluded that the grid cell pattern was effective in raising the water level and soil water tension enough to promote *Sphagnum* moss establishment; however the cells retained too much water in 2017 which would flood out any moss trying to establish. We estimated that in a normal year, with 200 mm less precipitation, water tables would have been ~-43 cm, which is slightly too low for ideal hydrological conditions for restoration. We conclude that water control structures would be required for gradual rewetting of fen restoration projects, ensuring a "Goldilocks" water level of not being too wet, or too dry, but just right, is achieved.

BOG SESSION

Measuring restoration progress using pore- and surface-water chemistry across a chronosequence of formerly afforested blanket bogs

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Abstract: Forest-to-bog restoration is a land management practice where drained afforested bogs, are restored to open bog by removing the trees and blocking drainage ditches. This management is carried out with the aim to re-create healthy blanket bog habitat and functionality e.g. carbon sequestration and nutrient cycling. However, the time required for conditions to become similar to open bog is not known. We proposed to measure restoration progress using a space-for-time substitution and measurements of pore- and surface-water chemistry.

Pore- and surface- water was sampled across a chronosequence of formerly afforested blanket bogs in comparison with standing forest and open bog controls. Our results imply progress in recovery towards open bog conditions during 0-17 years post-restoration. There were some legacy effects of drainage and afforestation, which recovered almost to open bog conditions (WTD, pH), while elements scavenged by trees (Mg, Na, S), completely recovered. Water chemistry variables, which showed an effect of restoration mostly recovered by ≤11 years, although NH_4^+ and DOC remained elevated compared to open bog 17 years post restoration. Excess N and lower WTD may have implications for the recovery of recovery of bog vegetation including key *Sphagnum* species.

Currently our results suggest that more than 20 years is required for complete recovery of water chemistry to bog conditions. However, newer restoration methods of conifer harvesting (stem plus brash) and blocking of plough furrows to increase the WTD, may be able to accelerate the restoration process. We conclude that monitoring of surface- and pore-water chemistry is useful in indicating recovery towards bog conditions and we recommend monitoring of WTD, pH, conductivity, Ca NH_4^+, PO_4^{3-}, K, DOC, Al and Zn as key variables.

Regenerative succession of Azorean peatlands, after disturbance, as an ecological restoration tool

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Abstract: In the 1980's and 1990's, natural and semi-natural habitats of all Azores islands declined because of agriculture promotion and changes in land use. There has been a paradigm change: European policies encourage the abandonment of non-profitable pastures to re-establish and preserve biodiversity. This study on regenerative secondary succession took place in abandoned public pastures where degradation had occurred. The experimental site was mapped in 2006 (still pastured), 2013 (two years post-abandonment) and 2015 (four years post-abandonment) for a broad perspective of *Sphagnum* spp. occurrence and colonization through the period of study. The baseline assessment of 2006, still under pasture, revealed that *Sphagnum* spp. was present in 7% of the area, pointing to some resilience of the peat ecosystem. After grazing exclusion, *Sphagnum* spp. cover increased to 17% and 39%, two and four years without major disturbance, respectively.

To improve understanding about this dynamic, 48 permanent plots were established in the abandoned pasture. A further 20 plots were established to examine patterns of succession, with ten plots in semi-natural areas and ten in natural peatland areas considered to be at a climax stage of succession and similar to pre-disturbance ecosystems. These plots were monitored three times each year between July 2012 and July 2015. After four years, formerly pastured peatlands showed considerable recovery, with a clear growth of *Sphagnum* spp. cover as well as other typical peatland species as *Calluna vulgaris.*

Grazing exclusion induces regenerative succession by key native peatland species and is a useful restoration tool in post-degraded peatlands in Azores.

Methane fluxes at a horticulture peatland complex in Seba Beach, Alberta

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Abstract: Peatlands are a source of methane (CH_4) emission to the atmosphere and a sink for carbon dioxide (CO_2). Disturbed peatlands generally become a source of CO_2 and a sink for CH_4, except for drainage ditches. Restoration of peatland ecosystems aims for recovery of the natural balance in carbon cycling by returning their hydrological conditions and regrowth of peatland vegetation.

Methane dynamics in extracted and restored peatlands are not fully understood. Environment Canada data on greenhouse gas emission from peat extraction account only for CO_2. Methane emission from extracted peatlands included in National Inventory Reports accounts only for CH_4 fluxes, while entrapped free-phase gas (FPG) is omitted. It is unknown how fast and to which extent extracted peatlands recover their FPG and CH_4 fluxes. Presented data are a part of a larger project that addresses these questions and the role of restoration in returning peatland CH_4 balance.

This presentation will show results on spatial and temporal patterns in CH_4 emission and environmental controls on CH_4 emission at a chronosequence of peatlands including a natural site, three sites restored in 1991, 2009, and 2012, an unrestored and a currently extracted (active) site located at the Seba Beach peatland complex managed by Sun Gro Horticulture. Methane and CO_2 fluxes were collected at six replicate plots per sub-site during the growing season using a portable gas analyzer and the manual method in 2016 and 2017, one of the driest and wettest years recorded, respectively. The diffusive fluxes have been calculated from linear changes in gas concentration over time and separated from ebullition when possible. Further calculations of ebullition contribution will allow for more accurate assessment of diffusive fluxes.

Sphagnum borrow sites for peatland restoration: do they regenerate?

Les sites d'emprunt utilisés pour la restauration des bogs se régénèrent-ils?

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Abstract: The North American restoration method for ombrotrophic peatlands (bogs), the Moss Layer Transfer Technique, involves the large-scale mechanical harvesting of plant material in a natural peatland called a borrow site. So far, only preliminary studies conducted on one borrow site have shown that *Sphagnum* mosses regenerate within 5 years. The only other studies available on *Sphagnum* regeneration after harvesting are in hand-harvested bogs in Chile and New Zealand. However, different mechanical harvesting and management methods are used across Canada, and therefore this requires further evaluation of borrow site recovery. We aimed to evaluate the regeneration of vegetation, especially of *Sphagnum* mosses, to determine which management methods are the best to enhance their recovery and to evaluate the influence of the environment (meteorology and hydrology) on their regeneration. A chronosequence of 25 borrow sites aged from 1 to 17 years since harvesting were inventoried along with 15 natural reference sites located in Quebec, New Brunswick and Alberta, Canada. All borrow sites aged of 10 years or more were dominated by *Sphagnum* mosses, though plant communities varied between borrow and natural reference sites because of the wetter conditions at borrow sites. Management methods strongly influenced borrow site recovery, showing that the skills of the practitioner are an essential ingredient. Less disruptive methods and harvesting when the soil is deeply frozen are recommended. This study demonstrated that harvesting for peatland restoration activities are not detrimental to natural peatland ecosystems.

Résumé : La méthode de restauration des tourbières ombrotrophes (bogs) en Amérique du Nord (technique de transfert de la couche muscinale) nécessite la récolte mécanique à large échelle de matériel végétal dans une tourbière naturelle qu'on appelle site d'emprunt. Jusqu'ici, des études préliminaires conduites sur un seul site d'emprunt ont montré que les sphaignes se régénèrent en 5 ans. Les seules autres études disponibles sur la régénération des sphaignes après la récolte ont été menées dans des bogs récoltés à la main au Chili et en Nouvelle-Zélande. Toutefois, d'autres méthodes de récolte et de gestion sont utilisées au Canada et cela requiert une évaluation approfondie de la reprise des sites d'emprunt. Cette étude évalue la régénération de la végétation, spécialement des mousses de sphaignes, afin de déterminer quelles sont les méthodes de gestion les plus appropriées afin de maximiser la reprise des sites d'emprunt et d'évaluer l'influence de l'environnement (météorologie et hydrologie). La chronoséquence a été étudiée pour 25 sites d'emprunt âgés de 1 à 17 ans, ainsi que pour 15 sites naturels de référence au Québec, Nouveau-Brunswick et en Alberta (Canada). Tous les sites d'emprunt de 10 ans ou plus sont dominés par la sphaigne, quoique les communautés végétales varient entre les sites d'emprunt et les sites de référence, en raison, entre autres, des conditions plus humides des sites d'emprunt. Les méthodes de gestion influencent fortement la reprise des sites d'emprunt, pouvant l'accélérer ou la ralentir. Des méthodes de récolte moins perturbatrices et la récolte sur sol gelé sont recommandées. Cette étude démontre que la récolte de végétation pour la restauration de tourbières ne porte pas préjudice aux écosystèmes naturels de tourbières.

Mineral roads in *Sphagnum* dominated peatlands: The peat inversion technique

Les routes minérales en tourbières à sphaignes : restauration par enfouissement

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Abstract: The electric power transmission lines network spans across the territory of the province of Québec on 34,000 km and some of its sections inevitably go through peatlands. This restoration project has been conducted on two peatlands where access roads were constructed under power lines: at Sainte-Eulalie (Centre-du-Québec) and Chénéville (Outaouais). A mineral road in a peatland changes the nature of the substrate and can influence the water table level and the physicochemical characteristics of the water and peat. These changes can modify the composition and diversity of the vegetal communities. We examined if burying the mineral material within the bog is an effective method to restore the peatland conditions. The restoration by the Peat Inversion Technic (PIT) consists in excavating and burying the mineral material beneath the underlying peat material. The method should allow to reach restorations goals by (1) confining the nutrients introduced with the mineral material, (2) by conserving a peaty surface elevation similar to the adjacent areas and (3) by re-establishing typical peatland vegetation. Whether it is 1 or 3 years post-restoration, the results of the physicochemical analyses of the water sampled at various depths and distances of the buried road presented similar nutrients concentrations to the means observed in the reference ecosystems. The small soil elevation differences in the restored areas between readings show that the compaction and leveling used in the PIT are appropriate to fulfill the pursued objectives. The return of peatland plants communities varied depending on the site, mainly because of local factors. Ultimately, the results of this project show that the PIT complies with restoration objectives. Furthermore, it is economically profitable in comparison with another restoration technic, the complete removal of the mineral material.

Résumé : Le réseau de transport d'électricité sillonne le territoire québécois sur plus de 34 000 km et certains tronçons traversent inévitablement des tourbières. Ce projet de restauration a été réalisé sur deux tourbières où des chemins avaient été construits dans des emprises de lignes de transport d'énergie, à Sainte-Eulalie (Centre-du-Québec) et Chénéville (Outaouais). Un chemin minéral en tourbière change la nature du substrat et peut influencer le niveau de la nappe phréatique et les caractéristiques physicochimiques de l'eau et de la tourbe. Ces changements peuvent conséquemment modifier la composition et la diversité des communautés végétales tourbicoles. Nous avons tenté de déterminer si l'enfouissement du matériel minéral permet de restaurer la tourbière. La méthode d'enfouissement sous déblai tourbeux (MESDT) utilisée consiste à excaver, puis enfouir in situ le chemin minéral sous la tourbe sous-jacente à la perturbation. La MESDT devrait permettre d'atteindre les objectifs de restauration en (1) limitant l'enrichissement de la tourbière par les éléments nutritifs introduits par le matériel minéral du chemin, (2) en permettant de conserver une surface tourbeuse d'élévation similaire à la tourbière environnante et (3) en facilitant le retour d'une végétation de tourbières telle que trouvée dans l'écosystème de référence. Que ce soit 1 an ou 3 ans post-restauration, les résultats des analyses physicochimiques de l'eau échantillonnée à différentes distances et profondeurs du chemin enfoui ont montré des concentrations en nutriments semblables aux moyennes observées dans les écosystèmes de référence. Les légères différences d'élévation du sol dans les bandes restaurées entre les relevés indiquent que la compaction et le nivellement utilisés dans la MESDT ont été adéquats pour atteindre les objectifs visés. Le retour des communautés tourbicoles a varié selon le site, principalement en raison de facteurs locaux. En conclusion, les résultats de ce projet d'étude montrent que la MESDT répond aux objectifs de restauration. De plus, elle demande moins de ressources humaines, matérielles et monétaires en comparaison à une méthode alternative qui consiste à retirer complètement le matériel minéral.

Propagule bank persistence through restoration at Bois-des-Bel, 1999-2015

Persistance de la banque de diaspores à la suite de la restauration de la tourbière de Bois-des-Bel (1999-2015)

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Abstract: The moss-layer transfer technique (MLTT) is used to restore disturbed peatlands in North America and internationally, and includes the movement of plant propagules from a borrow site to the area to be restored. This step is intended to provide rapid dispersal of propagules such as seeds, spores, and plant parts capable of regeneration into the restoration area such that a community of plants will grow that resembles the species composition of an undisturbed peatland of the region and the existing chemical and hydrological conditions at the site. Prior to restoration, a disturbed peatland may exist as an area of bare peat for many years, during which time some plants may become established on the site through spontaneous revegetation. As part of the normal implementation of the MLTT, ditches are blocked or filled and the surface is levelled or contoured to control hydrological considerations, burying or crushing any plants present on the site, killing adult plants but most likely allowing propagules to survive to potentially germinate or regenerate after restoration. The resulting plant community after restoration thus includes both plants that were brought to the site by intentional human activity and plants that persisted through the restoration events in situ. This provides an opportunity to test biogeographical hypotheses; in a restored peatland, it is true that 'everything is everywhere, and the environment selects'. This study uses vegetation surveys and environmental data collected at the Bois-des-Bel peatland (Québec province). Environmental parameters were measured and plants, as well as bare peat, straw, wood, and unidentifiable plant litter were counted using the pin-point method at transect positions. Vascular plants, bryophytes, and lichens were identified to species, and were scored by presence/absence every alternate year from 1999, immediately prior to restoration, to 2015.

Résumé : La technique de transfert de la couche muscinale (TTCM) est utilisée pour restaurer les tourbières perturbées en Amérique du Nord et à l'échelle internationale. Elle implique le transfert de diaspores végétales d'un site d'emprunt à la zone à restaurer. Cette étape vise à assurer une dispersion rapide des diaspores telles que les graines, les spores et les parties de plantes capables de se régénérer dans la zone de restauration, de façon à former une communauté de plantes semblable à celle d'une tourbière non perturbée de la région, en fonction des conditions hydrologiques du site. Avant sa restauration, une tourbière perturbée peut se présenter sous la forme d'une surface de tourbe nue pendant de nombreuses années, période au cours de laquelle certaines plantes peuvent s'établir sur le site grâce à une revégétalisation spontanée. Dans le cadre des travaux habituels de la TTCM, les canaux de drainage sont bloqués ou remplis et la surface de la tourbe est nivelée. Ces travaux ont pour conséquence d'enterrer ou d'écraser toutes les plantes présentes sur le site, tuant les végétaux adultes, mais permettant à des diaspores de survivre qui peuvent germer ou se régénérer par la suite. La communauté végétale résultante après restauration comprend donc à la fois des plantes qui ont été amenées sur le site par une action humaine intentionnelle et des plantes qui ont persisté pendant les événements de restauration *in situ*. Cela fournit l'occasion de tester des hypothèses biogéographiques : dans une tourbière restaurée, il est vrai que « tout est partout, mais que l'environnement sélectionne ». Cette étude utilise des relevés de végétation et des données environnementales recueillies à la tourbière de Bois-des-Bel, au Québec. Les paramètres environnementaux ont été mesurés et les plantes, ainsi que la tourbe nue, la paille, le bois et la litière végétale non identifiable ont été comptés à l'aide de la technique par point d'interception sur des transects. Les plantes vasculaires, les bryophytes et les lichens ont été identifiés aux espèces et ont été notés par présence/absence tous les deux ans, à partir de 1999 (immédiatement avant la restauration) jusqu'en 2015.

Is bog restoration bringing back all peatland plant species?

La restauration des tourbières ombrotrophes ramène-t-elle toutes les espèces de plantes des tourbières?

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Abstract: (Part of the Special Session next page) Of the 43 vascular plant species usually found in natural bogs, 8 species (16%) are recalcitrant to the Moss Layer Transfer Restoration Technique (MLTT), including *Maianthemum trifolium, Eriophorum angustifolium,* some orchids, *Carex trisperma* and *Rubus chamaemorus.* These typical bog species do not establish after restoration, despite their presence in their respective borrow sites. Finding the causes of their recalcitrance and how to facilitate their establishment in biodiversity-focused restoration projects will require further research.

Résumé : Parmi les 43 espèces de plantes vasculaires généralement présentes dans les tourbières naturelles, huit espèces (16 %) sont récalcitrantes à la technique de restauration par transfert de la couche muscinale, notamment *Maianthemum trifolium*, *Eriophorum angustifolium*, certaines orchidées, *Carex trisperma* et *Rubus chamaemorus*. Ces espèces typiques de tourbières ne s'établissent pas après la restauration, malgré leur présence dans leurs sites d'emprunt respectifs. Pour trouver les causes de cette récalcitrance et comment faciliter leur implantation lors des projets de restauration axés sur la biodiversité, il faudra des recherches plus approfondies.

SPECIAL SESSION

Improving the restoration methods and assessing success: 5 years of research on peatlands restoration and management

General summary

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Several research topics identified in partnership with the Canadian peat industry were addressed during the 2013-2018 period. Here are the main results of the last five years of research conducted under the third term of the NSERC Industrial Research Chair (IRC) in Peatland Management and the Collaborative Research and Development (CRD) grant entitled "Farm, restore and model: responsible management of peatlands for a sustainable Canadian horticultural peat industry". Note that the information given below may not be exactly the same as the one presented orally by the researchers.

Land-use management: Bogs

Peatland restoration initiatives were studied in order to assist future decisions in peatland management. Here are the main conclusions.

While the first two terms of the IRC focused on developing the mechanized bog restoration method, the so-called Moss Layer Transfer Technique (MLTT), this third term aimed at refining the method and assessing its efficiency. For instance, we now know that the viability of plant material collected for restoration starts decreasing after 6 months of storage. If it is not possible to spread the diaspores soon after their collection, the optimal scenario is to harvest them in the fall, pile them for the winter and to use them the following spring. Different fertilization scenarios confirmed that phosphate rock application remains an important step of the restoration method to improve the establishment of both vascular plants and mosses.

Long-term monitoring database (including plant cover data collected each year by L. Rochefort's team in 66 restored bogs restored since the end of the 1990's) were used to assess the success of bog restoration by the MLTT. Multivariate analyses suggest that the method was successful in about 68% of the sampled plots. About 40% of the plots exhibited plant communities similar to those found in the reference ecosystems (natural peatlands) and were classified as *Sphagnum*–cotton grass-dominated; 28% were described as *Polytrichum*–*Sphagnum* and could be fulfilling the ecological function of peat accumulation since they were dominated by a moss carpet. The remaining 32% were mainly bare of vegetation, even though *Eriophorum vaginatum*, *P. strictum* and *S. rubellum* were predominant, and undesirable exotic and non-peatland plant species were rarely found. A statistical tool was created to define the success of restored peatlands (community types). This tool is based on simple indicators (vegetation strata) and is applicable across Canada.

Of the 43 vascular plant species usually found in natural bogs, 8 species (16%) are recalcitrant to the MLTT, including *Maianthemum trifolium, Eriophorum angustifolium,* some orchids, *Carex trisperma* and *Rubus chamaemorus.* These typical bog species do not establish after restoration, despite their presence in their respective borrow sites. Finding the causes of their recalcitrance and how to facilitate their establishment in biodiversity-focused restoration projects will require further research (more information is presented by Sandrine Hugron, p. 16).

In some situations, invasive plants can become a problem in restored peatlands. Cattails (*Typha* spp.) and common reed (*Phragmites australis*) usually spread from the roadsides or former drainage ditches to colonize the wettest depressions. Through their prolific seed production and extensive rhizome system, the contamination risk for adjacent extracted peat fields and the risk of biodiversity decrease in the restored sites has highlighted the need to test several propagation control strategies. Results indicate that repeated mowing (3 times during the summer) of cattail stems is an efficient way to decrease their density (of 77%) and biomass (of 88%) in the short-term. To control common reed, various methods could limit the expansion of their colonies by impeding its regrowth, for example tarping the surface and planting willows.

The importance of restoring eco-hydrological gradients between restored peatlands and the adjacent landscape was emphasized. It seems that the impact of former peat extraction activities on the hydrology is important at 1 m next to the contour ditch into the adjacent peatland, still present at 8 m and absent at 25 m. To reduce those disturbances, reducing tree density at the margin of the bogs, filling the ditches completely and sloping of the soil surface along the edge of the artificial ecotones would re-create a progressive gradient similar to the reference ecotones.

For the restoration of coastal bogs influenced by salt water, three actions emerged from greenhouse and field experiments: 1) the salt marsh hay transfer method: mowing vegetation in a *Spartina pectinata* dominated area of a salt marsh, then spreading that material on the bare substrate; 2) the salt marsh diaspore transfer method: late-summer harvesting of salt marsh vegetation with a tiller, with the transfer of fragments to the bare peat substrate, and 3) the transplantation of *Carex paleacea*, although labour-intensive, produces a fast-growing vegetation cover.

Furthermore, the afforestation of a cutover bog at Paxson in Alberta with low doses of fertilizer favoured the establishment of *Picea mariana* while controlling birch invasion. Higher rates of fertilization caused dense *Betula papyrifera* colonization which created shading to black spruce and increased soil C release. Tree plantations on cutover peatland results in less C uptake than ecological restoration, but may be an alternative strategy on sites where rewetting is a challenge or site conditions unappropriated.

Finally, a study about resilience to fire of a peatland restored 9 years ago showed that lawn communities lost less biomass than hollow communities. However, for both plant communities, the plant production over the first growing season following the fire was similar between the burnt and unburnt zones.

Land-use management: Fens

Fen restoration has been of great interest in the last years. After peat extraction, when sedge-peat layers are exposed, the minerotrophic remnant peat may require restoration towards a fen ecosystem. Different approaches have been tried over the years.

For example, 19 years after the end of extraction activities, the Moss Spur fen in Manitoba showed that under some conditions the wetland vegetation can re-establish naturally without plant reintroduction, if a certain level of rewetting is reached. Moderately rich fens, bogs, and marshes formed a mosaic of habitats reflecting differences in soil chemistry across the site.

Nonetheless, active restoration strategies should be developed for most of the sites. At the Bic–Saint-Fabien (BSF) peatland (Québec), several restoration methods have been tried on a small scale, including the MLTT and manual introduction techniques. The results of the mechanized MLTT were unfortunately uneven and less successful (especially with mosses) than in bogs, and none of the restoration techniques were effective at establishing fen bryophytes.

In order to better understand the peculiarities of the regeneration of fen true mosses, Petri, greenhouse and field experiments were undertaken with diaspores. See the presentation of Sébastien Meilleur for more information about this subject (p. 7).

However, to bring back fen vascular plants, two techniques gave promising results in terms of species composition, although their cover remained low. In areas where sparse cover of fen species may have spontaneously established, rewetting should be carried out to raise water levels and create favourable conditions for their expansion. In areas covered with undesirable species or with inadequate topography for rewetting, surface peat should be remodeled and vegetation introduced. Alternatively, fertilization with phosphorus proved to have a positive effect on vegetation establishment and could be an effective solution to enhance the establishment of mechanically introduced plant diaspores in fen restoration; however liming has no effect on vegetation reestablishment.

Following these first trials in fen restoration, two important large-scale projects have then been conducted in Manitoba, which scaled up the results of various approaches, including rewetting, surface preparation and contouring techniques. Additionally, an ecosystem-level fen restoration project implemented in Manitoba is being used as an integrated research site where carbon balance, hydrology and vegetation recovery have been assessed (see presentations by Laurence Turmel-Courchesne p. 8, Pete Whittington p. 9, and the text below). So far, some key species to reintroduce have been identified. For example, *Scirpus cyperinus* communities have shown to be among the most diversified and to establish rapidly, which could also prevent surface erosion.

The revegetation trials of pools re-created in the BSF restored fen showed that species richness was higher for moss-revegetated pools than for the other treatments with sedges and bulrush. In the case of shallow pools or wet depressions (hollows) revegetation, the MLTT should be favoured in future restoration projects. Care should be taken to collect pool margin plant material for the transfer and thereby ensure the restoration success of these local biodiversity hotspots. At BSF peatland, creating pools of variable depths and introducing graminoid-type vegetation on their margins have also optimized the return of arthropods assemblages similar to what is observed in reference ecosystems.

Hydrological functions after management

Peatlands exist because of the prolonged saturation that results in anoxia (low oxygen content) and hence, incomplete decomposition of organic material. Maintaining or re-establishing conditions that ensure requisite levels of saturation with water is a key to a successful peatland restoration, for *Sphagnum* fibre production, and for reducing carbon emissions.

The possibility to restore not only the *Sphagnum* carpet, but also the vertical hydrological dynamics between the remnant peat and the newly formed *Sphagnum* carpet, has been tested at the Bois-des-Bel research station (Québec). More than 10 years after the restoration of this bog, there was limited hydrological connectivity between the regenerated *Sphagnum* moss and the relatively dense remnant cutover peat below. Mechanical field scale compression was performed at that restored bog, resulting in an increase in moisture content and in hydraulic conductivity above the former cutover peat, generating increased hydrological connectivity between the surface of the moss and the water table below. More details are given in Tasha-Leigh Gauthier's presentation (p. 4).

Research projects focusing on fen rewetting and their hydrological context were conducted during 2015 and 2016 in Manitoba. In the Prairies, short snowmelt period in the spring brings new challenges to the restoration approaches developed in Québec and New Brunswick. Flooding in the summer of 2016 at the South Julius site illustrated how tricky rewetting specific areas within actively extracted sites can be. When conducting large-scale restoration projects in fens, rewetting techniques should be adapted to take into account the water flow inputs from the surrounding environments and careful consideration of the existing drainage network capacity is needed to ensure both successful rewetting and maintenance of operations. At Elma North, contouring strategies to enhance water retention on site have been developed and should be part of the restoration plans whenever possible. Similarly, the return of the eco-hydrological connection between the restored and adjacent natural ecosystems should now be included in the post-extraction management plans. For more information, see Pete Whittington's presentation (p. 9).

Sphagnum farming

Sphagnum farming is the sustainable production of non-decomposed *Sphagnum* fibre biomass on a cyclic and renewable basis. Previous research programs at Shippagan peatland no. 527 (New Brunswick) in 2004-2013 showed that it is possible to mechanically initiate and maintain large-scale *Sphagnum* farms in former trenches of block-cut peatlands. According to these researches, a fine control of hydrology is the most important factor to improve the productivity of the *Sphagnum* carpets.

Automated irrigation was thus experienced during the current research programs and implemented at two sites in Québec (St-Modeste) and in New Brunswick (Shippagan peatland no. 530). Irrigated basins with a -10 cm water table target reached full *Sphagnum* cover (90-100%) twice as fast as unmanaged basins (3 vs 6 years) and yield 1.5 to 2 times more biomass. After three growing seasons, *Sphagnum* covers were always higher in basins with automated control of the irrigation compared to the basin with manual control. Water table fluctuations (seasonal maximum – minimum) should be less than 15 cm to optimize *Sphagnum* growth, suggesting that the next step in developing *Sphagnum* culture in Canada would be a greater automation of the irrigation system (see the Ph.D. project of Sebastian Gutierrez Pacheco on this subject, p. 5). Moreover, we found as early as the 2nd growing season that basins with the most stable water table levels had the greatest CO_2 uptake and were closer to acting as CO_2 sinks.

Other aspects of *Sphagnum* cultivation have been studied. It appears that the mechanical control (by repeated mowing) of graminoid vascular plants in farming basins has no effect on *Sphagnum* cover and biomass. Moreover, if the dominant graminoid plant is *Eriophorum angustifolium* or a graminoid plant with similar growth habits (individual stems, spreading by rhizomes and producing minimal amounts of litter), mowing is unnecessary to promote *Sphagnum* productivity. Depending on the *Sphagnum* farming purposes, mowing might not be needed to maximize biomass accumulation, but it may be considered for other reasons. For example, control method may be necessary to facilitate *Sphagnum* fibre harvesting, since vascular plants can jam the machinery mechanisms. The end use of the fibres may also influence the decision. If they are destined to be used for specialized horticultural substrates such as orchid propagation, vascular plants might need to be eradicated to minimize the risks of seed contamination. However, if cultivated *Sphagnum* mosses are intended to be used as diaspores for ecological restoration projects, the presence of vascular plants is not a concern and could even allow for the return of typical peatland vascular plants.

Other previous work (2013) at the Shippagan no. 527 *Sphagnum* farming station measured the unsaturated hydraulic conductivity and water retention properties of *Sphagnum* moss of different ages. The van Genuchten-Mualem model has been fit to these data, and models are being designed to predict optimum water table management strategies for the system as the moss-profile ages (see the presentation of James Elliott, p. 2).

Finally, the addition of phenolic compounds to strengthen the enzymic latch mechanism and reduce decomposition in *Sphagnum* farm was tested in greenhouses and in the field. In greenhouses, the additions of woodchips mixed with the top layer of the peat surface gave promising results. This experiment was scaled up in the field and results are currently being analyzed.

Carbon sequestration and greenhouse gas (GHG) exchanges following peat extraction and restoration

Continuous measurement of CO_2 and CH_4 exchange at paired unrestored and restored peatlands in Québec and Alberta has clearly illustrated that restoration reduces carbon emissions and can return sites to net annual carbon sinks by 15 years post-restoration. The young (2-4 years) restored site in Alberta remained a net carbon source during the study period, but emissions were reduced ~100 g C m^{-2} yr^{-1} compared to the unrestored site. Spatial heterogeneity in water table caused by local topographic differences resulted in different vegetation groups flourishing. To examine the effect of these differences on the net C exchange, in 2016, continuous measurements were made from two locations representing 'drier' and 'wetter' conditions. The wetter location remained a net annual source, despite being farther along the expected post-restoration trajectory. At the older unrestored and restored peatlands in Québec (15-17 post-extraction or restoration, respectively), carbon emissions were reduced, with the restored site acting as a sink of -79 ± 18 g C m^{-2} yr^{-1}. This is within the range of values for net ecosystem carbon exchange measured over 16 years at the undisturbed Mer Bleue bog. Furthermore, chamber-based measurements indicate that ditches, particularly when colonized by cattails (*Typha* spp.) were hotspots of CH_4 emission, but covered only a small area of the unrestored and restored sites. Therefore, CH_4 emissions from restored sites of 1-7 g C m^{-2} yr^{-1} were within the range observed at undisturbed peatlands.

Sites used as a source of donor material for bog restoration recovered rapidly with moss cover even higher than the reference bog within five years. Exchange of CO_2 was similar to the reference bog, while CH_4 emissions remained slightly higher due to wetter conditions following the removal of the surface layer and the high cover of *Eriophorum vaginatum* at the borrow site.

In Manitoba, at the spontaneously revegetated Moss Spur site, all studied vegetation communities remained sources of atmospheric carbon, but emissions were lower than bare peat areas. At South Julius, where sites were actively rewetted, all areas were net carbon sinks at rates comparable to or greater than the reference fen, except for a section of the site that was deeply inundated. All rewetted sites were also large CH_4 sources, likely due to inundated conditions and dense sedge cover.

The modelling of the change in carbon dynamics using a modified version of the Holocene Peatland Model (HPM), that we call Restore-HPM, is complete and the results are included in two manuscripts. One describes the modifications to the HPM for Restore-HPM and the simulations of the test site peatland. We have incorporated a simple function for methane emissions and have computed emission factors from the model output to compare with those of the IPCC Tier one default values. The other is based on simulations of peatland extraction of 1.5 to 2.0 m to compare with the IPCC default values. This work demonstrates that Canadian peatlands, particularly with restoration, emit fewer GHGs than is assumed to occur based on the IPCC values.