Plant establishment in restored peatlands: 10-years monitoring of sites restored from 1995 to 2003

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Summary

Chemin-du-Lac peatland (Québec, Canada) is a good example where restoration has been implemented by a peat company in their after-use management practices. As areas were progressively closed to peat harvesting, restoration has been done on 1.2 to 12 hectares (ha) per year, from 1995 to 2003. Plant establishment was monitored every year or second years from 1998 to 2007. Plant establishment was rapid and a complete moss carpet was rehabilitated within 4 to 7 years following restoration. Most species colonizing the restored zones were typical peatland species.

Key index words: Restoration, monitoring, Sphagnum mosses, plant establishment, cutover bog.

Introduction

Peatland restoration aims to reinitiate self-regulatory mechanisms that will lead back to functional peat accumulating ecosystems. As this process takes time, specific objectives have been defined regarding plant establishment following restoration, which are: 1) the rapid establishment of a typical peatland plant cover and 2) the presence, and eventually the complete coverage of a moss carpet composed of *Sphagnum* species, key species for the accumulation of peat (van Breemen, 1995; Wheeler and Shaw, 1995; Sliva and Pfadenhauer, 1999; Rochefort, 2000; Gorham and Rochefort, 2003). In North America, one approach to peatland restoration is based on direct *Sphagnum* diaspores reintroduction on peatlands abandoned after peat extraction; this approach is fully described in Quinty and Rochefort (2003) and Rochefort *et al.* (2003) and illustrated in Rochefort and Lode (2006).

Once a disturbed peatland has been restored, monitoring is essential to evaluate if restoration goals have been achieved or not. A long-term monitoring program should be set up in order: 1- to assess the success of the restoration compared to reference ecosystems, 2- to study the long-term changes in plant establishment and communities, 3- to understand the factors underlying these changes and 4- to eventually help to develop early criteria for restoration success. Such long-term monitoring programs have been designed in Eastern Canada. Most restored peatlands are being monitored with over 230 permanent plots so far. Typically, plants reestablishment is monitored every year or second years. Associated with each plot, various factors are described and measured such as the abiotic characteristics prior to restoration, the techniques used and species reintroduced, as well as hydrological and climatic factors.

The objective of this paper is to present the evolution of plant establishment over a 10-years period following restoration for one of the restored peatlands included in the long-term monitoring program. The particular site, Chemin-du-Lac peatland, is a site where restoration has been carried out since 1995.

Materials and Methods

Study area

Chemin-du-Lac peatland is part of the larger Rivière-du-Loup peatland (47°48'N, 69°28'W), which is a 3375 ha bog–poor fen complex, classified as a "domed bog" (National Wetlands Working Group, 1997). The average annual temperature is 3.2 °C, with average January and July temperatures of -12.6 and 17.8 °C respectively. Local annual precipitation averages 963 mm, of which 71% falls as rain (Environment Canada, 2005).

Premier Horticulture ltd is one of the main users of the peatland and currently 900 ha are vacuum harvested for horticultural purposes. Since 1995, this company is planning restoration within their peatland management strategies. As a consequence, several hectares are restored every year as they are abandoned after peat harvesting. Adjacent zones of the Chemin-du-Lac peatland were thus restored in 1995, 1997 and yearly from 1999 to 2003 (hereafter named R1995 to R2003).

Restoration techniques

Restoration work was usually carried out in fall because of machineries and operators availability. The restoration techniques followed the general guidelines proposed by Quinty and Rochefort (1997, 2005). However, there were some differences in one or more restoration steps because of increasing expertise gained over years or because of site particularities.

Table 1. Monitoring effort and sequence at the Chemin-du-Lac restored peatland, in zones restored from 1995 to 2003 and measured after 1 to 11 years following restoration (from 1998 to 2007). Monitoring effort is represented by the number of permanent plots (5 m x 5 m) installed in each restored zone. Numbers in the table correspond to time (age) since restoration.

Restored Zones	N plot /zone	Years of measurements									
		1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
R1995	6	3	4	5	.	7	.	9	.	11	.
R1997	6	1	2	3	.	5	.	7	.	9	.
R1999	2	.	.	1	.	3	.	5	.	7	.
R2000	4	.	.	.	.	2	3	4	5	6	7
R2001	3	.	.	.	.	1	2	3	.	5	.
R2002	4	.	.	.	.	.	1	2	3	4	5
R2003	4	.	.	.	.	.	.	.	.	3	.
TOTAL N	29										

Peat surfaces were levelled in order to modify the typical domed shape of the peat fields. Before 1999, concave shapes were created, resulting in one to three shallow "depressions" in the direction of the field length. In 1999 and after, peat surfaces were flattened and the peat scrapped from the surface was used to build fills (berms) in a chessboard pattern. In any cases, drainage ditches were completely filled with peat. Plant diaspores were collected in a natural peatland designated for future industrial development or in adjacent natural bog remnants. The upper 10-cm layer of the bog vegetation was mechanically collected and spread on the restored sites (reintroduction surface ratio of approximately 1:10). The reintroduced plant diaspores were then covered with straw mulch (ca. 3000 kg ha^{-1}). Machineries used during these operations varied years to years, depending on availability.

Restored superficies varied from 1.2 to 12 hectares. Residual peat depth ranged from 30 to 160 cm and degree of decomposition was estimated as H4 or H5 according to the von Post ordinal humification scale. The dry bulk density of the upper peat profile was ca. 0.160 g/cm^3.

Monitoring

A monitoring program was started in1998 and plant establishment has been surveyed annually since then. Monitoring is done in 5 m x 5 m permanent plots that are installed in restored zones as they are implemented. The number of permanent plots surveyed at Chemin-du-Lac peatland (Table 1) might appear a small sampling effort but remember this is part of a larger monitoring program that involves all restored sites in eastern Canada. However, representativity of each plot was visually estimated at each monitoring campaign and the number of permanent plots can then be adjusted if needed but it was not the case for this site. Table 1 presents the "age" of each zone since restoration, according to years of restoration works and years of measurement; restored zones have hence been monitored after 1 to 11 years following restoration. Monitoring has always been carried out in fall, at the end of the growing season and when sites are less susceptible to suffer from drought because mosses are more difficult to identify when dry.

Many variables were collected on each permanent plot. First, total plant cover and covers of each vegetation strata were evaluated at the plot level on a 0 to 5 class scale (0=0%; 0.5=<1%; 1=1-10%; 2=11-25%; 3=26-50%; 4=51-75%; 5=76-100%). This allows us to be confident on yearly data as it is unlikely to make error in class cover estimation, although cover is not precisely evaluated. The mean height of each stratum was also measured. Strata were defined as follow: tree (including non-ericaceous shrubs), ericaceous shrubs, herbs and mosses. Secondly, total cover as well as cover of each vascular plant species were estimated in 4 medium size quadrats (1 m x 1 m) systematically distributed within the permanent plot. Finally, total moss cover and covers of moss species were estimated in 20 small quadrats (25 cm x 25 cm) also systematically distributed.

For the purpose of this paper, the total plant establishment estimated with cover classes will be presented, following the complete monitoring sequence. Classes have been converted to percent covers using the median of each class. Measurements taken in 2006 will then be examined for each stratum, according to direct percent cover estimation in medium and small size quadrats.

Results and discussion

Plant establishment at the Chemin-du-Lac restored peatland was quite successful and rapid. All restored zones showed an increasing plant cover over time (Fig. 1; as results presented in this figure are calculated from class covers, percent cover cannot be higher than the median of the upper class).

Maximum cover (88%) was reached after 11 years in the oldest zone (R1995). It will also probably take 10 to 11 years to reach a complete cover in the zone restored in 1997, as this area had 84% of its surface covered by vegetation 9 years after restoration. In contrast, the zones restored between 1999 and 2002 were recolonized much faster. R1999 and R2000 reached maximum covers after 7 years while R2001 and R2002 were completely revegetated after 4 and 5 years respectively. Plant establishment was not as fast in R2003, which showed a 38% plant cover after 3 years. This is comparable to results obtained in the zones restored between 1995 and 2000 but lower than the ones

Figure 1. Plant establishment (total plant cover) at the Chemin-du-Lac restored peatland, in zones restored from 1995 to 2003 and measured after 1 to 11 years following restoration. Plant cover was estimated within permanent plots (5 m x 5 m) on a 0 to 5 class scale, converted to percent cover using the median of each class and then averaged for each restored zone (see table 1 for specific n).

restored in 2001 and 2002. In this case, it is likely that the maximum coverage will be achieved approximately 7 years after restoration.

If we look further at the 2006 measurements where all the restored zones were monitored (Fig. 2), we can observed that high covers were achieved in each restored zone, with total plant covers varying from 85 to 95%. Only the youngest zone (R2003) had lower plant establishment with a plant cover of 35% after 3 years. Similar total plant covers are often encountered in other restored sites of the same "age" (Sottocornola *et al.*, 2007; Peatland Ecology Research Group, unpublished data).

Whatever the time since restoration, the tree cover remained low (< 1%). The trees were mostly dominated by birches, which are widespread in disturbed peatlands (Lavoie *et al.,* 2005a), and a few *Picea mariana* (Miller.) BSP. In 2006, mean tree height ranged from 8 to 130 cm, depending on time since restoration.

The cover of ericaceous shrubs increased, ranging from 3% after 3 years to 38% after 9 years, before decreasing to 20% after 11 years. However, more time will be needed to confirm or deny this trend as this phenomenon has been observed in only one zone (the oldest R1995). The ericaceous shrub stratum was dominated by *Chamaedaphne*

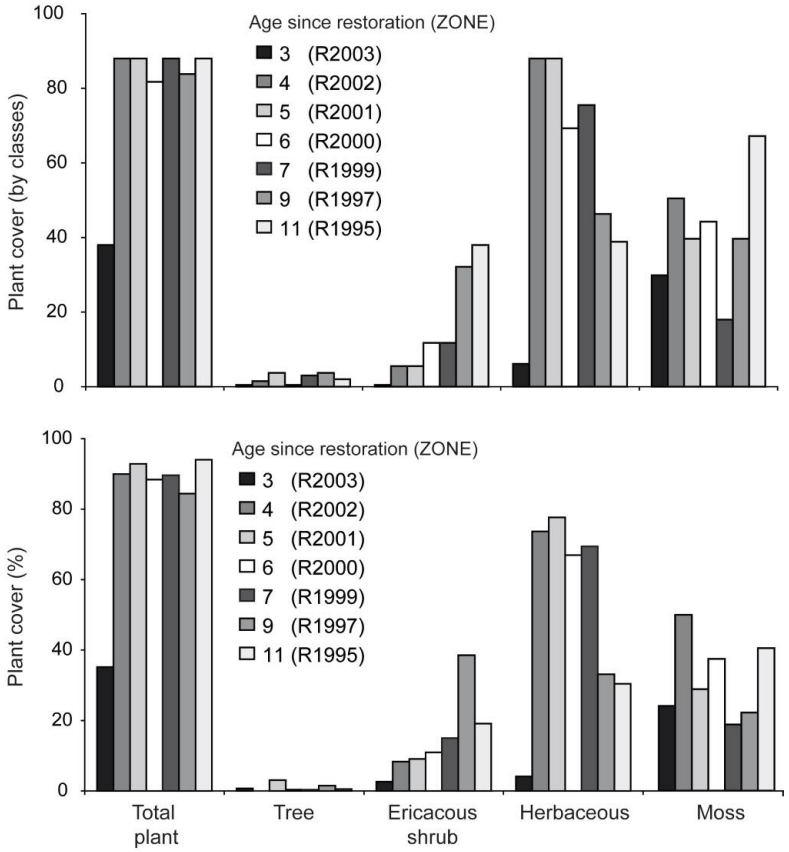

Figure 2. Plant establishment according to strata, measured in fall 2006 in zones restored since 3 to 11 years at the Chemin-du-Lac restored peatland. Total plant cover as well as tree, ericaceous shrub and herbaceous strata covers were estimated in 4 medium quadrats (1 m x 1 m) systematically distributed within permanent plots (5 m x 5 m). Moss cover was estimated from 20 small quadrats (25 cm x 25 cm) also systematically distributed.

Table 2. Moss establishment (as percent cover) at the Chemin-du-Lac restored peatland, in zones restored from 1995 to 2003 and measured after 1 to 11 years following restoration (from 1998 to 2007). Moss cover was estimated from 20 small quadrats (25 cm x 25 cm) systematically distributed within permanent plots (5 m x 5 m).

Restored Zones	Years of measurements								
	1998	1999	2000	2002	2003	2004	2005	2006	2007
R1995	6,9	10,7	10,6	30,7		39,0		42,0	
R1997	4,5	8,0	5,1	16,8		17,4		23,0	
R1999			4,7	14,1		17,9		19,5	
R2000				7,9	11,8	33,5	56,6	38,9	35,4
R2001				1,2	6,4	30,0		29,9	
R2002					2,4	26,7	51,0	51,8	11,1
R2003								24,9	

calyculata (L.) Moench. and *Rhododendron groenlandicum* (Oeder) Kron & Judd with a mean height of 32 cm (ranging from 10 to 50 cm).

For the herb stratum, a clear trend was observed. After only a few years following restoration, herbs were dominant with covers reaching almost 80%, before decreasing to 30% after 9 years. This stratum was dominated by *Eriophorum vaginatum* L. and *Scirpus cyperinus* (L.) Kunth. with a mean height of 43 cm (ranging from 33 to 62 cm). Temporary invasion of *Eriophorum vaginatum* has been frequently observed in abandoned and restored site (Lavoie *et al.*, 2005b).

The cover of mosses did not show clear trends according to the time since restoration. It varied between 20 to 50% in 2006. This stratum was mostly dominated by *Sphagnum* mosses (essentially *S. rubellum* Wils.) followed by *Polytrichum strictum* Brid.. The mean height of the moss carpet varied from 1 to 20 cm, according to "age" of the restored zones.

Plant recolonization in abandoned peatlands is a good point of comparison between actively restored and naturally revegetated sites. After a large survey of abandoned vacuum harvested sites in eastern Canada, mean covers were estimated at 12% for trees, 20% for ericaceous shrubs, 16% for herbs and less than 10% for mosses with very few *Sphagnum* mosses (Poulin *et al.*, 2005). There is no doubt that restoration is necessary to speed up the establishment of a typical peatland plant cover and to ensure the return of *Sphagnum* mosses.

Table 2 shows in more details the evolution of moss covers in each restored zone. Moss covers increased more or less rapidly over the years for zones restored between 1995 and 1999. However, for R2000 and R2002, significant decreases were measured after 5 and 6 years respectively while for R2001, no increase in moss cover was detected after 3 years. The significant decrease to 11% measured after 5 years (in 2007) in the R2002 zone was particularly low.

Since there was not much dissimilarity in the general characteristics and properties between the restored zones some hypothesis can be raised to explain differences and changes in plant establishment. The quicker total plant establishment in "younger" zones could be explained at some point by the improvement of the restoration techniques or the workers know-how over time. As a fact, the Peatland restoration guide was reissued in 2003 to include new knowledge on the subject (Quinty and Rochefort, 1997, 2003). However, other factors come into consideration, as can be seen with the zone restored in 2003 which was restored in the same way as the previous ones but where the establishment of plants was slower. The continuity of the monitoring program in the coming years is thus very important in order to detect plant establishment progress and analyse further the factors related to success or failure.

The establishment of moss cover is undoubtedly the key to a successful restoration project in peatlands and its evolution should be scrutinized carefully. Among explanatory factors to moss establishment, the annual climate could have a great influence on moss cover, especially if a drought period is occurring shortly before measurements. This climatic effect can be particularly important for assessing *Polytrichum strictum* covers, as in time of water stress, its leaves fold up against the stem in order to reduce water loss (Mögenson, 1985). Climate at the time of plant reintroduction (year of restoration) can also have a strong influence on future moss establishment (Chirino *et al.*, 2006).

Another factor that may influence plant establishment success is fertilization. Indeed, some areas of the zone restored in 2002 were fertilized with rock phosphate (15 g m^{-2} of 0-13-0) in order to assess the effect of P addition on plant recolonization. These data are not included in this paper but herb cover was significantly higher in these fertilized areas, especially for *Scirpus cyperinus* which increased from 1% when not fertilized to 42% with fertilization. Fertilization also had a noticeable impact on the moss stratum, with nearly 30% after 5 years (in 2007) compared to 11% when not fertilized.

Conclusion

Plant establishment at the Chemin-du-Lac restored peatland was fast and complete plant covers were rehabilitated after 7 years or less following restoration. Most species colonizing the restored zones were typical peatland species. Trees colonized poorly while ericaceous shrubs slowly increased in cover with time. Herbs quickly invaded restored sites but their cover decreased with time. Although the moss establishment was quite variable between the restored zones, *Sphagnum* mosses were the dominant gender of this stratum.

The continuity of the monitoring program in the coming years should be maintained in order to detect plant establishment progress. Further multivariate analysis should be made to point out the underlying factors explaining plant establishment in relation to abiotic, climatic or management conditions and to develop early criteria for peatland restoration success.

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