Peatland Restoration Guide

Second Edition

François Quinty and Line Rochefort






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Canadian Sphagnum
Peat Moss Association

New Brunswick Department of
Natural Resources and Energy

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Foreword

The authors wish to thank the Canadian Sphagnum Peat Moss Association (CSPMA) who gave us the mandate to develop this second edition of the *Peatland Restoration Guide* and the New Brunswick Department of Natural Resources and Energy, Minerals, Policy and Planning Division who also funded the project.

We are especially grateful to Suzanne Campeau for her comments on the Peatland restoration section, and to Jonathan Price, Stéphanie Boudreau, Julie Bussières, Bruno Drolet and Jacques Gagnon for revising different parts of the *Guide*. Gerry Hood, president of the CSPMA, made a substantial contribution to the technical vocabulary relative to the peat industry.

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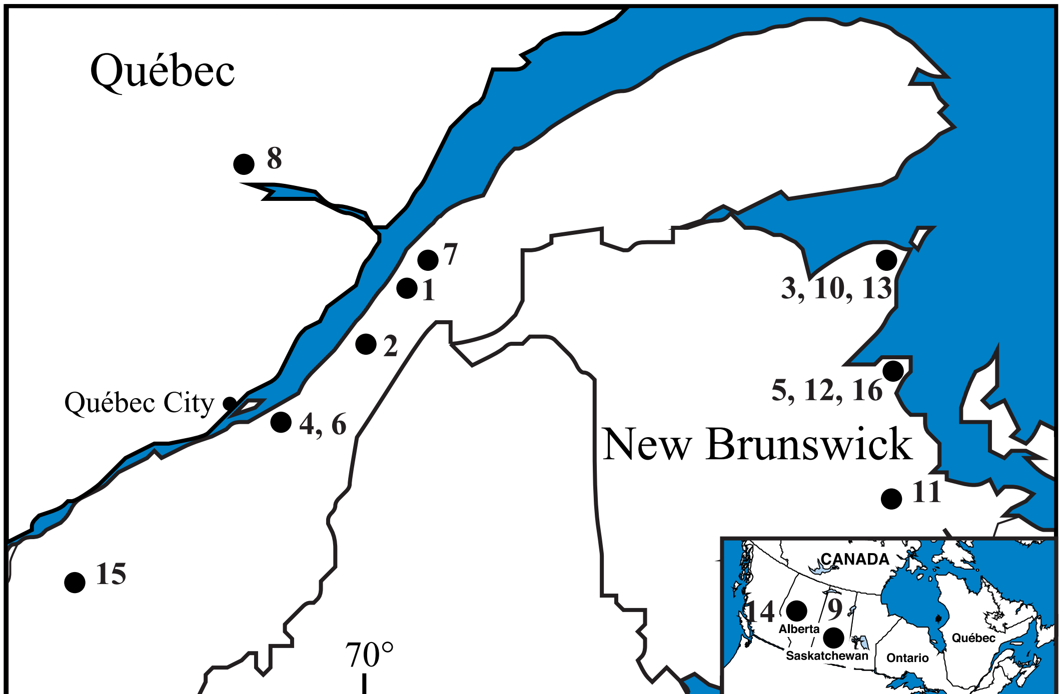
1 Introduction

Canadian peatlands have received little attention until recently in terms of "sustainable" management. They were, and still are considered by many as unproductive or wasted land. Their roles were poorly understood and their values were recognized only by a small number of people, mostly scientists. Peatlands, where peat was once extracted, were left to natural recolonization processes for their future evolution. An exhaustive survey of all these sites conducted from 1993 to 1995, revealed that peatlands where peat was block cut regenerated more easily than vacuum-harvested sites. Actually, *Sphagnum* mosses were found only on a few abandoned vacuum-harvested peat bogs. Facing the growing awareness toward the environment, Canadian peat producers launched a research project in 1993 in collaboration with universities and provincial and federal authorities, aimed at developing techniques that could help restore harvested peatlands. The project was conducted by the Peatland Ecology Research Group (PERG) under the direction of Dr. Line Rochefort from Université Laval, Québec. In 1997, F. Quinty and L. Rochefort produced a *Peatland Restoration Guide*, published by the Canadian Sphagnum Peat Moss Association (CSPMA), which briefly presented the state of research at that time. The Canadian peat industry now has to comply with new regulations and requirements from provincial authorities and there is a need for a comprehensive guide.

This *Peatland Restoration Guide, Second Edition* was developed as a practical tool for peat producers. It presents, in an accessible way, the approach that is proposed for restoring milled peatlands. It is based on the research that has been done in Canada in the last 10 years by the PERG, on the application of the method in restoring over 160 hectares of the Sainte-Marguerite bog in Québec by Planirest environnement inc. (Figure 1) and on the experience of practitioners from Canadian peat producers who shared their knowledge at annual workshops. The experimental restoration of a whole ecosystem — Bois-des-Bel peat bog, Québec — in collaboration with several Canadian peat producers was an important source of information. The Bois-des-Bel site was restored in 1999-2000 and is now monitored closely to study the recovery of usual peatland functions. It can be visited upon request to peat producers or the PERG. The approach especially addresses the Northeastern American context, which is characterized by acidic and nutrient-poor residual substrates to restore and treeless open natural peat bogs. The approach was applied successfully in a number of peatlands and was adapted to site-specific conditions. The information presented here will likely change as research progresses. The application of the approach on various sites across Canada should result in improvements of the restoration techniques, especially if monitoring information is centralized in a database.

The first section presents basic concepts on peatlands and peatland vegetation and hydrology that helps improve understanding of the processes associated with restoration. The second part describes in detail the Canadian approach to peatland restoration, from the planning phase of a project to the monitoring phase to evaluate its success. The description of the restoration techniques is central and occupies the largest place. Following the restoration techniques, a section gives an overview of alternative management options such as the flooding approach commonly used in Europe and reclamation options for agriculture and forestry uses. Three short sections that serve as complementary tools for users complete the *Guide*: a quick reference sheet that summarizes technical aspects of the Canadian approach to peatland restoration; a key to identification of collection sites that is based on plant communities suitable for restoration; and a list of useful references for those who would like further reading. The guide is completed by three appendices: a table listing large-scale restoration and reclamation projects in Canada; a von Post scale; monitoring forms; and a glossary of the scientific and technical terms used in this *Guide*. Plant species were named after Scoggan (1978)[1] for the vascular plants and Anderson (1990)[2] for mosses.



1- Chemin-du-Lac	9- Pit Bog
2- Rivière-Ouelle	10- Maisonnette
3- Inkerman Ferry	11- Kent
4- Saint-Henri	12- Pointe-Sapin
5- Baie-Sainte-Anne	13- Pokesudie
6- Saint-Charles-de-Bellechasse	14- Sudgen Bog
7- Bois-des-Bel	15- Saint-Bonaventure
8- Sainte-Marguerite-Marie	16- Bay-du-Vin

Figure 1. Map showing the location of Canadian peatlands where large-scale restoration or reclamation procedures have been implemented and that served as a source of information for this Guide.

[1] Scoggan, H.J. 1978. *The flora of Canada*. National Museums of Canada, Ottawa.

[2] Anderson, L.E. 1990. A checklist of *Sphagnum* in North America north of Mexico. *The Bryologist*, 4: 500-501.

2 The peatland ecosystem

This section presents basic concepts on the ecology of peatlands that underlie the actions described later in this *Guide* to successfully accomplish a restoration project. Each step should be done with care: the recommendations are based on experimental testing of a range of dosage (e.g. determining the right amount of straw mulch) or on testing a variety of techniques (e.g. testing six types of protective covers). In brief, this peatland restoration approach is not designed to be labour intensive, but the imperative ecological equilibrium of this unique ecosystem is considered.

Peatlands

Peatlands are widespread ecosystems in the northern hemisphere. For instance, they cover an impressive 11% of Canada' s territory. However, they are poorly known and have often been considered as unproductive land, but their values are now widely recognized.

Peatland development

Peatlands are ecosystems where the production of biomass exceeds its decomposition. The result is the accumulation of organic matter coming from plant debris and especially *Sphagnum* mosses that dominate peatland vegetation. This more or less decomposed plant biomass forms the peat. *Sphagnum* mosses grow a few centimetres a year in height, but because of the subsequent decomposition and compaction processes, the rate of accumulation of peat is only about 0.5 to 1 mm per year. Thus, deep peat deposits are the result of thousands of years of accumulation of plant debris. Therefore, it is clear that restoration will not regenerate peat at a rate that would permit peat extraction in the near future.

Peatlands can develop by two processes: 1) *terrestrialization* or infilling of shallow lakes; or 2) *paludification* of poorly drained land, which is the formation of peat directly on mineral soil. With time, the accumulation of plant debris changes the environmental conditions of the substrate, causing a shift from aquatic to semi-aquatic habitats to fen that can then evolve to a bog environment with increasing peat thickness.

Fens are a type of peatland that are fed by precipitation and surface runoff water. Because runoff water comes in contact with mineral soil, it is enriched in base cations. For this reason fens are also called minerotrophic peatlands. Fen vegetation communities vary a lot, but they are often dominated by sedges that are the origin of sedge peat (Figure 2). With the accumulation of peat, peatlands slowly become higher than the surrounding ground and reach a point where they are only fed by water from precipitation. From this moment, plants cannot have access to mineral rich water coming from adjacent lands and this triggers the change toward a bog environment: minerals availability decreases significantly, acidic conditions develop and *Sphagnum* dominated plant communities capable of supporting such conditions replace sedge vegetation.

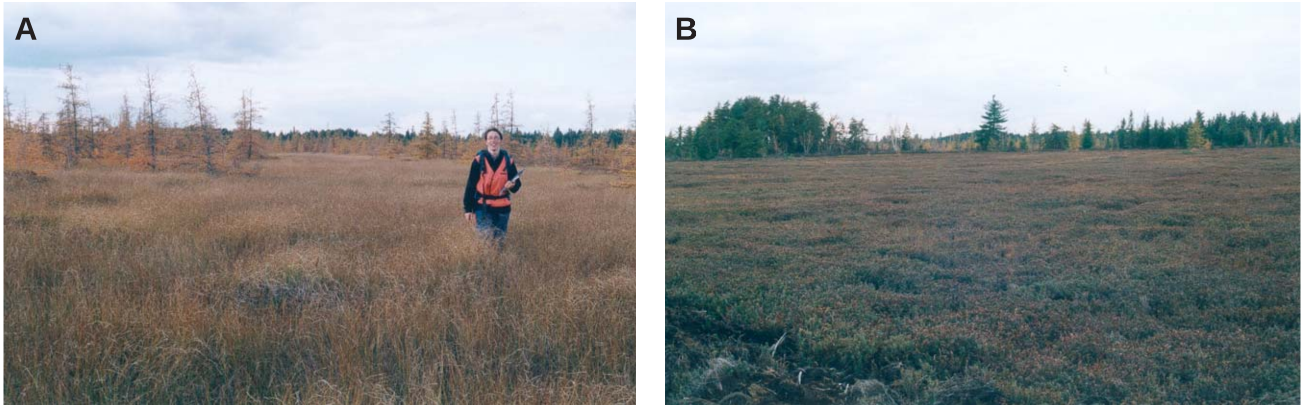


Figure 2. Photos showing a poor fen (A) and a bog (B). Poor fens often have sedge dominated plant communities along with Tamarack (*Larix laricina*) while bogs commonly have a shrub layer with Black spruce (*Picea mariana*) as trees. (Photos: M. Poulin)

Distribution of peatlands

Peatland distribution is closely associated with climatic conditions. Peat accumulation is a consequence of low decomposition rates rather than high biologic productivity, which are caused by water-logged conditions found in peatlands and poorly drained environments. Few organisms responsible for plant decomposition can live in water saturated soils because of lack of air and oxygen or anaerobic conditions. These environments are found under climatic regimes characterized by an annual water surplus that depends on the balance between precipitation and evaporation. Peatland distribution is limited northward by low precipitation and southward by a high evaporation rate. Most of the temperate and boreal regions of the northern hemisphere offer favourable conditions for peatland development. They have cold and wet winters that compensate for summer evaporation.

Functions and values of peatlands

Several functions and values of peatlands make them valuable ecosystems. Although the definitions of functions or values vary according to individual perception and interest, some of them are widely recognized. Their role as a carbon sink has gained visibility recently because of its impact on the greenhouse effect and climate change. Natural peatlands emit greenhouse gases such as methane (CH_4), but they also stock a large amount of carbon present in plant debris and peat. Following drainage and extraction, peat is exposed to air and decomposition processes cause the emission of carbon dioxide (CO_2), thus contributing to greenhouse gas build-up in the atmosphere.

Biodiversity is another value that gives special status to peatlands. Since they are unique, acidic ecosystems, peat bogs support specific plant communities. A number of plant and bird species are found only in peatlands. Recent studies suggest that large peat bogs have a higher value because they have a greater variety of habitats such as pools, and hence, a larger number of species.

Peat bogs also play a role in regulating water flow: by stocking water, peat bogs act as buffers, in case of abundant precipitation. The importance of this role appears when peatlands are lost or drained: water that would normally be stocked reaches watercourses more rapidly, thus contributing to higher peak flow.

Peatlands are also used by many people for recreational uses such as fruit picking and hunting. Their aesthetic and educational values are also recognized since more people have access to nature interpretation trails, especially in parks.

The function of peatlands as paleo-archives is well known by scientists. Because of the low rate of decomposition and anoxic conditions, many plant parts, especially seeds and pollen, are preserved in peat for thousands of years. With modern techniques of dating the age of organic matter, it is possible to reconstruct the past environment and climate through the identification of seeds and pollen present within the superposed peat layers.

The restoration of functioning peatland ecosystems should allow restored peatlands to play most of their roles and recover some of their values that were lost following peat extraction or other perturbations. A functioning peatland, which is a self-sustaining ecosystem, will restart accumulating carbon, regulate water flow, support a variety of habitats and species and provide recreational activities. However, paleo-archives will be lost forever unless peat cores are taken prior to peat extraction.

Vegetation

Natural peatlands represent a harsh environment for plants because of acidic and nutrient-poor conditions, a high water table and exposition to desiccation due to the absence of protection against wind and sun. A few plant communities dominated by *Sphagnum* mosses are specialized in colonizing these ecosystems.

Habitats and plant communities

Different habitats can be distinguished based on plant communities, but many are restricted to small surfaces such as floating mats around bog pools. A few habitats occupy most peat bogs. They can be divided into two groups based on their position relative to the water table. The first group is composed of habitats that form depressions where the water level is close to the surface. These habitats are called lawns or hollows depending on the area they cover. Lawns cover large surfaces, while hollows are small depressions (Figure 3). Plant communities of lawns and hollows are dominated by *Sphagnum* species from the group *Cuspidata* like *Sphagnum fallax* and *Sphagnum angustifolium*. These species grow into rather loose colonies that are not adapted to retain water. These plant communities typically comprise sedges or graminoids species.

The second group of habitats form large plateaus or small mounds called hummocks (Figure 3). These habitats are higher than lawns and hollows by about 40 to 80 cm and thus they have drier conditions. *Sphagnum* species colonizing plateaus and hummocks grow in dense colonies that allow efficient water retention and water supply. The most common species are *Sphagnum fuscum* and *Sphagnum rubellum*, which belong to the *Acutifolia* group. Drier conditions found on plateaus and hummocks favour the presence of shrubs and trees as well as other mosses such as *Polytrichum* and lichens. However, large plateaus can form wide open areas devoid of trees. Under

Figure 3. Photo showing the succession of hollows and hummocks that is typical of many peat bogs. Hollows can be recognized by the presence of graminoid species (in yellow) while hummocks support shrubs (in brown). Both habitats usually have a complete *Sphagnum* cover, but hummock - forming species are more suitable for restoration. (Photo: M. Poulin)

low water table conditions, shrubs and trees can form a dense cover with a sparse moss layer. A common feature in peat bogs is a mixed habitat characterized by the succession of hummocks and hollows.

Experiments comparing hummock and hollow plant communities show that hummock vegetation gives much better results when used as plant material for peatland restoration. Hummock-forming *Sphagnum* species are better adapted to conditions found in restoration sites. The presence of other mosses like *Polytrichum* contribute substantially to the rapid establishment of a new plant carpet. Labrador tea *(Ledum groenlandicum)* and Leatherleaf *(Chamaedaphne calyculata)* are two shrub species present in hummocks that establish easily and add to the diversity of establishing vegetation on restoration sites.

Sphagnum

Sphagnum mosses are the dominant feature of peat bog vegetation. They have specific characteristics that allow them to play a major role in the formation and sustainability of these ecosystems. *Sphagnum* mosses contribute directly to maintain water-logged

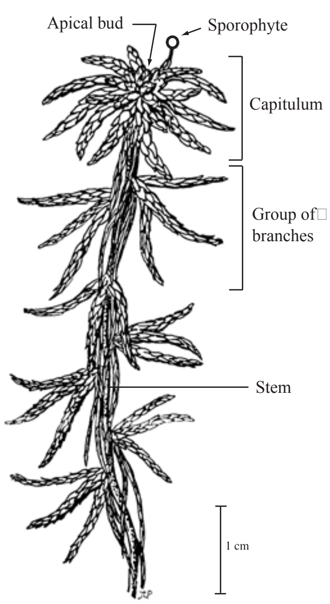


Figure 4. Sketch illustrating the different parts of *Sphagnum* mosses. The sporophyte contains spores. (Sketch by J-L. Polidori, redrawn from Payette & Rochefort 2001 with the permission of Les Presses de l'Université Laval.)

conditions in peatlands because of their ability to retain water, especially for hummock-forming species. They play a role in the acidification process by releasing humic acid and are efficient at absorbing and keeping nutrients. All these characteristics favour *Sphagnum* growth and make them harsh competitors against other plant species. They also give *Sphagnum* peat its characteristic structure that makes it a valuable product, especially for horticultural uses.

The structure of *Sphagnum* mosses is composed of a capitulum (head) made by the concentration of young branches at the top (Figure 4). This is where the growth occurs from the apical bud. Hanging branches disposed along the stem and covered by imbricated leaves are responsible for the capillary water supply. Stems have leaves (caulinary leaves) of different shapes, which are used in identification of species.

Hydrology

Peat bogs differ from other types of wetlands because they receive water only from precipitation. Nevertheless, they are complex hydrological systems and the relationship between water and peat is strongly affected by peat harvesting. For the purpose of peatland restoration, three factors are of major importance: 1) the structure of peat that comprises the acrotelm and the catotelm, 2) the fluxes of water, and 3) the water tension near the peat surface.

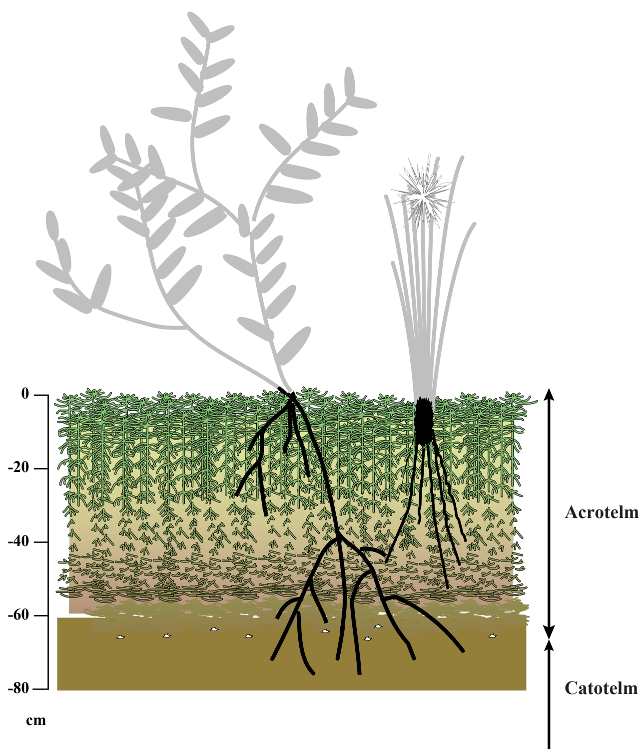


Figure 5. Diagram showing the structure of the acrotelm and the catotelm. The acrotelm is the living part of peat bogs. It is made of loose material creating large pore space that is periodically occupied by water. (Redrawn from Payette & Rochefort 2001 with the permission of Les Presses de l'Université Laval.)

Acrotelm/catotelm

The acrotelm and catotelm represent two distinct soil layers in undisturbed peat bogs that control the hydrological regime (Figure 5). The catotelm is the bottom layer of peat that is permanently below the water table. Under these anaerobic conditions, microbial activity and peat decomposition are very slow. The catotelm is composed of relatively decomposed compacted peat and water movements are slow.

The acrotelm overlies the catotelm, and is the layer in which water table fluctuations occur. Its thickness usually varies between 30 and 50 cm, but it largely depends upon the habitat (hummocks or hollows). Anaerobic and aerobic conditions alternate periodically with the fluctuation of the water table, favouring more rapid microbial activity than in the catotelm. It is also the zone where other living activities, such as rooting occur. The acrotelm consists of the living parts of mosses and dead and poorly decomposed plant debris. It has a very loose structure that can contain and release large quantities of water in a manner that limits variations of the water table in peat bogs.

Sphagnum mosses depend on water for their growth and they are mainly responsible for the creation of the acrotelm that in turn, maintains the water table close to the surface and provides them with suitable conditions for growth. This fragile equilibrium between vegetation and hydrology is the basis of the functioning of peat bogs. However, the acrotelm is the first layer that is removed by current peat harvesting methods and this represents a major impact. Restoration has to proceed from the catotelm that does not provide adequate conditions for the establishment and growth of *Sphagnum*. The catotelm represents a large water reservoir because of its depth, but given the compaction of peat, the proportion of water available for plants is much less than in the acrotelm where water may occupy the large open spaces. Thus, the loss of a given volume of water will result in a greater lowering of the water table in the catotelm compared to a similar loss in the acrotelm. Therefore, the absence of the acrotelm has to be compensated for by different techniques such as the ones presented in this *Guide*. In other words, it can be considered that a peatland will essentially be restored once a new acrotelm has developed.

Water fluxes

Peat bogs receive water only from precipitation (input); it can be stored within the peat deposit or leave the peatland. This flow of water can be expressed by the following equation:

Water Input – Water Output = Water Storage

Water output in natural peatlands is mainly by evaporation, which accounts for more than 80 % of water losses during the summer season. Small amounts of water are lost by surface or subsurface runoff. The difference between water input and output corresponds to the water that is stored in the peat deposit. Peat extraction affects water output and water storage. In currently harvested sites, drainage becomes more important and water storage decreases substantially. Thus, storing more water (limiting loss) is an important objective of peatland restoration.

Recent studies show that blocking drainage ditches can be very effective in limiting loss of water by runoff. The use of straw mulch in peatland restoration is also effective in reducing loss of water by evaporation. However, the loss of the acrotelm, subsidence following drainage and the decomposition of peat resulting from its exposure to air greatly reduce the water storing capacity of peat deposits in harvested peatlands. Hence, this situation must be balanced by keeping as much water as possible in restoration sites, specifically by building berms. It has been demonstrated that peat deposits swell following rewetting associated with restoration, suggesting that part of water storage capacity can be recovered in the short term.

Water tension

Water is stored in a number of ways in peatlands: it can be water standing at the peat surface or in pools; gravitational water held in the acrotelm; or water stored in smaller pore spaces of the catotelm. In harvested peat bogs, bare peat surfaces are often wet because water is supplied to the surface from the water table by capillary flow along peat fibres. When conditions become very dry in summer, however, water supply is not rapid enough to compensate for losses by evaporation at the surface. Capillarity is broken and the water supply stops. Then the peat surface becomes desiccated and the small quantity of water left is so strongly retained by peat that mosses cannot have access to it. The suction by which water is held to peat particles is called the water tension. This problem is restricted to mosses because they do not have roots and physiological adaptations to overcome high water tension. However, given the importance of *Sphagnum* mosses in peat bogs, this is a major problem. The use of straw mulch helps to solve the problem. Straw mulch keeps the daytime temperatures lower, and provides a shield against direct radiation. This reduces evaporation that, in turn, decreases the water tension at peat surfaces enabling *Sphagnum* to access water.

3 Peatland restoration

This section of the *Peatland Restoration Guide* presents detailed descriptions of the procedures that were developed to restore damaged peatlands. These procedures are guidelines that should be adapted to site-specific conditions.

Restoration principles

Because very little was known until very recently on peatland restoration, the development of the present approach was based on a few basic principles that come from field observations and scientific knowledge. Small and large scale experiments, as well as field restoration trials, later confirmed the relevance of these principles.

Impacts of peat extraction

Like any other human activity, peat extraction has an effect on its environment. Considering that peat extraction involves draining of peatlands and removing a variable layer of peat from the top, it is clear that the most important impacts are on vegetation and hydrology.

Right after cessation of peat extraction, there is no living plant or diaspore left on peat fields. The original vegetation has been removed and periodic extraction of peat prevents the establishment of new plants. Recolonization of abandoned fields by peat bog species is slow because the closest source of seeds or other diaspores is often hundreds of metres away and, unless remnants of natural peatland still exist, they are bordered by forest or agricultural fields. Peat fields also present harsh conditions for germination of seeds falling on their surface because they become very dry in summer and are devoid of anything that could offer protection against wind, sun, etc.

Intensive drainage associated with peat extraction activities results in a lower and more variable water table in harvested sites compared to natural peatlands. The disappearance of the acrotelm, and changes in the physical properties due to compression and decomposition of peat, reduces the space between peat particles. This decreases the water storage capacity of remaining peat and increases the variations of the water table.

However, there is no major chemical difference between natural and harvested bogs unless the deep peat layer or mineral substrate is reached.

Self-regeneration — possible or impossible?

Surveys of all post-harvested bogs of Québec and New Brunswick suggest that these sites do not rapidly return to their original state if nothing is done at cessation of peat extraction. In fact, only 17 % of trenches of former block-cut peat bogs have been recolonized by *Sphagnum* mosses, while *Sphagnum* are almost absent in abandoned milled fields. This situation is due to the adverse conditions that impede plant establishment, especially on milled surfaces. Harsh conditions of bare peat surfaces, namely poor water availability, exposition to desiccation, erosion and lack of seeds, spores or any plant parts able to give new plants are the main factors responsible for this situation. Consequently, some interventions are necessary to restore peatlands in a shorter term.

Goal and objectives of peatland restoration

Ecological restoration is the process of assisting the recovery of a damaged ecosystem. It is an intentional activity that initiates or accelerates the recovery of an ecosystem with respect to its health, integrity and sustainability[1]. **In the case of peatlands, the goal of restoration is to re-establish self-regulatory mechanisms that will lead back to functional peat accumulating ecosystems.** In other words, this means that a successfully restored peatland should be self-sustaining and start accumulating peat again without further human intervention. It is clear that this goal cannot be reached in the short term because time is needed for plants to establish, grow and produce debris that will accumulate and become peat. Dead plant parts will accumulate only if the water table is high enough throughout the year to impede decomposition.

Objectives are the more concrete steps that have to be taken to meet the general goal. Objectives are linked to activities that produce measurable results in a short period of time that determine if a site evolves toward successful restoration or not. The approach to peatland restoration developed in Canada, has two specific objectives:

1. **Re-establishing a plant cover dominated by peatland species including *Sphagnum* mosses, and**

2. **Re-wetting harvested sites by raising and stabilizing the water table near the surface.**

These two specific objectives focus on peatland vegetation and the hydrological regime because they are the principal elements affected by peat extraction. They are also the key factors responsible for most functions of peatlands. The Canadian peatland restoration approach proposes a series of precise operations in order to meet these two objectives.

The Canadian peatland restoration approach

The Canadian peatland restoration approach is based on active reintroduction of peat bog plant species and hydrological management in order to raise and stabilize the water level. It consists of the following operations:

- Surface preparation
- Plant collection
- Plant spreading
- Straw spreading
- Fertilization
- Blocking drainage

[1] Society for Ecological Restoration Science & Policy Working Group. 2002. *The SER Primer on Ecological Restoration*. www.ser.org/

This approach serves as a general guideline and it is important to understand the underlying principles because it requires adaptation to site-specific conditions. Planning is another key element in the success of restoration. It is essential to set the appropriate goal and objectives to allow for greater efficiency in conducting the operations and reducing the cost of restoration.

Planning the restoration

Any restoration project should begin with the preparation of a restoration plan to ensure that the right option and time frame are set up. In other words, one should pose some questions before going off to the bog with a tractor to restore it. Planning is also a key factor in determining the success and the cost of restoration. A good restoration plan should have two different components:

- Site conditions, goal and objectives, and
- Planning restoration operations.

Identification of the site conditions is the first necessary step because site characteristics dictate the right goal to achieve: in-kind restoration, out-of-kind restoration or reclamation. The second step is defining the operations that need to be done, planning the resources and time required, setting up a schedule and evaluating costs.

Reclamation

The term reclamation, is commonly used in the context of mined lands in North America and the UK. The main objectives of reclamation include the stabilization of the terrain, assurance of public safety, aesthetic improvement, and usually a return of the land to what, within the regional context, is considered to be a useful purpose. Revegetation, which is normally a component of land reclamation, may entail the establishment of only one or a few species.

Site conditions, goal and objectives

The Canadian peatland restoration approach has been developed as a basic "recipe" for the restoration of harvested peatlands in North America based on the establishment of a new plant carpet and the raising and stabilization of the water table. However, conditions vary greatly from site to site, and it is necessary to adapt the general procedures to the local environment. Thus, the first step is to collect information on site conditions and define a goal and specific objectives to be achieved for each site. This information should include the following elements:

- Site characteristics prior to peat extraction
- Hydrological environment
- Topography
- Peat characteristics
- Chemical aspects
- Existing vegetation of the restoration site
- Source of plant material
- Surrounding landscape
- Setting the right goal
- Setting the right objectives
- Monitoring

Site characteristics prior to peat extraction

Many peatland types can be distinguished across North America and even locally. They can be forested or open, with or without pools, have a deep layer of sedge peat or consist of *Sphagnum* peat from top to bottom, and they can be located in the forest or surrounded by human settlements, agricultural fields or the sea. It is essential to know the characteristics of a peatland and its surroundings that existed prior to the opening for extraction activities because they determine the goal and objectives to be set up at the beginning of the restoration process, as well as the evaluation of the success. In fact, these conditions represent the ideal reference ecosystem that the restoration site should be compared to and serve as a goal. However, it is possible that the site can no longer support the same type of peatland or even a wetland due to changes in the local environment or alterations of the surrounding landscape. In such a case, reclamation may be a more appropriate goal, and this should be known from the beginning.

Site characteristics prior to peat extraction determine:

- The right goal
- The right objectives
- How to evaluate success

Information on conditions that existed prior to opening of a peatland can be found from many sources:

- Geological reports, ecological descriptions, maps, vegetation surveys
- Historical and recent aerial and ground-level photographs
- Peat workers and local people
- Paleoecological evidence, e.g. fossil pollen, tree-ring data
- Similar local natural peatlands or natural remnants of the harvested peatland

Reference ecosystem

A reference ecosystem or reference can serve as the model for planning an ecological restoration project, and later serve in the evaluation of that project. Typically, the reference ecosystem represents a point of advanced development that lies somewhere along the intended trajectory of the restoration. In other words, the restored ecosystem is eventually expected to emulate the attributes of the reference ecosystem, and restoration project goals and strategies are developed in light of that expectation. The reference ecosystem can consist of one or several specified locations that contain model ecosystems, a written description, or a combination of both. Information collected on the reference ecosystem includes both biotic and abiotic components.

The value of the reference ecosystem increases with the amount of information it contains, but every inventory is compromised by limitations of time and funding. Minimally, a baseline ecological inventory describes the salient attributes of the abiotic environment and important aspects of biodiversity such as species composition and community structure. In addition, it identifies the normal periodic stress events that maintain ecosystem integrity.

Hydrological environment

Water availability is preponderant in peatland restoration. Because harvested peatlands have lost their natural ability to store water and regulate water table fluctuation, management procedures have to be undertaken to reduce water losses and to provide a water supply to *Sphagnum* and other introduced plants. A restoration plan must identify all possibilities of water loss through surface or subsurface drainage as well as possible sources of incoming water to the restoration site (Table 1). Ideally, a map locating main and secondary ditches and future blockages and berms should be drawn. Sometimes only sections of a peatland site are abandoned and restored, while peat extracting activities continue on adjacent fields. In such cases, the impact of rewetting should be evaluated as not to impede peat extracting activities. Mineral outcrop or any possibility of leakage through the ground should also be noted because it can require special measures to prevent water loss. In more complex situations, more elaborate water management options than just the blockage of the former drainage system may be necessary. For example, a main ditch alongside the restoration site might need to remain active. Then a solution such as redirecting drainage or digging a new ditch to bypass the restoration site has to be evaluated. The presence of a large natural bog alongside a restoration site needs to be taken into account, since it represents an important source of water that can cause extensive flooding in certain cases.

An additional water supply should also be considered to ensure sufficient rewetting. For example, water from active extracting areas could be redirected to the restoration site and partial blocking of active ditches may raise the water table in the restoration site without affecting harvested fields. In some situations, it can be possible to pump water from a ditch into the restoration site. In these situations, water chemical characteristics should be like those of a bog environment, having low pH (< 5.0) and electric conductivity (< 100 µSiemens, corrected values). In any case, water entering a site under restoration should be managed in such a way as to avoid extensive flooding or runoff. Water can also be directed into basins or ditches in order to feed the groundwater and keep the water level close to the surface.

Table 1. Most common loss and source of water for a restoration site

Loss of water
Nearby active main ditch
Current harvested zone
Sandy mineral outcrop
Impervious layer broken up at bottom of ditch
Source of water
Nearby ditch or basin
Natural zone
Rain/snow
Pumping

Hydrological environment determines:

- Surface preparation and ditch blocking
- Options between restoration and reclamation

Look at:

- Water loss possibilities
- Potential source of water and its chemical characteristics
- Future blockage of ditches

Topography

Water distribution is highly influenced by topography and appropriate measures are often needed according to site characteristics. The objective is to achieve an even distribution of water throughout the restoration site while avoiding deep and permanent flooding. Water flowing at the peat surface will disturb the reintroduced plant material and the protective straw mulch that are spread during the restoration procedures. In the presence of sloping fields it is necessary to build berms along contour lines in order to distribute water evenly over the site and avoid dry conditions upslope and flooding downslope. The creation of pools or water reservoirs can also help control flooding because they can store excess water. A general field assessment of the slope could be enough to position berms, but it may be necessary to survey the site, especially when complex slopes occur on a large area (see Surface preparation).

Another aspect of topography is the shape of the former peat fields to be restored. Peat fields are typically dome shaped (convex) to favour rapid drainage of water. These fields have to be flattened to allow even water distribution on the entire surface and thus re-profiling of fields should be included in restoration procedures.

Topography determines:

- Surface preparation procedures
- Use and location of berms
- Use and location of ponds

Look at:

- General slope of the site
- Dome shaped fields

Peat characteristics

A restoration plan should also include some information on peat characteristics such as: peat thickness, type of peat (*Sphagnum* peat, sedge peat, etc.) and degree of decomposition of peat on the von Post scale (see Appendix B). This information is needed in order to choose the right management option. A thin layer of peat will allow plants to root and contact with the enriched groundwater and the mineral subsoil, thus creating good conditions for colonization of non-peatland plants that may compete with peatland species. Moreover, well-decomposed peat has low water storage capacity and creates very dry surface conditions especially for *Sphagnum*. Hence, a thin layer of well-decomposed peat overlying the mineral subsoil will present difficulties for the restoration of a bog environment. In such cases, it is more suitable to seek other management options.

It is believed that a minimum layer of 50 cm of peat is necessary for restoration, but there are cases where bog conditions are still present even when a thin layer of peat remains. Thus, no threshold has yet been determined for the minimum peat thickness required for restoration, but it is recommended to leave at least 50 cm of peat. In fact, it is better to rely on peat chemistry and botanical composition of the peat (sedge peat vs *Sphagnum* peat) to decide whether to restore a bog, a fen, a marsh or to prepare the site for forest plantation or other uses. More often, thin layers of well-decomposed peat are found at one end of peat fields toward the margin of the peat bog, defining a strip where other restoration or reclamation options may be used.

Peat surface characteristics also have to be investigated for deciding the appropriate surface preparation. Loose peat is often left behind at the surface by the last harrowing of usual extraction activities. In many cases, a very unstable peat surface can develop under frost heaving actions. Frost heaving is associated with freeze and thaw cycles of the peat surface that loosen the first centimetres of peat. Another phenomenon on abandoned peat fields is the formation of a fine crust that prevents *Sphagnum* mosses easy access to water. It is uncertain how this crust arises, but the different causes are hypothesized to be: oxidation of peat, proliferation of micro-organisms or the development of an algae or liverwort layer. Loose peat or crusting prevents reintroduced plant fragments to access water by capillarity from the underlying peat deposit. Frost heaving also creates microtopography and instability of the ground that can prevent plant establishment (Figures 6 and 7). In the presence of any of these phenomena — loose peat, crust or frost heaving — it is suggested to scrape off or refresh the peat surface before spreading plant fragments.

Peat characteristics determine:

- Option between restoration and reclamation
- Surface preparation procedures
- Possibility for creation of ponds

Look at:

- Peat thickness
- Type of peat (*Sphagnum* peat, sedge peat, etc.)
- Degree of decomposition (von Post scale)
- Presence of minerals at the surface, type of mineral (clay, sand, etc.)
- Loose peat, frost heaving or crust at peat surface

Frost heaving

Frost heaving occurs in spring and fall when the temperature goes over and below 0°C and in the presence of sufficient groundwater. When the freezing temperatures go down from the peat surface, usually at night, groundwater is attracted by the freezing front where it freezes and forms ice needles. The surface peat particles and reintroduced plant fragments are then lifted up by the ice. The following day, the ice needles melt and peat particles and reintroduced plant fragments settle down. After many repetitions, this action loosens the surface peat, turns over plant fragments and impedes rooting. It may even break newly established moss carpets. Frost heaving can be easily identified by the typical microtopography it creates at the surface.

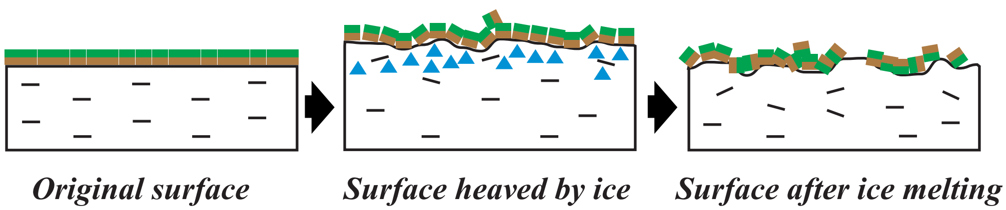


Figure 6. Diagram illustrating surface perturbation by frost heaving.

Chemical aspects

The chemistry of sub-surface water and peat should be analyzed to ensure that a site is suitable for peat bog plant species. For most sites, a mere analysis of pH and electric conductivity will tell if ombrotrophic conditions are still present. It is recommended that water pH of 5.1 or lower and corrected conductivity of less than 100 µS/cm should be the limit for restoration to a peat bog environment. With higher values, it may be better to consider restoring fen or marsh wetland ecosystems or to opt for reclamation. There are examples of sites with a peat pH of 5 where *Sphagnum* grow along with more minerotrophic sedge species. When minerotrophic deep peat layers or mineral subsoil are reached due to peat extracting activities or when the influence of rich water is suspected, a thorough analysis should be conducted to detect detrimental levels of elements like calcium and to assess the possibility of nutrient enrichment (nitrogen or phosphorus) that may lead to weed invasion.

Chemical aspects determine:

- Option between restoration and reclamation
- Possibility of invasion by undesirable species

Look at:

- Water pH and electric conductivity
- Signs of nutrient enrichments (Nitrogen and Phosphorus)

Figure 7. Photo of typical surface topography resulting from frost heaving. (Photo: F. Quinty)

Existing vegetation of the restoration site

For sites where peat extraction has ceased for many years, it is possible that natural colonization by plants has occurred. When plants cover most of the area, it may be too late to restore. However, scattered trees or other plants can be cleared by scraping off the peat surface with a leveller. On the other hand, colonizing species are good indicators of the chemical conditions and water regime and therefore, should be used to determine what option is best.

Little is known on the long-term influence of non-peatland and invasive species on restoration, and more information will become available as more sites are restored.

Existing vegetation determines:

- Option between restoration and reclamation
- Surface preparation procedures

Look at:

- Dominant species (bog vegetation or not)
- Vegetation cover (dense, scattered, etc.)
- Species that may be indicative of nutrient enrichment (ex. Cattail)
- Species within or around the restoration site that may invade the site

Source of plant material

Because the Canadian peatland restoration approach is based on active introduction of peat bog plants, a sufficient source of plant material is necessary to proceed with restoration. The quantity of plant material to be used for restoration was determined experimentally to:

- Ensure rapid establishment of new plant carpets on restoration sites
- Minimize the amount of work required for plant collection and transportation
- Minimize impacts to natural sites

The quantity of plant material for reintroduction is generally reported as a ratio of the area of the collection site to the area of the restoration site. A ratio of 1:10 is suggested (i.e. the collection site is 10 times smaller than the restoration site). This seems like a rough estimation, but it takes into account the loss of surface due to the passage of machinery and the loss of plant material during handling. Hence, the size of the restoration site is an important factor in restoration planning because it determines the size of the collection site. Usually, the dimensions of peat fields are known and this information can be easily calculated.

Ideally, plant material is collected near the restoration site to minimize transportation. However, when choosing a collection site, it is essential to look at plant communities. The quality of plant material in terms of plant species is a major factor for the success of restoration. A few plant species can be used as a diagnostic for the suitability of a collection site (see Key to identification of collection sites). Peat forming *Sphagnum* species are vital to rebuilding a bog ecosystem, while other mosses like *Polytrichum* contribute substantially to the success of restoration. A site dominated by these plants is ideal while a site lacking *Sphagnum* should be discarded. Some sedge and shrub species that usually occur along with these moss species may also help determine the suitability of a collection site for restoration.

Source of plants determines:

- Option between restoration and reclamation
- Plant collection procedures

Look at:

- Area of the restoration site
- Area of the collection site
- Presence and cover of *Sphagnum*
- Access to collection site

Size of the restoration site

It is highly recommended to restore a large area at one time. No minimum size has been defined, but research shows that larger sites have a better chance of being restored successfully, especially regarding the restoration of hydrological conditions. It is not realistic to raise the water table to create suitable hydrological conditions for plant establishment on a few abandoned peat fields surrounded by fields being harvested. It should be taken into account that the water table is lowered on a distance of about 15 m from the active ditches and this will negatively influence the establishment of peat bog plants at the edge of the restoration site. If it is considered that this side effect will affect too large a proportion of the site, restoration could be postponed until adjacent peat fields are abandoned. A site is best restored when its main ditch can be blocked.

Surrounding landscape

Landscape and human activities going on nearby a harvested peatland directly influence the possibilities for restoration of a site, and hence the choice of the right goal. For example, it may be impossible to restore a bog surrounded by cropland because agricultural drainage has lowered the water table on a large scale. On the other hand, investigation of the surroundings may reveal the presence of a small bog, which can serve as a source of plants.

Surrounding landscape determines:

- Option between restoration and reclamation
- Possibilities for additional source of water
- Possibilities for additional source of plants

Look at:

- Change in land use
- Drainage network
- Presence of bogs

Setting the right goal

Most harvested peatlands in North America present conditions close enough to those of natural peat bogs to be restored to a bog from harvested peat fields. However, sectors of peatlands, especially toward their margins as well as peatlands with a thick layer of fen peat, may present conditions that require options other than restoration to a bog. These conditions are more often encountered in Northwestern America, and in such cases, restoration to a fen type of peatland or reclamation might be best. It is important that the right goal be chosen at the beginning of a project, otherwise all efforts may be useless and lead to failure. Hence, identification of site conditions represents an unavoidable step in the restoration process, because it is the only way to ensure that ecological restoration is the appropriate option for a given site. Analysis of the data collected should then provide an answer to the question:

> Is it possible and realistic to restore this site back to a peat bog using the Canadian peatland restoration approach based on present conditions?

If the answer is NO, another option should be considered.

Setting the right objectives

Site conditions also determine the more specific objectives to be met in the short term. The expected hydrological conditions and the plant communities to be found a few years after the restoration work should be defined from the beginning, based on site conditions. For example, it is possible to raise the water table close to the surface and find peat bog plant species in a site surrounded by natural peatland. But it would not be realistic to set up such objectives for a site without natural fragments or severely affected by agricultural drainage.

Setting up the right objectives is also important because they will serve as a reference in evaluating the success of restoration. The information collected in the planning phase should help answer the following questions:

- Is the water table likely to be maintained close to the surface?
- Are the conditions so dry that the water table will stay far down from the peat surface?
- Is it possible to provide suitable conditions for the establishment of *Sphagnum* fragments?
- What will the new vegetation carpet be like?

Answering these questions will define more precisely what should be done at a site and how the general procedure will be adapted to site-specific conditions. For example, if water is available and the water table is likely to rise rapidly, one will decide to block ditches only once other restoration operations are done.

Monitoring

It is paramount to consider the right timeframe when setting specific objectives and evaluating the success of restoration. Peatland restoration is a process that will not be achieved before the acrotelm has reconstructed, which means several years. However, establishing a full plant carpet dominated by peatland species including *Sphagnum* and stabilizing the water table near the surface can be achieved in about five years. A site should be monitored only from the second year after restoration work. Its evolution toward a peat bog or not could be determined after plant establishment and hydrological conditions have been monitored two or three times.

Planning restoration operations

The second component of a restoration plan is the planning of restoration operations. Planning operations is a major factor of success because:

1. **Planning allows the restoration work to integrate into usual peat harvesting operations.** For example, restoration of abandoned fields and opening of new fields can be done simultaneously allowing plant fragments to be collected on fields that are being open. Access to these new fields and work with machinery will be facilitated after ditches are dug out.

2. **Planning ensures that the right operation is done at the right place, at the right time, in the right way.** Successful plant establishment depends upon a series of details associated with each major operation. Remember that “living” biological material is used. Lack of care in doing one thing usually has little impact, but the addition of many may result in failure of restoration efforts. Examples of such details are:

    a. Pick up and pile up plant material soon after it has been shredded with a rotovator at the collection site. Waiting a few days allows plant fragments to dry and reduces their regeneration potential.

b. Avoid running over plant material that has been spread onto the fields before it is covered with straw mulch because that can mix plant fragments with peat, break them or bury them into the peat. In such a case, the establishment of a full vegetation carpet is much slower and can even be inhibited.

c. Apply the right quantity of straw. Using too little straw may reduce the cost of restoration in the short term, but straw mulch may not provide enough protection to plant fragments and this can seriously affect their establishment.

3. **Planning ensures having the right material and equipment at the right time.** The time spent waiting in the field for some equipment or material is wasted time. It can also affect restoration success if plant fragments that have been spread have to wait for a straw spreader to be covered by protective mulch. Some equipment and/or material are not easily available in some regions, especially where agriculture is less intensive. The best example is the difficulty in finding large quantities of straw in the Acadian Peninsula of New Brunswick. Someone can probably find what he needs at the last minute, but at what price? In this case, planning should involve contacting local farmers a year in advance and even try to encourage them to grow grain to produce more straw. Given the amount of straw needed in restoration, this may result in a substantial reduction of the cost of restoration per hectare.

4. **Planning helps to keep a record of what is done and thus helps further develop the peatland restoration approach.** Recording of information on site characteristics prior to restoration, type of vegetation at the collection site, timing and details on the flow of operations, etc. will allow the creation of a database. Analysis of these elements, along with data on plant establishment and hydrological status for many sites, will help point out factors responsible for the success or failure of restoration. It will be the variety of restoration projects that will contribute to the development and amelioration of peatland restoration techniques.

5. **Planning lowers the cost of restoration.** If all of these recommendations are put into practice, planning will certainly reduce the cost of restoration. Everyone will benefit from a lower cost per hectare and there will be more restoration projects that will help improve restoration techniques.

Operations described in this *Guide* must be considered as guidelines. They have to be adapted to suit local conditions based on the information collected in the first phase of planning. Thus, in the light of this information, all operations should be defined as precisely as possible, and for each of them the time and resources required should be described in detail. Timing of restoration is another important factor because operations should be done in a precise sequence. Some operations can be done at any time of the year, but others have to be conducted at specific periods.

To help ensure that nothing will be left behind and everything will be done correctly, this part of the restoration plan should include the following elements:

- Map of the site showing location of collection site, berms, pools, etc.
- List of operations, and for each operation:
    - description of the operation
    - human resources required
    - equipment required
    - material required
    - evaluation of cost
- Schedule

The Quick reference sheet included in this *Guide* is designed to help plan the operations because it summarizes the basis of most of these elements. It is recommended to use it for planning. Forms are also provided in Appendix C to facilitate and standardize monitoring of operations.

Timing of restoration

Restoration should be done as soon as possible after cessation of peat harvesting on a bog section. Leaving out restoration too far in the future will require additional operations and cost and decrease the chance of success. Over time, conditions deteriorate as a result of the degradation of surface peat and the loss of water storage capacity of peat deposits due to the oxidation and decomposition of peat, frost heaving phenomena and the formation of a crust. Risk of invasion by undesirable plant species also increases as time passes. If a site cannot be restored in the year or two after peat harvesting has ceased, it is best to harrow the site up to the start of restoration.

Surface preparation

The goal of surface preparation is to improve site conditions and increase water availability and its distribution to favour the establishment of plant fragments that will be reintroduced later in the restoration procedures. In more concrete terms, surface preparation aims to reshape peat fields that were profiled in a way to favour drainage and drying of peat surfaces for extraction. This usually involves more than one operation.

Specific objectives are based on general principles that universally apply and should be kept in mind at every step of any restoration project. These specific objectives are as follows:

- **Keep as much water as possible within the site**, because peat bog plants need water. We must compensate for the loss of the property of peat deposit to store a large quantity of water due to the removal of acrotelm.
- **Achieve an even distribution of water** using water management options like levelling of sloping fields, building berms or creating basins when needed. In fact it is necessary to re-profile upper parts that would stay dry and depressions that are prone to flooding. Peat fields were profiled to drain into secondary ditches and empty into main ditches. This system has to be reversed in some way.
- **Avoid flooding for extensive periods** or at great depths by levelling sloping and uneven surfaces.
- **Avoid flooding on large areas** because wave action can disturb establishing plant fragments and straw mulch.
- **Remove loose surface peat and crust at peat surface** that impede contact between plant fragments and peat substrate, which consequently prevent their access to water. Plant fragments heavily rely on capillary water for water supply; thus the presence of clean flat surfaces ensures better contact with the wet peat substrate. Loose peat results either from recent harrowing, frost heaving phenomenon and/or peat decomposition.
- **Remove or use existing vegetation** on the site, depending on the type and density of plant species colonizing the site.

One way to retain some water and avoid extended flooding is the creation of permanent open water bodies. They represent reservoirs that absorb water surplus and serve as a source of water in dry conditions. Open water bodies can be created by leaving sections of ditches open or by digging pools (see Pool creation).

There are different ways to meet these objectives, and generally more than one operation is required to improve surface suitability for plant establishment. The choice mainly depends on site-specific conditions, and the information collected in the planning phase helps in selecting the best options for a given site. Table 2 presents a list of surface preparation options and summarizes their benefits and site conditions. Procedures along with site suitability and benefits for each option, are described in more detail below.

Flooding

The climate of North America is characterized by a long winter during which precipitation fall as snow and accumulate on the ground. Typically, all this snow melts in a short period causing water runoff and flooding in some sites.

Recent studies suggest that flooding for a short period is not harmful to mosses and may in fact help their establishment. However, flooding for a long period of time (> 1 month) or deep flooding (> 30 cm) may have negative effects such as physiological perturbation of plant fragments and the displacement of mulch. Wave action on large flooded areas can cause erosion and breakup of berms. The loss of melt water through runoff can cause erosion and a rapid drop of the water level. However, once a new plant carpet has formed, these problems associated with excess water are less likely to occur.

Blocking drainage is the first thing that comes to mind when thinking of keeping water in a site, but it is considered as a separate operation and will be treated in a the Blocking drainage section. However, building berms will block drainage ditches and water will start to rise on the site. For sites surrounded by drained land, blocking the drainage may pose less of a problem. For sites bordered by natural peatland areas, blocking ditches first can result in a rapid rise of the water table and make further operations difficult because of soft ground and sinking machinery. In those cases, berms can be left open when crossing ditches and be closed at the end of operations.

Re-profiling fields

Dome shaped fields are a common feature of harvested peat bogs as they favour rapid surface water runoff. If they are left in this state, the top of fields will stay dry and peat bog plant species will barely establish. Such fields have to be flattened to prevent water runoff and to provide an even distribution of water. Fields with irregular topography also have to be re-profiled because mounds, ridges and other positive relief will stay dry and prevent plant establishment. On the other hand, frequent or prolonged flooding in depressions present adverse conditions for plant establishment. Re-profiling fields also has the advantage of scraping the peat surface and improving surface conditions.

Flattening fields involves moving variable volumes of peat usually from the top and centre of fields toward the edges. Although different equipment can be used, a leveller gives the best result because it creates even, regular surfaces. Other equipment, like front end loaders, are more likely to create some microtopography or roughness at the peat surface, which is unsuitable for restoration. The peat scraped from the surface can be used in berm construction or disposed of in ditches. However, berm construction is the preferred alternative because it is recommended to leave ditches open because they play a role in restoring biodiversity.

Table 2: Surface preparation options with their benefits and site conditions

Surface preparation options	Benefits	Site conditions
Re-profiling fields	• Favours a better distribution of water • Removes loose surface peat and crust	• Dome shaped fields • Sites with depressions or mounds
Filling ditches	• Facilitates work with machinery • Removes loose surface peat and crust • Removes undesirable vegetation	• Short fields • Presence of loose peat or crust • Vegetated sites
Building peripheral berms	• Keeps water in the site • Acts as windbreak	• Around most sites or sections within a site
Building berms across the slope	• Keeps water in the site • Favours a better distribution of water • Avoids flooding on large area • Removes loose surface peat and crust • Acts as windbreak	• Sites with slopes • Long peat fields (> 100 m)
Building chessboard-like berms	• Keeps water in the site • Favours a better distribution of water • Avoids flooding on large area • Removes loose surface peat and crust • Acts as windbreak	• Sites with slopes • Sites with complex slopes
Creating basins	• Keeps water in the site • Favours a better distribution of water • Avoids flooding on large area • Removes loose surface peat and crust • Acts as windbreak	• Flat fields • Dry sites
Scraping surface peat	• Removes loose surface peat and crust	• Sites with loose surface peat or crust
Removing existing vegetation	• Facilitates the work with machinery • Prevents invasion by undesirable species	• Sites densely vegetated with trees and non-peat bog species
Using existing vegetation	• Helps protect plant fragments • Increases biodiversity and site ecological value	• Sites colonized by peat bog species
Blocking drainage	• Keeps water in the site	• All sites

Filling ditches

Filling or leaving ditches open provide contradictory benefits that complicate the choice of one option or another. Filling ditches really helps the work with machinery, as it makes it possible to run in every direction with tractors. On the other hand, open ditches, when they are blocked, form water bodies that increase biodiversity. The right option is often imposed by site-specific conditions. In short peat fields for instance, filling ditches may be necessary to be able to work with machinery. Mixed procedures, such as filling one ditch out of two or filling ditches on either sides of berms only on a few metres to allow passage of machinery, can be practical solutions.

Ditches are filled by pushing and compacting peat collected on nearby surfaces using different equipment such as a leveller or a front end loader. Typically, filling ditches is done while conducting other operations like scraping loose surface peat or flattening dome shaped fields. Ditches that are not filled up to the peat surface or where peat is not compacted will create shallow, more humid depressions with related peat bog species.

Berms

Roles of berms

Berms can play many roles in peat bog restoration. Their main purpose is to limit water movement and to keep water as long as possible on the site rather than retaining large masses of water. In the North American climatic context, large amounts of water occur at snowmelt and concentration of this water causes flooding, runoff and erosion. Berms play a key role in limiting these problems by distributing the excess water over large areas. This can be best achieved with numerous low peat mounds built across slopes or in a chessboard pattern or shaped into basins, and with a peripheral berm built around the restoration site.

The construction of berms also helps clean the peat surface from loose peat and crust, which are characteristic of fields abandoned for a few years. Finally, a positive side effect of berms is that they also act as windbreaks, which prevent straw and plants from being blown away by wind, and work as snow traps that contribute to accumulate more water on site.

Procedure for building berms

All types of berms that have been made in peatland restoration to date in North America were built by using peat. Thus, any machine capable of pushing or moving peat can be used to build berms. However, a leveller gives better results in less time. The height of water retained behind a berm will determine the water pressure that will apply on the berm. Thus, the greater the expected height of water, the stronger the berms must be built. Consequently, it is recommended to follow these general rules when building berms. They will help in constructing more resistant and impervious berms and reduce the possibility of corrective work later.

- It is necessary to **compact the peat** thoroughly once it has been pushed into a mound, to ensure its imperviousness and make it more resistant to water and wind erosion. The use of any heavy machine, one that would sink in a natural peat bog is highly recommended. Remember that tractors equipped with 4-6 wheels are used in peat bogs because they apply a very low pressure on the ground and therefore should not be used to compress peat.

- **Use well decomposed peat** whenever possible because it provides better impermeability than fibrous peat.

- The presence of wood, branches or other **debris in the peat can weaken the berm** and lead to leaking.

- **Clean peat surfaces** provide a better contact between the berm and the peat surface and limit the risk of water infiltration and leaking. Scrape the surface peat and any vegetation at the location of a berm prior to building on it. One way to work is to push or move the peat into a mound and then push it back on the clean peat surface.

- It is better to **build wide berms instead of high berms.** They are more resistant to pressure from water bodies. In winter, berms protrude through the snow and freeze deeper than the surrounding area. In spring, the core of berms stays frozen for a long period after snowmelt making them resistant to water erosion and retaining water efficiently. Higher berms accumulate more snow on each side and may prevent freezing of berms to the base. In spring, such berms will be more easily eroded by water. However, the size and height of a berm depends on its purpose (peripheral berm, chessboard berm, etc.) and the quantity of peat that has to be moved. A height of 40 to 50 cm after compaction is usually sufficient to provide good blockage.

- Peat is a material that erodes easily even when it is compacted, and breakages through berms is a common problem. One way to prevent the erosion of berms is to install devices to **allow discharge of surplus water.** Many commercial overflow systems exist. Installing a pipe through the berm during its construction is the simplest overflow system, but it often leads to erosion.

- In any case it is important to **push the peat up the slope** rather than down the slope. Pushing the peat toward the bottom of the field will accentuate the existing slope (Figure 8). Pushing peat toward the top of the slope will help create flat terraces.

Peripheral berms

Peripheral berms are so named because they enclose a whole restoration site or sections of a restoration site. Their main role is to contain water into a restoration site rather than favour better distribution of water. They represent a necessary feature around sites bordered by ditches that cannot be blocked or bordered by flat and depressed areas. These berms are of no use when the restoration site already forms a depression compared to the surroundings and from which water cannot escape.

Since they often enclose large areas, peripheral berms are likely to collect large amounts of water and they have to be strong enough to resist water pressure. Wide berms may work better than high ones and they should be reinforced or be wider at places where pressure is likely to be greater. Avoid 90 degree angles because they weaken berms, and use round shaped corners instead.

In the case of peripheral berms bordered by a ditch, it is possible to use deeper layers of peat or even mineral material from the bottom of the ditch to make more resistant berms. In such a situation, an excavator will be used to build the berm. If mineral material is used, it should be placed on the external side of the berm to prevent contamination of the restored area. The presence of mineral subsoil will facilitate plant colonization of the berm and will help protect it against erosion.

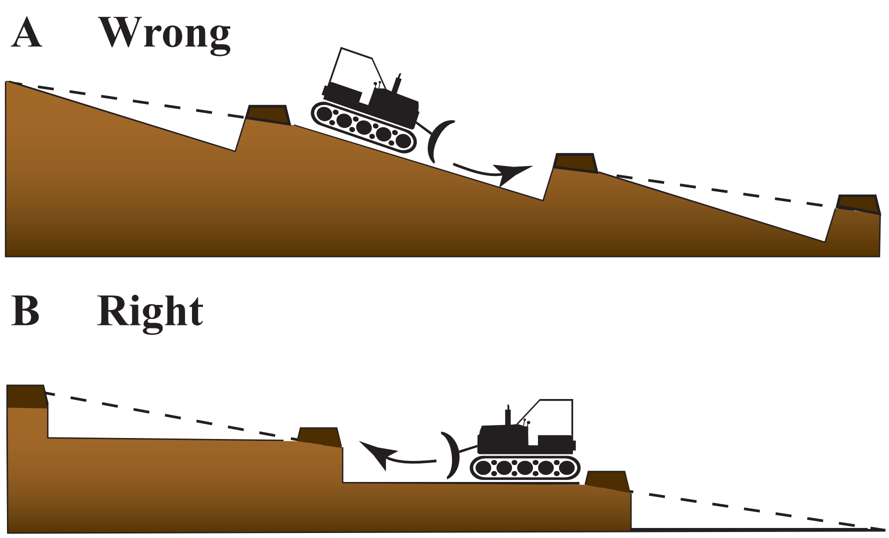


Figure 8. Diagram showing the resulting topography when berms are built by pushing peat downslope (A) or upslope (B). Pushing peat upslope results in the creation of flat terraces while pushing peat downslope accentuate the slope.

Across slope berms

Berms should be built across the slope in almost all sites to achieve better distribution of water. Even a gentle slope will have dry conditions upslope and periodic or permanent inundation downslope. For example, a slope of 0.5 % on 400 m long fields results in a differential elevation of 2 m. Across slope berms are usually built perpendicular to the slope when a difference of 30 cm of height is reached. For instance, in the case of a 0.3 % slope, berms will be located every 100 m (Table 3).

Although large peat bogs have generally regular gentle slopes, convex, concave or more complex slopes often occur along the margin or around large ponds. In this case, it is recommended to survey the site and build berms along contour lines. That was the case at the site of Inkerman Ferry, New Brunswick where berms built along contour lines allowed a better distribution of water than if they had been built perpendicular to the slope (Figure 9).

Chessboard berms

Creating chessboard berms or small basins improves conditions for plant establishment and represents an alternative to berms built across the slope in some situations. For example, the site of Chemin-du-Lac located at the west end of the Rivière-du-Loup peat bog, Québec, is characterized by complex slopes and short fields. To achieve an even distribution of water all over the site, berms in a chessboard pattern forming square cells about 30 m across were created with a leveller (Figure 10). The leveller scraped the surface peat and created small terraces aiming to distribute water more evenly over the site. Berms are about 30 cm high after compaction. The passage of machinery during plant and straw spreading did not damage them to the point of losing their efficiency.

Table 3: Horizontal distance between berms separated by elevation of 30 cm according to slope angle

Field length (m)	Slope angle (%)	Difference in level from one end to the other (cm)	Number of berms	Distance between berms (m)
100	0.50	50	2	50
200	0.25	50	2	100
300	0.33	100	4	75
400	0.12	50	2	200
400	0.19	75	3	130
400	0.25	100	4	100

Figure 9. Aerial photo of Inkerman Ferry restoration site, New Brunswick. Across slope berms were built along contour lines after the site was surveyed. Restoration work took place in the fall of 1997 and the photo was taken in September 1998. (Photo: F. Quinty)

Basins

The use of shallow basins proved to be efficient in promoting the establishment of *Sphagnum* and other peat bog plants in a number of experiments. Basins differ from chessboard berms by the fact that they are dug to a greater depth, up to 10 cm. At some sites, the depth of remaining peat may limit the use of basins. The peat resulting from digging basins is usually placed around them. These shallow basins retain water in the spring or during rain events, providing a wetter environment for the reintroduced plant material. They also have clean flat surfaces that offer good contact between plant fragments and wet peat. These basins also help protect plant fragments and straw by acting as snow breaks. It is important to create relatively small basins to prevent damage by wave action and to dig them not too deep (< 20 cm) to avoid water standing for long periods.

Figure 10. Aerial photo of Chemin-du-Lac restoration site, Québec. To achieve good distribution of water over the site, chessboard berms were created because of the complex slopes and short fields, forming cells about 30 m across. (Photo: Premier Horticulture Ltd.)

Scraping surface peat

Abandoned fields are often covered by a layer of loose peat resulting from harrowing, frost heaving, wind erosion deposition or from the process of peat oxidation and decomposition. In some cases, microscopic vegetation composed principally of algae and liverworts, grows on peat and forms a crust that peels off when it is dry. Such degradation of peat surfaces worsens with time after peat harvesting stops. All these characteristics negatively affect the establishment of new vegetation because they represent a barrier between plant fragments and the wet, compact peat substrate, which is a major source of water and humidity. Loose peat layers also dry rapidly in summer. Plant fragments lying on top of such layers will have diminished water supply and are less likely to survive.

In general, surface preparation involves scraping or refreshing of peat surfaces associated with constructing berms or flattening of dome shaped fields. However, it happens that all surfaces are not scraped by these operations. For example, in the case of long flat fields requiring only the building of berms across slope at intervals of 50 metres or more, only a fraction of the peat surface will be scraped in order to gather enough peat to build berms. In such a case, scraping the entire area should be done if loose peat is present at the surface.

A leveller is the perfect machine to scrape peat surfaces, but other equipment such as a front end loader or a tractor with a back plate can be used. Loose surface peat must be scraped until the solid, undisturbed peat layer is reached. Preferably, the peat will be used for the construction of berms, but it can also be put into ditches.

Existing vegetation

Vegetation colonizing abandoned peat fields can help the restoration of a peat bog or it can be a nuisance. The most common situations are:

1. More or less dense cover of ericaceous shrubs
2. More or less dense cover of cottongrass or other herbaceous species
3. Presence of trees
4. Presence of non-peat bog species

The presence of peat bog species should be considered as a good sign that a site presents peat bog conditions. A scarce or scattered cover of shrubs or cottongrass should be preserved as it represents a source of diaspores and a protective cover for the establishment of new plants. Restoration procedures should be followed as usual even if plants will intercept some of the fragments. If the cover is dense to the point that it can prevent most spread plant fragments to reach the ground, it may be scraped away or trimmed. A site visit is essential to evaluate the situation.

The presence of a few trees, located along ditches is frequent in abandoned sites. They may provide benefits by offering shadow to plants and shelter to birds and fauna. However, trees use a lot of water to survive and grow. They literally pump water from the substrate, thus contributing to lowering the water table. A few mature trees may represent a source of seeds precluding to an invasion, especially in the case of birches. Since few data exist on the overall effect of trees, it is recommended to cut them off.

In the presence of a large quantity of trees forming a young forest, options other than restoration should be sought. If trees are scattered all over the site, they pose a problem for mechanical operations and they should be cut down. They can be useful if they are put in ditches or pools in order to create shelter places for fauna.

The presence of non-peat bog species must be carefully considered. Some ubiquitous species, such as Field Sorrel (*Rumex Acetosella*) often occur in small colonies and have no negative effect on restoration. They may be associated with the presence of sand or other mineral at the surface. Other species like reed-grass (*Phragmites communis*) may be an indicator of adverse conditions for restoration and that other options should be considered. For example, the occurrence of Spartina (*Spartina pectinata*) in some abandoned peat fields in New Brunswick was a clear sign of the impact of sea water. In any case, vegetation should be characterized and some species should be identified by a specialist for further interpretation.

Situations to avoid and other problems related to surface preparation

- It may be difficult to re-profile peat fields or build berms in the spring because the **peat stays frozen for a long period of time** and once it is thawed it is saturated with water. It is therefore better to proceed with site preparation during the summer or fall. On the other hand, the presence of frozen peat may facilitate some operations.

- When doing any type of work, it is important **not to reach the mineral substrate.** This enriches the peat surface and promotes colonization by non-peatland species. The best way to avoid this situation is to leave a minimum of 50 cm of peat.

- Creating **microtopography** does not improve the establishment of *Sphagnum* and other mosses. An experiment comparing the effect of ploughing, bulldozer tracks, harrowing and flat surfaces concluded that flat surfaces represent the best option. The other types of microtopography offer sheltered sites (bottom of tracks and furrows) but overall conditions are not better than that of flat surfaces because of dryness that occurs on positive relief.

- Re-profiling dome shaped fields is an important factor contributing to wetter conditions. An experiment showed that creating "V" **shaped fields** or inversing the original profile of domed shaped fields improved the establishment of *Sphagnum* species at the bottom of the slope. However, this led to dry conditions on the upper parts of the slope. Moreover, the new slope may induce erosion of peat, plants and straw by water runoff and deposition and burying of plant fragments down the slope. Therefore, when re-profiling a dome shaped field, it is important to do so up to the point where the new shape is a flat field, not to the extreme of inversing the original profile.

- Berms are subject to collapse because of **erosion from water runoff.** Good compaction of the peat can prevent these problems. Some overflow systems can also prevent this problem but another, unusual cause of collapsing found with peat berms is the digging up year after year by mammals, probably muskrats. This has been observed at the Saint-Henri peat bog south of Québec City, on the peripheral berm. No experiment has yet addressed this problem.

- Keep as much water in the restoration site
- Achieve an even distribution of water over the site, especially by building berms at strategic locations
- Avoid flooding on large areas for a long period or at depths over 30 cm
- Keep open water by leaving ditches open or creating pools

Site preparation depends on site-specific conditions and the time required may vary a lot. Gentle sloping fields abandoned for a short period of time need little time and effort. Sites abandoned for a longer period with loose surface peat and non-peatland vegetation demand better planning and more resources. The average time is around three and a half hours of work per hectare (Table 4).

In general, a leveller is the most appropriate equipment for surface preparation. It can flatten domed fields, scrape surface peat and build berms. It is also the best equipment for creating flat and even peat surfaces. A front end loader or a bulldozer can be used for filling ditches and building berms, but they create tracks or fluffy peat by moving back and forth. Such surfaces decrease the chance for plants to establish.

Table 4. Time and material required for surface preparation

	Machinery (hr./hectare)	Material ($/hectare)
Site preparation	3.5	No specific material required
TOTAL	3.5 hours	$0

Plant collection

The Canadian approach to peatland restoration is based on active introduction of plants in order to accelerate the formation of a new plant carpet. The most important feature of this plant carpet is the presence of *Sphagnum* mosses, which are largely responsible for the unique characteristics of peat bogs and for the accumulation of peat. Thus, the plant material that is introduced must contain an important fraction of *Sphagnum* diaspores. It must also contain other pioneer species because *Sphagnum* mosses are poor primary colonizers. The most practical and abundant source of peat bog plant diaspores is a bog itself. In North America, large natural remnants of harvested peatland or small peat bogs are commonly available and accessible at short distances from restoration sites. The collection of plants consists essentially in shredding the surface vegetation and picking it up. This plant material will be spread over the restoration site to form a new plant carpet. Collection of plants, when done properly, allows rapid recovery of collection sites and does not result in permanent damage.

Diaspores

Diaspores are any part of a plant capable to grow as a new plant. This includes seeds and spores, which are the seeds of mosses, but also roots, stems, leaves, branches, etc.

How to choose a collection site

The two major factors to consider when choosing a collection site are **plant composition** and **size of the collection site**.

Plant composition

Plant communities play a major role in the success of restoration. For most people, peatland vegetation seems to be a more or less homogenous mossy cover. For the purpose of restoration, *Sphagnum* moss carpet must be the dominant feature and low shrubs, like Labrador tea, can be abundant. However, a closer look is needed to detect **favourable or unfavourable plant species** regarding the establishment of the moss carpet. As stated previously, *Sphagnum* mosses are vital for peat bog restoration, but not all species are suitable for this purpose. Hummock-forming species like *Sphagnum fuscum*, a small brown species, and *Sphagnum rubellum*, a little red one, work best. **The choice of a collection site of poor quality will have a direct impact on the results obtained and thus be a waste of effort and money**.

The targeted plant communities must cover the entire surface of the collection site. Otherwise, introducing unsuitable *Sphagnum* and other moss species, or no moss at all in some cases, may lead to failure and loss of time and energy. To facilitate the use of machinery, it is preferable to choose a site without trees. Roughly, plant species can be grouped into four vegetation types according to a few easily recognizable characteristics. Use the Key to identification of collection sites and the description of the few bog species to ensure that a collection site has the right plant community. The identification key describes four groups: two suitable and two unsuitable for restoration. It may be more practical to hire a specialist to locate and map the potential collection sites on a given peat bog.

Size of collection site

The size of the collection site is an important factor to consider because it determines the quantity of plant material that will be available for the restoration. The Peatland Ecology Research Group conducted many experiments to evaluate the right amount of plant material to reintroduce. This amount should allow the rapid formation of a new plant carpet on restoration sites as well as limit the impact to natural sites. Reducing the quantity of plant material to transport is also an important factor that was considered.

The best way to assess the amount required is by determining the ratio between the surface of the plant collection site and the surface of the restoration site. In theory, a ratio of 1:15 is adequate, but in practice, ratios of 1:12 to 1:10 are used to compensate for losses of material, damage to plant carpet by the machinery or the presence of trees (Figure 11).

Collecting plant material

Depth of collection

The depth of collection of plant material plays an important role in the success of plant establishment, particularly for mosses. Past experiments showed that the potential of regeneration of new plants from moss fragments decreases rapidly with depth (Figure 12). For example, most common *Sphagnum* species could be considered as dead when collected below 10 cm from the surface. This means that collecting plants to a depth of 20 cm will result in introducing 50 % dead fragments. Considering the effort and associated cost needed to pick up and transport the plant material, it is highly recommended to pay particular attention to the depth of collection. In practice, some sites present surprisingly flat and even surfaces that help in collecting the top 5 to 10 cm. However, most sites are bumpy with a succession of hummocks and hollows. In this case, the best scenario is to stay at a depth of 10 cm when collecting plants even if the bottom of hollows are not shredded because hummock forming species are more suitable for restoration. Using a ratio of 1:10 as recommended previously, helps take into account the loss of material since the hollows are not collected.

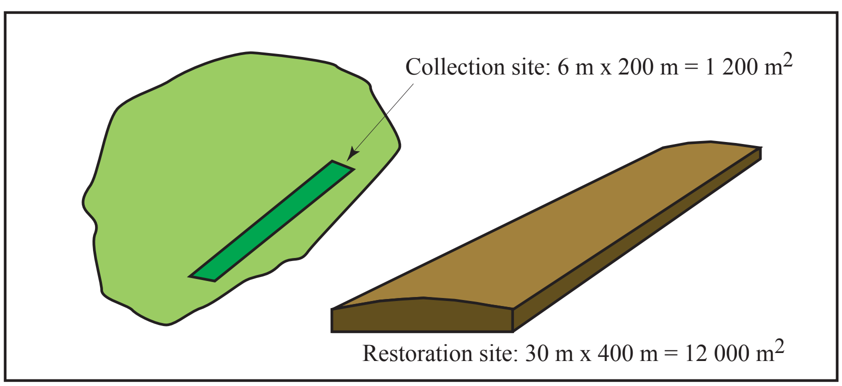


Figure 11. Diagram showing the ratio between collection and restoration sites.

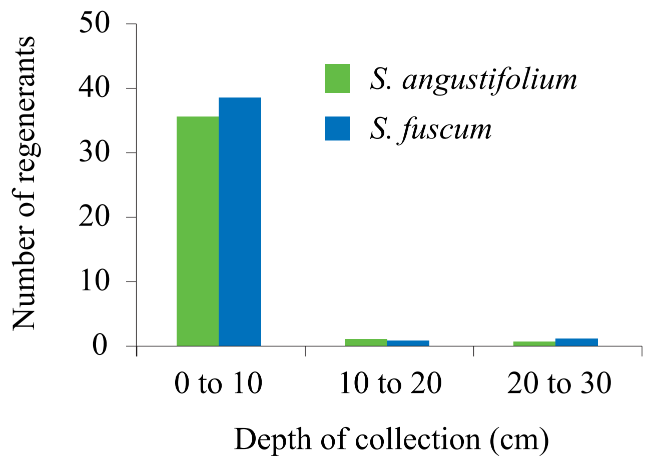


Figure 12. Chart illustrating the rapid decrease in the number of fragments regenerating a new plant according to depth of collection. Most plant material collected 10 cm below the surface of the bog does not regenerate. *Sphagnum angustifolium* and *Sphagnum fuscum* are two common *Sphagnum* species usually present in peatlands.

Collecting only the top 10 cm of the surface vegetation also has the advantage of allowing a rapid recovery of collection sites. The root system of shrubs stays in place and moss fragments that are left can regenerate easily. However, plant collection must be done with great care and damage should be limited to allow this. The idea of using the same collection site more than once could even be considered as a possible option.

Using the same collection site more than once

A vegetation survey of small collection sites showed that a complete Sphagnum moss cover had recovered four to six years after plant collection. Since plants were picked up with great care on these sites it is expected that recovery would take a few more years on large-scale sites because of the damage caused by machinery. However, these data suggest that it may be possible to use the same collection site more than once. This has never been done, but it is obvious that such an opportunity would require conducting operations with great care to protect plant regeneration. Spring collection would be recommended as it limits damage by machinery and favours a more rapid recovery. Such planning is in accordance with sustainable development.

Shape of collection site

It is preferable that the collection site be a long and narrow strip to minimize the risk of sinking machinery. The root system of plants forms a supporting layer for the machinery. Once it is broken after shredding the surface vegetation, machinery sinks easily. Working from the undisturbed side of the collection site facilitates plant pick up. The Figure 11 shows the proportion between the collection site and the restoration site: the ratio should be about 1:10.

General procedure for plant collection

The first step is to identify a collection site of appropriate size with the right plant communities and to mark it with flags or stakes. Attention should be given to the shape of collection site since it may facilitate the work with machinery. It is advantageous to collect plants on fields being open.

Afterwards, surface vegetation is shredded to a depth of 10 cm using a rotovator (Figure 13). Table 5 presents other types of equipment that have been used to collect plant material more or less successfully. The ideal plant material is composed of loose fragments a few centimetres long or in small chunks. Well loosened fragments will spread better, and give better and more uniform results than chunks. However, it is important not to break plants into too small pieces or to mash the plant material into a slurry; the ideal fragment size is between 1 and 3 cm. It is up to the restoration supervisor to adjust the speed of the tractor. A chopper shreds plants in smaller fragments than a rotovator so a tractor must go faster when using a chopper. It is recommended to pass only once to shred the vegetation, but it may be necessary to pass a second time over the plants if one judges that the fragments are in too big chunks after one pass.

Collect plants on fields being opened

It is possible to collect plants on fields that are being opened for future extraction activities. This option reduces the cost of restoration and minimizes damage to natural peatlands. Even then, it is important to ensure that suitable plant species are collected. Most often, plant collection takes place after ditches are dug to provide better ground conditions for transportation. In this case, strips along ditches where the peat was rejected by the ditcher must be avoided.

One should also look for the opening of new fields by other local peat companies or for industrial or agriculture development affecting peatlands. These opportunities can save money.

After being shredded, plant fragments can then be picked up and loaded readily or put in windrows or piled up to facilitate collection and loading for transportation. The plant material is brought to the restoration site in bog wagons. This operation presents some risks for the machinery because it is often conducted in natural, undrained sections of peatland. Plant fragments are usually soaked with water and thus are a heavy material to carry over soft ground. Tractors and wagons easily sink under such conditions. On sites that are drier and on fields being opened for future extraction, this problem is not critical and work can be done at any period of the year. On wetter sites it is preferable to proceed in spring on frozen ground. Plant pick up and transportation is the operation that has the highest probability of unexpected problems.

Fragment size

All parts of Sphagnum mosses except their almost microscopic leaves, can give new plants. Past greenhouse experiments showed that fragments as small as 0.5 cm have the potential to grow a new plant. However, surface vegetation should not be broken into too small fragments to limit stress. Plant material is living matter and it must be handled with care.

Table 5. List of equipment already used for plant collection and their efficiency

Plant shredding

Rotovator	Gives good results, best recommended equipment.
“Frandent” rotary harrow	Gives good results, does not break plants.
Chopper	Breaks plants too much if tractor goes too slow.
Discs	Goes too deep and collects dead material.
Screw leveller	Collects dead material with roots, plants in big chunks.
Clamshell bucket	Collects dead material with roots, plants in big chunks.

Plant pick up

Windrow rake and root picking conveyor	Gives good results on fields being opened (the only condition tested).
Bulldozer	Gives good results for piling up on frozen ground.
Back plate or similar device	Gives good results for piling up on frozen ground, but weaker than a bulldozer to push plant material.
Screw leveller	Can be used only to put plant fragments in windrow.
Front end loader	Gives good results especially with a bucket with teeth, but often lacks flotation especially when loading plants into wagon.
Clamshell bucket	Gives good results for loading once plants are piled up, slow to pick up and pile up plants.
Snowblower	Not good, too heavy, breaks plants too much, leaves a lot of material.

Unexpected problems

An unexpected problem occurred during the restoration of the Bois-des-Bel site. The plant material that was soaked froze when it came in contact with the cold steel of machinery (Figure 14). This situation is more likely to happen when temperatures are below zero. It is better to work when the temperature is above the freezing point, either in the spring or in the fall.

In the case of large restoration sites, it is important to stockpile plant material at locations that will minimize transport with the manure spreader. However, it is better to keep plant material in larger piles if it is not spread within a few days.

Evidence suggests that cold plant material can be kept in stockpiles for months and even a year. An experiment showed that plant material collected in June kept its regeneration potential until October of the same year. The plant material used for this experiment represented only a small pile about one metre high. At a larger scale, plant material collected in the spring was kept in a three metre high stockpile until it was used the next year. This material contained a lot of snow and ice that kept it cool and humid for a certain period. Preliminary results showed that plant fragments still had some regeneration potential after a year, but it was lower than for fresh plant material. It also turned out that the stockpile sank in the remaining peat deposit during this period and that some of it could not be recovered. Little is known about the probability of heating problems in plant material stockpiles.

- Collection sites must have a full moss carpet with dominance of *Sphagnum* species
- Use the Key to identification of collection sites or hire a specialist to make sure the collection site has the right plant community
- Treeless sites facilitate the work with machinery
- Collecting plants on fields being opened for harvesting reduces cost and damage to natural peatlands
- Use a collection site a tenth of the size of the site to restore
- Where possible, delineate collection sites as long and narrow strips to facilitate the work with machinery
- Shred the surface vegetation with a rotovator not exceeding an average depth of 10 cm
- Pile up, windrow or pick up the plant material and load it into wagons to transport it to the restoration site

Resources, time and money

Plant collection is the most time and resource consuming operation of peat bog restoration. Time required is highly variable because it depends on the conditions of the natural sections of peatland where most of the work is conducted. For example, wet collection sites will require a reduction of plant material loaded in trailers, and hence more trips will be necessary. Time required for hauling plant material also depends on the distance between the collection site and the restoration site. Therefore, careful planning of the collection operation and using the appropriate techniques (collecting at the right depth, loading the right weight to avoid sinking) has the most chances of saving. This also means that good collection sites are valuable.

The equipment used also makes a difference in the time allocated for plant collection since some are much more efficient than others (Table 5). It is important to allow the right resources for this operation to minimize loss of time. For example, numbers given in the Table 6 for plant pick up and transport may represent one loader and two tractors and wagons working for a little less than three hours. Note that numbers and areas (hectares) are given for the restoration site and not for the collection site.

Figure 13. Rotovator being used for plant shredding. (Photo : S. Campeau)

Table 6: Time and material required for plant collection

	Machinery (hr./hectare)	Material ($/hectare)
Plant shredding	1	No specific material required
Plant pick up and transport	8	No specific material required
TOTAL	9 hours	$0

Note that the numbers and areas (hectares) are given for the restoration site and not for the collection site.

Spring plant collection

Conducting plant collection in spring offers many advantages: the presence of the frozen ground supports machinery; it reduces losses of plant material because it can be picked up like on a paved surface; working on a frozen ground ensures that only the best regenerating plant material is collected; and finally, it protects the collection site from severe damage. Observations show that conducting plant collection when the ground is still frozen leaves the root system of plants intact and allows for a rapid recovery of collection sites.

Figure 14. Photo showing the consequence of plant material freezing in trucks or trailers when temperature drops below 0 degree Celsius. (Photo : F. Quinty)

Collection site delineation and preparation

It is very important to proceed with the delineation of the collection site when plant species are visible in the fall prior to the time of collection in the spring. It is also important to mark the site and access roads to ensure they will be visible when there is a deep snow cover.

A collection site with a lot of trees will accumulate a thicker snow pack and prevent deep ground freezing. In this case it is recommended to clear trees before winter. This remark also applies to access roads. It is better to clear any pile of peat, trees or whatever material to impede more snow accumulation.

Freezing of collection site

Despite severe winters in Northeastern America, it is common that the ground does not freeze deeply in natural peat bogs. The presence of a snow cover, well before below zero temperature occurs, may prevent the formation of a frozen layer thick enough to support the machinery during the spring. Thus it is highly recommended to favour deep ground freezing, particularly in the maritime region where the climate is milder.

Snow is full of air just like fibreglass wool making it a very good insulator. To ensure that the frost will reach the ground, snow has to lose its insulation property. The easiest and cheapest way to do it is to pack the snow with whatever is available, a tractor, a bulldozer, etc. Even a snowmobile will help when snow cover is too deep and tractors cannot pass. It is recommended to pack the snow on access roads as well. Depending upon winter meteorological conditions, it may be necessary to compact the snow a few times in order to obtain a deep enough frozen layer.

Pack the snow

It is amazing how large an area a tractor can prepare in an hour and at a fairly low cost. Compacting the snow allows deeper ground freezing. Any heavier equipment such as a bulldozer will compact snow even more and will be more efficient. The cost of this operation is low compare to the benefit it provides during plant collection in the spring.

Thickness of frozen layer

A solid frozen layer of about 15 cm is required to support the machinery. However, this number does take into account that the top 10 cm will be collected. Consequently, the real **depth of freezing should be 25 cm from the surface.** This number represents a minimum because the work can extend over a long period of time while the frozen ground will start melting. It is important to note that the thickness of the frozen layer can vary a lot locally. For instance, there is often a frost-free zone around trees while hummocks freeze more deeply and their cores stay frozen for a long period in the spring. Also, drained peat bogs freeze much more rapidly than natural zones meaning that access roads located on harvested areas need to be packed less often.

In practice, it is suggested to take measurements at a number of places on the collection site and the access roads to assess the thickness of the frozen layer. This can be done easily with a cordless drill equipped with a long bit. These measurements will help determine if the frozen layer is thick enough.

Access roads

Plant pick up and transport is a costly operation because it requires time and sinking problems can easily occur. Solid frozen ground helps prevent sinking, but bumpy roads reduce the speed of tractors hauling wagons loaded with plant material and are a source of machinery breakdown. Levelling these roads in the fall is likely to be a cost benefit as it will facilitate and accelerate this operation. It is impossible to level these roads when the peat is frozen solid.

In the spring, thawing of the frozen ground does not occur or is very slow as long as the snow cover remains. Once snow has melted, thawing also proceeds rather slowly. For example, in the Lac-Saint-Jean region thawing of 15 cm of frozen ground took 20 days with maximum and minimum daily temperature averaging 10°C and -3°C.

Snowblowing

After a winter of heavy snowfall, it may be appropriate to clear the snow cover to proceed with plant collection before the temperature warms too much. Blowing the snow away should be done one to three days prior to surface rotovating to allow enough thawing of the surface plant layer; otherwise rotovating a solid frozen ground can result in the breakdown of the rotovator. It is recommended to use a strong snowblower because snow becomes very heavy in spring when melting. The snowblower should not reach the top of hummocks because this is the plant material that has the best regeneration potential; instead, it is better to leave a thicker layer of snow in between the hummocks.

Plant pick up and transport

The procedure for plant collection in spring is the same as in fall. Nevertheless, the following precautions have to be taken in spring conditions:

- Hummocks stay frozen longer and may create bumpy conditions; it may be more difficult to work with a rotovator

- Rapid snowmelt can transform plant material into a soup that is difficult to pick up and results in the loss of plant fragments

- Tractors may have problems hauling heavy loads of plant material because they slip on icy roads

- The location of stockpiles of plant material is of great importance. There is plenty of snow and ice mixed with plant material that melts slowly during spring and summer. This creates wet and soft ground conditions all around the stockpiles. For this reason it is recommended to pile up plant material on a well drained area rather than in a depression.

- Mark the collection site and access road to be able to find them when there is snow
- Clear trees before winter on the collection site to limit snow accumulation
- Compact the snow prior or during cold temperatures to allow deep ground freezing

Resources, time and money

Spring plant collection requires only a little more time than fall plant collection (Table 7). Most extra time is spent preparing the collection sites compacting snow and snowblowing. It takes less than two hours to compact the snow on one hectare and it takes about five hours to clear 30 to 40 cm of snow over one hectare. Given that one hectare of a collection site provides plants for the restoration of 10 hectares, the time for compacting and blowing the snow per surface of restored bog is almost insignificant.

Table 7. Time and material required for spring plant collection

	Machinery (hr./hectare)	Material ($/hectare)
Snow compaction	0.2	No specific material required
Snowblowing	0.5	No specific material required
Plant shredding	1	No specific material required
Plant pick up and transport	8	No specific material required
TOTAL	9.7 hours	$0

Note that the numbers and areas (hectares) are given for the restoration site and not for the collection site.

Plant Spreading

Spreading the plants represents an easy step in peatland restoration as it consists merely of spreading the right amount of plant material. Very few technical problems are associated with this intervention. However, care is needed at this stage because applying the right quantity of plant material in an even layer on peat substrate is a determinant of restoration success.

Quantity of plant fragments

It is difficult to precisely determine the exact amount of plant fragments that have to be spread for a given surface because of differences in plant material quality. For planning purposes and for plant collection a surface ratio is used, but when it is time to spread the plant material in the field, the right amount is assessed visually. Past experiments comparing different quantities of plant fragments showed that a continuous thin layer of fragments gives the best result (Figure 15). Table 8 describes what the right and wrong quantities of plant material look like. It is important to keep in mind that:

- Fragments have to be in contact with the peat substrate to have a better access to water
- Fragments on top of too thick a layer of plant material will dry off and bury underlying fragments
- Fragments buried under too thick a layer will not have access to light and will hardly develop into new plants
- The ground must be totally covered by plant fragments because vegetation does not spread itself rapidly afterwards, so that areas without plant material may remain as bare peat spots for a long period of time

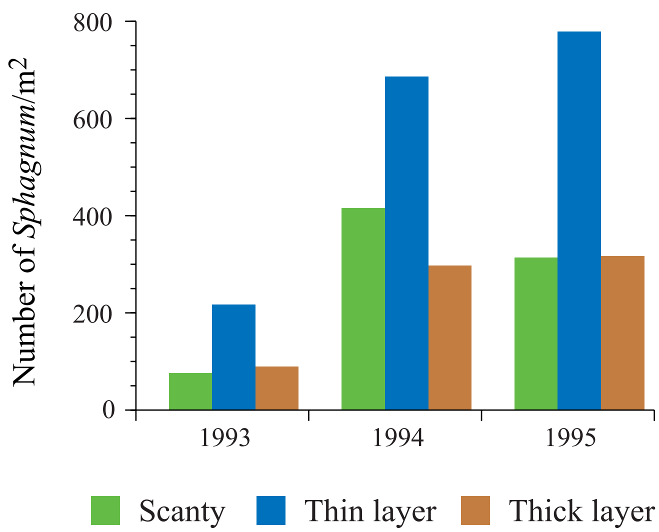


Figure 15. Graph illustrating how the density of plant material affects the number of regenerating *Sphagnum* mosses. The gain from spreading a thin layer persisted over the three years of this experiment.

Table 8. Description of right and wrong amounts of plant material after being spread

Good/Not good	Amount	Description
Not good	Scanty	Plant fragments do not cover the ground entirely. It can be either scanty chunks or sparse small fragments.
Good	**Thin layer**	The ground is more or less totally covered by a continuous layer of plant fragments 1 cm to 5 cm thick when in a fluffy state. It is possible to see some of the underlying peat through the plant fragments.
Not good	Thick layer	The peat substrate is thoroughly covered by a layer of plant material more than 5 cm thick and the ground cannot be seen. Fragments on top of the layer are not likely to come in contact with the peat substrate.

One factor that influences the amount of plant material to apply is the depth of collection of plant fragments. Since the regeneration potential of plants decreases rapidly with depth, larger quantities of plant material should be applied if it is collected at a greater depth. Spreading plant material that contains snow or ice can also lead to confusion as to the quantity of plants being spread. In any case, it is important to stay in the range of the correct amount.

Plant material that contains snow or ice

When plants are collected in spring, a certain amount of snow comes with the material. This snow melts slowly and can form ice lenses in stockpiles and stay frozen until the end of the summer in larger piles. It may be difficult to pick up and load the plant material into a manure spreader when it is frozen. Also, frozen blocks can damage the shafts of manure spreaders that break the material. One way to solve this problem is to move the pile of plant material a few metres away a few days before plant spreading to allow the ice to melt.

It is also important to pay attention to spreading the right amount of plants when working with material that includes snow or ice, as one might get the false impression that more plant material is spread than it actually is.

Spreading the plants

Plant fragments are spread using a standard box manure spreader (Figure 16). Most manure spreaders give satisfying results in terms of spreading an even layer of plant material. The first load of plants is used to calibrate the speed of the apron chain and to select the appropriate gear for

Figure 16. Standard box manure spreader spreading plant material. (Photo : F. Quinty)

the speed of the tractor. The best way is to first have someone walking at a safe distance behind the manure spreader to check the amount of plant material delivered by the spreader and signal the operator accordingly. Once the right gear combination is found, only one operator is needed.

It is highly recommended to follow a procedure that will prevent passage of machinery over the plants. Driving a tractor or other machine over plant fragments can bury or mix them with the peat. It is usually possible to spread a few rows of plants and spread the straw over them from the side to avoid passing over the plants.

The presence of branches or small trees growing on abandoned fields may cause problems with the apron chain of the manure spreader. The use of a manure spreader equipped with an hydraulic panel moving backward instead of an apron is recommended to avoid this problem. A manure spreader with flotation tires and two sets of wheels works better especially on soft terrain. "V" shaped spreaders that spread sideways have not yet been tried, but they are made to spread more liquid material.

The circulation of a manure spreader loaded with plant material on soft ground can result in sinking of the machine because it is very heavy. The best conditions for spreading plant material are:

- When the ground is frozen
- In spring when the ground gets drier after snowmelt water has receded
- Before fields get too wet in the fall

Biologically, mid-summer is not the best time to spread plants as they may suffer from lack of water during the crucial time of their early establishment. In practice, this is not likely to happen because mid-summer represents the busiest period for peat harvesting and hence, little availability, if any, of operators and machinery for restoration work. At very wet sites however, mid-summer work may be recommended as it may be the only time of the year when machinery could access the site without having trouble and causing damage.

It is also recommended to avoid spreading plants when the ground is too soft because the machines leave deep tracks. Field trials have proven that the presence of tracks on the peat surface have a negative effect on the success of restoration. In theory, depressions created by tracks provide wet sheltered conditions that are favourable to moss establishment. But in practice, tracks represent only a small portion of the restoration surface and areas between tracks stay drier. Sometimes straw mulch is blown away from the positive reliefs and the absence of mulch between tracks leads to frost heaving phenomenon: a situation known to often prevent the formation of a new moss carpet. In addition, windblown straw often accumulates in the ruts, effectively smothering the plants under a thick carpet with no light.

Once spread on bare peat substrate, plant fragments are exposed to sun and wind and they dry rapidly. In such conditions their regeneration potential may decrease substantially. Hence, it is imperative that straw mulch be spread as soon as possible for their protection.

- Spread a thin, continuous layer of plant material
- Never run over the plant material that is spread
- Spread the protective straw mulch as soon as possible after spreading plant fragments

Resources, time and money

The equipment needed for plant spreading is a tractor, a manure spreader and some equipment to load plant material into the manure spreader. The use of a large manure spreader reduces the time for plant spreading. The cost for renting a standard box manure spreader can vary a lot. It is usually easy to rent one from nearby farmers. In Eastern Canada it costs around $150/day for a large size spreader. It is estimated that plant spreading can be conducted on about two hectares in one day by only one operator with the appropriate machinery (Table 9).

Table 9. Time and material required for plant spreading

	Machinery (hr./hectare)	Material ($/hectare)
Plant spreading	4	
Manure spreader		75
TOTAL	4 hours	$75

Straw Spreading

It has been proven that it is necessary to improve the growing environment of plant fragments because they face very harsh conditions once spread on bare peat surfaces. Numerous experiments conducted over the past 10 years in Eastern Canada compared the performance of plant fragments simply spread on bare peat to plant fragments in modified environments. Most results, if not all, concluded that plant fragments left on bare peat die before getting a chance to form a new plant carpet.

Many treatments aimed at improving growing conditions have been considered and tested experimentally: sprinkler irrigation, pumping water into irrigation ditches, companion (nursing) plants, windbreaks, etc. Among them, the use of a protective cover gives the best results.

The use of mulch

Mulches have long been used in agriculture to provide plant and soil protection against exposure to adverse conditions. In peatland restoration, research has repeatedly shown that **straw mulch** is one of the three key elements for success in any peatland restoration project using the present approach; the other two being **reintroduction of diaspores** and **rewetting of restoration sites.** Spreading a straw mulch is like putting a roof over plant fragments. It creates an air layer that induces cooler daytime temperature and higher relative humidity around plant fragments (Figure 17). Straw mulch also helps maintain a higher water level. These conditions allow better access to water for plant fragments and decrease the risk of desiccation. Mulches also prevent damage caused by frost heaving to establishing plants.

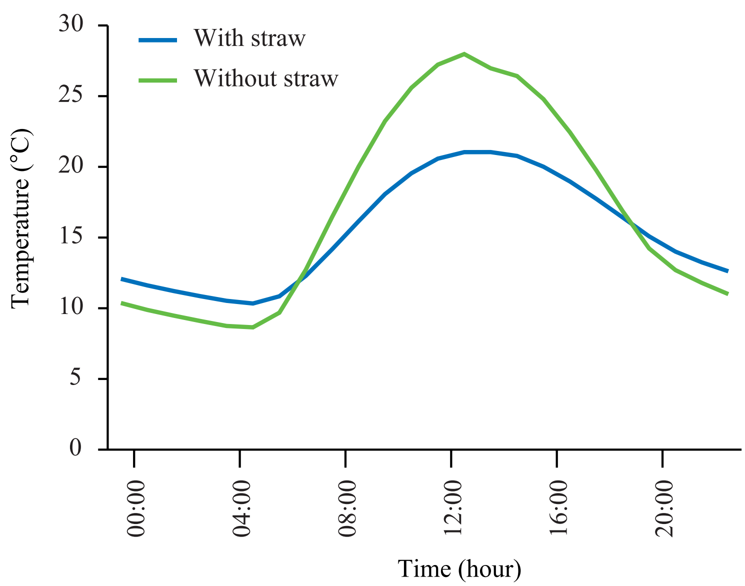


Figure 17. Graph showing surface temperature with and without straw mulch. Midday surface temperature can be almost 10°C higher without straw mulch. Straw mulch creates an air layer that induces cooler daytime temperature and higher relative humidity around plant fragments. This in turn, results in higher soil moisture and water level closer to the peat surface.

Why use straw?

In developing restoration methods, straw was compared to commercial covers or mulches such as *Curlex* and *Eromat*. For protecting plant fragments, straw is better than commercial mulches mainly because it is thicker and it is easily applied with a straw spreader. It also has the advantage of being available almost everywhere at a relatively low cost. Bales of hay can be used if straw is not available, but hay is usually more expensive and it may favour the growth of weeds because it contains more viable seeds than straw.

One important quality of straw is its ability to create an air layer that stays fresh and more humid. This is because straw is made of long and more or less rigid stems that criss-cross together when they are spread, and form a sort of mattress with plenty of air space. After rain events, the straw mattress becomes stable and can resist strong wind without being blown away. Beware of old straw bales: wet or rotten straw does not have the same structure as fresh straw and it collapses into flat layers instead of creating a fluffy mattress. The same way, if straw is chopped too small, it will collapse and stay flat instead of creating a protective air layer and light may not pass through.

How much straw?

It is very important to apply the right quantity of straw because:

- Too much straw can retard and even **impede plant establishment**
- Too little straw will not provide enough protection to establishing fragments and can cause **failure of plant establishment**
- Straw accounts for a large part of the **cost of restoration**

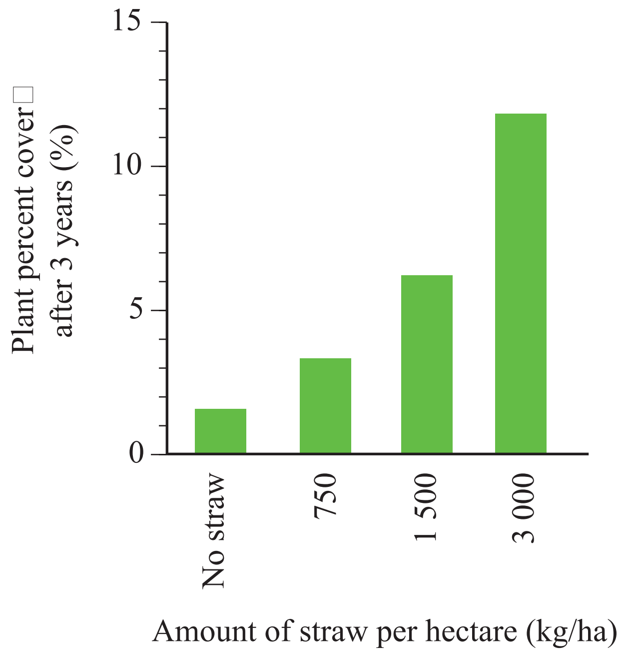


Figure 18. Diagram showing the influence of the quantity of straw on plant establishment. Not using enough straw may lead to failure of restoration.

Past experiments showed that 3 000 kg of straw per hectare is a minimum to maximize the success of plant establishment (Figure 18). Although it is difficult to associate weight and volume because of changes in the humidity of straw, this amount roughly represents 18 to 20 big round bales of a diameter of 5 ft per hectare (Table 10).

Table 10. Number of round straw bales required per hectare

Bale diameter (feet)	Number of bales per hectare	per acre
4	25 to 30	10 to 12
5	18 to 20	7 to 8

Big round bales

Using bigger straw bales decreases restoration cost. A 5 ft diameter bale has about 1.5 the volume of straw of a 4 ft diameter bale. This means that handling time can be reduced by 25 to 33 % by using 5 ft diameter bales instead of smaller bales. Handling costs are expensive given that straw bales have to be carried to the peat bog by trucks, unloaded, loaded in trailers or wagons and brought to the restoration site, unloaded, loaded into the straw spreader and spread on fields. For example, it takes 1 to 2 minutes to spread one bale but it may take up to 10 minutes to go back and forth loading the bales.

Visually, a good straw mulch must be thick enough to create an air layer, but allows some light to pass through and reach plant fragments. It should be possible to see the ground or the plant fragments in some places. It is not known whether using more straw would result in higher plant cover, but visual observations revealed that plant fragments do not survive where straw mulch is thick and compact, probably because of lack of light. It is important that the stems of the straw be well detached and overlapping, not matted together or forming chunks.

Using fresh straw is much more efficient than using straw from bales that have been left uncovered outdoors for a year or two. Fresh dry straw spreads more easily and gives a regular cover. Old bales have an outside layer of a few centimetres that has been through many dry and wet phases. Straw from this layer is more or less rotten and often forms chunks. It takes more straw from old bales to achieve a good protective cover.

Spreading the straw

Straw mulch must be applied as soon as possible after the introduction of plant fragments because *Sphagnum* and other fragments dry rapidly when exposed to air. It is usually done concurrently with plant spreading. Few devices have been used so far to spread straw mulch (Table 11 and Figure 19). A sideways round bale spreader is now commonly used to apply the straw. It can apply a straw mulch sideways on a width of 10 to 15 metres. The main advantages of this machine are:

- Only one operator can do the whole work because it is self-loading
- One bale is applied in 1 to 2 minutes
- Machinery does not have to pass over plants because straw is spread sideways

Table 11. List of equipment already used for straw spreading and their efficiency

Straw cannon	**Efficient but not practical.** This device, made to spread straw mulch on roadsides, uses **square bales** and spreads nice even layers of straw. The principal disadvantage is that it has to be pulled behind a tractor and needs a wagon of straw attached to it. Also, 3 to 4 people are required to handle the bales. Straw is chopped.
Stable straw shredder	**Not efficient.** This equipment is made of a barrel that can receive one **square bale.** It is equipped with a small engine and has to be carried on a wagon. Straw is chopped.
Sideways straw spreader	This equipment uses **round bales.** It spreads straw sideways over 10 to 15 metres. It is **self-loading** and **rapid** since it spreads one bale in 1 to 2 minutes.
Vertical straw spreader	This equipment uses **round bales.** The problem with it is that the tractor has to pass over the plants and this may **cause damage.** The straw is not spread over a great distance.

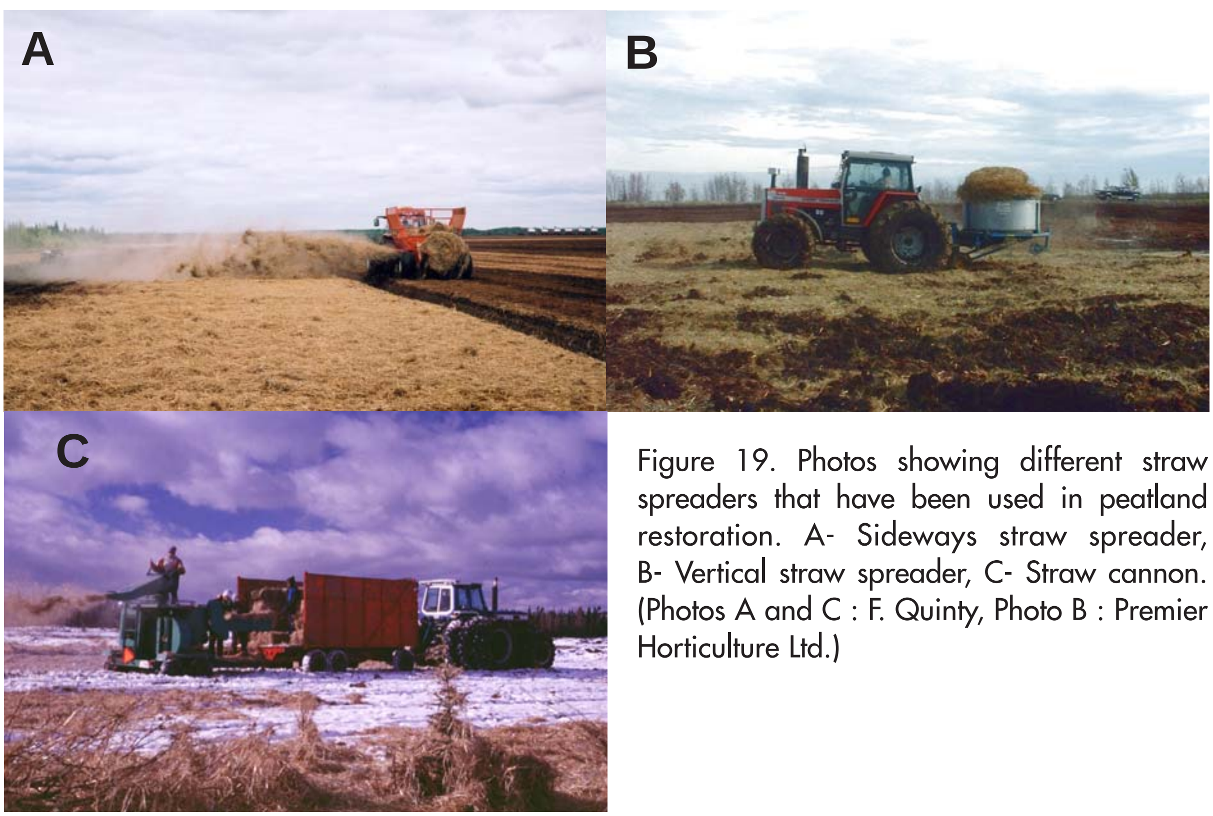


Figure 19. Photos showing different straw spreaders that have been used in peatland restoration. A- Sideways straw spreader, B- Vertical straw spreader, C- Straw cannon. (Photos A and C : F. Quinty, Photo B : Premier Horticulture Ltd.)

When spreading straw mulch, the operator must avoid passing over the plants that were just reintroduced. Doing so usually mixes fragments with peat and decreases plant survival and establishment. One has to keep in mind that these small moss fragments need careful handling. A practical way to proceed is to spread the plants on half of the field (15 m) lengthwise and then apply the protective straw mulch. For the second half, proceed as usual with the manure spreader to reintroduce the plant fragments and then spread straw mulch from the adjacent field on the other side of the ditch to cover the plant material.

Spreading straw under windy conditions may be a tricky operation. Spreading against strong wind is almost impossible. On the other hand, the wind can greatly help spreading straw mulch and save time if it blows from the right direction.

- Apply an even layer of straw as soon as possible after spreading plant fragments
- Apply the right quantity of straw: too little straw will not give enough protection to the plants and will reduce the chance of success. Too much straw will not let enough light through for plant growth
- Avoid using equipment that chops straw in small parts because it will collapse instead of forming a fluffy mattress over plants
- Large bales reduce the cost of restoration
- Using fresh straw reduces the amount of straw needed and the cost of restoration

Resources, time and money

The time and resources needed to spread straw mulch were estimated when using a sideways straw spreader (Table 12). Sideways spreaders are frequently used by farmers in the prairies but they are less common in the eastern regions. The time required for spreading straw mulch was estimated for one operator. Most of this time is spent transporting straw bales and going back and forth with the straw spreader.

Since straw spreading takes more time than plant spreading, it is recommended to have more resources allocated to straw spreading in order to follow the same pace as plant spreading and reduce the cost of renting the equipment.

The cost of straw was estimated at $18/bale for 4' in diameter round bales delivered at the restoration site. In case the restoration site has no access, extra cost for straw transportation should be added. This is roughly equivalent to $1.50/square bale. This number is likely to vary from region to region and from year to year. Advance planning increases the chance of finding cheaper straw through arrangements with local farmers.

Table 12. Time and material required for straw spreading

	Machinery (hr./hectare)	Material ($/hectare)
Straw spreading	7	0
Straw spreader rental		100
Straw		540
TOTAL	7 hours	$640

Fertilization

Fertilization facilitates plant establishment. In restoration experiments, it was shown that phosphorus fertilization increases the development and spreading of mosses like Hair-cap moss (*Polytrichum*; see Key to identification of collection sites). These mosses, in turn, provide suitable conditions for the establishment and growth of *Sphagnum* fragments. Rapid colonization of bare peat substrate by Hair-cap moss also helps decrease or prevent damage caused by erosion and frost heaving phenomena. In addition to favouring mosses, phosphorus application may help the germination and establishment of several vascular plant species typical of peatlands. Phosphorus fertilization is a major factor in contributing to the success of plant establishment.

Phosphate

There are many fertilizers containing a phosphorus component, but only a few can be used in peatland restoration. It is recommended to use fertilizers that bring mostly phosphorus to plants. Nitrogen fertilization is not needed in peatland restoration because bare peat surfaces already contain enough nitrogen to ensure plant growth. Fertilizers rich in calcium must be discarded because high calcium concentrations are detrimental to *Sphagnum* growth and they can favour invasion by undesirable species.

Among fertilizers that contain mainly phosphorus, granulated phosphate rock is often used because it allows good distribution of phosphorus and it is a slow release fertilizer. Phosphate rock contains 25 % phosphate and approximately half of it is readily available to the plants and the other half becomes available later. Phosphate rock also provides small quantities of calcium and oligo-elements. More concentrated fertilizers such as superphosphate are not recommended because they have to be applied in such a small quantity that they cannot be spread uniformly.

Despite its slightly higher cost, granulated phosphate rock fertilizer is preferred to powdery phosphate rock because fine particles are easily blown away, even when there is hardly any wind. This reduces the efficiency of fertilization operations and can cause contamination of neighbouring watercourses and peat fields that are still in production.

Undesirable species

A potential drawback of fertilization is that it can favour the growth of non-peatland plant species to some extent. Species that will thrive from phosphate fertilization vary according to the local seed availability. Fireweeds and agricultural weeds whose seeds come with the straw are commonly found on fertilized restoration sites. In certain cases, trees such as birch and poplar may also be seen. Although little long-term data are available so far, it is expected that over time non-peatland species will decline as phosphate becomes less available and competition from peatland species will increase. Phosphate fertilization has already been applied on a number of sites in Eastern Canada and benefits largely exceed potential problems.

Dosage

The recommended dose of phosphate rock is 150 kg/hectare (60 kg per acre). For example, 180 kg of fertilizer is needed for a field of 30 m x 400 m (100' x 1 200'). As phosphate rock contains only 13 % of available phosphate (P_2O_5), **this dose represents 19.5 kg of phosphate per hectare.**

Dosage and time of application are now being tested experimentally in order to maximize the positive effect of fertilization while minimizing potential impacts. New developments are likely to occur in the near future.

Application

The fertilizer is commonly applied after the straw mulch. A simple conic spreader that fits on the three-point hitch of a tractor is enough because only small quantities of fertilizer are used (Figure 20). It was used successfully at many sites. Similar electric or wheel powered conic spreaders exist that can be mounted on or pulled behind all-terrain vehicles. A wheel powered model was tried at the Bois-des-Bel peat bog, and it did not give satisfying results in terms of dispersion of fertilizer because it bounced on the ground's uneven surface.

The spreader has to be calibrated before the fertilizer application in order to spread the right dose. It may happen that spreaders cannot be calibrated precisely. A simple way to calibrate a spreader is to add known weights of fertilizer and put marks for quantities required for a given surface. It is also necessary to determine the width covered by the spreader. It is best estimated visually. With a conic spreader mounted on a tractor, two passes per peat field of 30 m in width are usually enough.

Running over areas where straw mulch has already been applied does not cause as much damage as passing over reintroduced plant material without straw. The flotation of a tractor is improved by the presence of the straw mulch and it will not leave tracks, unless a site is very wet and soft. This is especially true when the spreader is fixed to a tractor equipped with flotation tires because the weight of fertilizer is then distributed to the tractor itself.

Figure 20: Fertilizer being spread with a standard conic spreader. (Photo: F. Quinty)

It is recommended to fertilize before or when plants need it most, which is during the period when most of their growth takes place. It is also important to fertilize when it causes the least environmental damage to the water bodies of adjacent areas. Fertilizer is thus applied only between late spring, once snowmelt water has receded and the ground is dry enough to support the machinery and mid-August. If fertilizer is applied later in the season it will be of little use to the plants and it risks being washed away with excess water from precipitation in the fall or snowmelt in the spring.

Impact on the environment

Little is known on the effects of fertilizing for restoration but it is considered that risks of impacts are low for the following reasons:

- Low doses are applied
- Rock phosphate is a slow release fertilizer
- Phosphorus has a low mobility and it is retained by peat
- Drainage is blocked

However, phosphorus can have important negative effects when it reaches watercourses. It is known that even small quantities of phosphate fertilizer favour growth of algae and aquatic vegetation contributing to the eutrophication of streams and lakes. Hence, as with any product, safety measures have to be taken when using phosphate fertilizer:

- Manipulate carefully especially when close to watercourses and avoid spill
- Respect the recommended dosage, even if it seems low. Adding more fertilizer does not necessarily mean better results — the opposite may be true as too much phosphate may favour a proliferation of non-peatland species
- Make sure water cannot escape restoration sites by blocking ditches before, or as soon as possible, after fertilizer application
- Keep surplus in a dry place for future use in restoration

- A dose of 150 kg of phosphate rock per hectare (60 kg/acre) is recommended to accelerate moss carpet establishment. This represents 19.5 kg of phosphate (P_2O_5) per hectare
- Carefully calibrate the fertilizer spreader
- Use granulated fertilizer instead of powdery fertilizer
- Manipulate fertilizer carefully to avoid contamination of peat fields and watercourses

Resources, time and money

Fertilization requires little time and resources (Table 13). One operator with a tractor and a fertilizer spreader can fertilize about two hectares in one hour. Small conic fertilizer spreaders can be borrowed from farmers at low cost if any. Even if they are not used often nowadays many farmers still have them in their backyard.

Phosphate rock is a natural fertilizer that fertilizer dealers do not usually keep in stock, but it is possible to order some at a cost of about $500/ton for granulated rock. Non-granulated ground phosphate rock is less expensive but it is more difficult to manipulate and it can cause environmental impacts and contamination of adjacent peat fields.

Table 13. Time and material required for fertilization

	Machinery (hr./hectare)	Material ($/hectare)
Fertilizer spreading	0.5	0
Fertilizer spreader rental		10
Fertilizer		75
TOTAL	0.5 hour	$85

Blocking drainage

Hydrology is a key factor in peatlands, and restoration of an appropriate hydrological regime is a major goal along with the re-establishment of a moss carpet in peatland restoration. Peat harvesting greatly modifies the natural water regime because it requires an efficient drainage network that can evacuate large quantities of water out of a peat bog in a short time. Aerobic conditions during peat extraction activities cause changes in the peat structure resulting in low water storage capacity. The objective of blocking drainage is to keep water within the restoration site and also improve the distribution of water.

Procedures for blocking ditches

Blocking ditches looks like an easy operation, but it deserves particular attention. The most important quality of a blockage is its imperviousness. Some precautions must be taken to obtain efficient blockages:

- **Use wet peat**. Only pushing surface peat into a ditch and running over it with a tractor often leads to leaking or breakage of blockage after one or two years. Instead, scrape and remove the dry surface peat and use the underneath, wet, more decomposed peat. Scraped off peat can then be used to fill the depression.
- **Clean both sides of ditches of vegetation**. Fresh wet surfaces provide better contact and sealing (Figure 21).
- **Compact the blockage** thoroughly with heavy machinery.
- **Blockages should be 2 to 3 m wide** to better resist erosion and allow the passage of machinery.
- **Blockages should be higher than the surrounding surface** by about 30 cm and extend 1 to 2 m on each side of the ditches.
- **Do not reach the mineral substrate** because it can lead to loss of water and contaminate the restoration site with mineral soil and favour colonization of non-peatland species.

The ditch blocking procedure should be used when constructing berms across ditches. Remember that peat is only pushed in the ditches when constructing the berms and this non-compacted, loose surface peat does not stop the flow of water. There should also be more blockages than berms along a slope to favour better water distribution. If, for some reason, no berm is built, ditches should be blocked every 75 metres or closer in the case of a steep slope.

Loss of water

When a porous mineral layer like sand is reached, it can lead to a drastic loss of water. Coating the bottom of the ditch with well-decomposed peat may help, but it has never been tested experimentally in peatland restoration practices of Northeastern America.

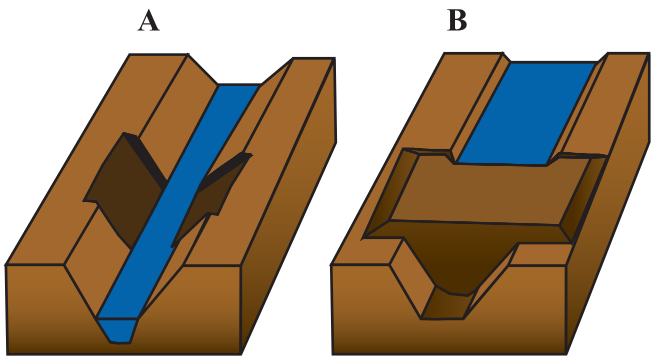


Figure 21. Diagram illustrating how to block drainage ditches. The first step is to refresh the sides of the ditch and clear any vegetation to insure a better contact and sealing (A). The ditch is filled with peat 2 to 3 metres wide and the peat is compacted (B).

The best recommended equipment to block ditches are a backhoe or a clamshell, especially if the sides of ditches have to be cleared of "weedy" vegetation. They can also collect wet peat from deeper layers. Moreover, they do not damage large surfaces if ditches are blocked after the plant material and straw have been spread. By comparison, blocking ditches by pushing peat at the end of restoration operations, will damage large surfaces around blockages. To avoid this situation, the material to be used for blocking may be piled up at blocking sites when preparing surfaces, although it is better if it stays wet.

Timing

The right timing for blocking ditches depends on the risk that the restoration site will rewet to the point that working with machinery will become impossible before the end of operations. Water comes either from adjacent areas or precipitation. Past experiences show that the water level can rise surprisingly fast after blocking ditches especially for sites that are bordered by a natural zone that is not affected by drainage. In such cases, it is suggested to block ditches only when the other operations are finished. Although it is recommended not to run over the site after plant fragments have been spread, simply blocking drainage does not cause a lot of damage. Straw mulch forms a buffer that limits this impact. Blocking of drainage itself may affect 20 to 30 square metres around each blockage; that represents a relatively small area given the usual size of restoration sites that is measured in hectares (1 ha = 10 000 m^2). In the case of large sloping restoration sites, it is recommended to start restoration work upslope. Working this way, blocking ditches of the upper section will not flood the next section downslope.

For sites where the main source of water is rain, ditches can be blocked at the beginning if one judges that operations can be conducted before the ground becomes too soft. Besides the risk of sinking machinery, working on the soft ground has a negative effect on plant establishment because of the creation of ruts by machinery and the risk of plant fragments being mixed and buried with peat.

- Clean both sides of ditches
- Fill ditches 2 to 3 metres wide with wet peat from deep layers, and compact it
- Never reach the mineral substrate

Resources, time and money

Blocking drainage does not require lots of time and resources (Table 14). It is estimated that one operator with the right equipment can block drainage for one hectare in one hour. For example, as one hectare is a common size for peat fields (30 m x 300 m), this represents blocking one ditch at a few locations along one field. Generally, flat sites need less blocking than sloping fields.

Table 14. Time and material required for blocking drainage

	Machinery (hr./hectare)	Material ($/hectare)
Blocking drainage	1	No specific material required
TOTAL	1 hour	$0

Pool creation

Bog pools represent an interesting feature of peat bogs in coastal and maritime regions. Not all sites have pools, but some peatlands have hundreds of them. Pools are important because they support a wide variety of organisms that greatly contribute to the biological richness of peatlands. Many plant and insect species are found only in or around bog pools and nowhere else in peatlands. In fact, peatlands with pools have a much greater biodiversity than peatlands without pools. Thus, the creation of pools is strongly encouraged because it can increase the value of a restored peat bog, especially if the presence of pools has been seriously lowered regionally.

There are several examples of creating lakes in depleted peatlands in Europe, but there are very few attempts at creating real bog pools. The restoration of the Bois-des-Bel experimental site in 1999 included the creation of eight pools. These pools were created following simple rules. Since little is known about pool creation, these are presented as informal and in progress recommendations:

- **Size and shape:** It is suggested to create pools about 75 –150 m^2 (Figure 22). This represents a minimum range of size to be useful for wildlife such as birds during migration. At Bois-des-Bel, the newly created pools were 6.5 x 12 m (78 m^2), designed in a rectangular shape to facilitate the work with an excavator.
- **Depth:** Pools must have a depth that allows the presence of permanent standing water all summer. It should be between 1 and 2 metres. It is also important not to reach the mineral substrate. Meeting these conditions will help find the best location for pools.
- **Slopes:** The creation of a gentle slope on one side and an abrupt slope on the opposite side should help increase the diversity. It is also the easiest way to create pools with an excavator.
- **Location:** The location of pools is dictated by the combination of two factors: the possibility of having permanent water and the need to have 2 metres of peat to avoid reaching the mineral substrate. Digging pools at the end of open ditches is not recommended because they might fill up with sediments.
- **Emergent structures:** The presence of some sort of structure in and out of the water is important for the establishment of many species. A simple way to create such structure is by leaving tree stumps with branches across pools.

The pools of the Bois-des-Bel peat bog were dug out with a small excavator. The disposed peat was spread out all around the pools except on the upper side to allow surface runoff water to feed them. Peat could also have been used to build berms.

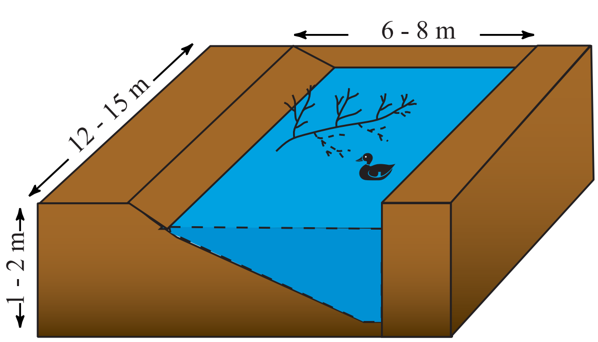


Figure 22: Diagram illustrating the ideal shape of a pool, with a steep slope on one side and a gentle slope on the opposite side.

It is important to keep in mind that pools are aquatic habitats that do not need to be beautiful to meet fauna requirements. The approach used at Bois-des-Bel appears to be successful since many amphibians, insects and micro-organisms had settled back into pools after two years. They are also visited by migrating birds, ducks, geese and small and large mammals. Vegetation does not return as fast. At Bois-des-Bel, shrubs and other plant species were transplanted successfully in half of the pools, on the gentle slope side.

- The creation of pools is strongly encouraged because it can increase biodiversity and ecological value of restoration sites
- To create pools, it is recommended to follow the same simple rules as for the Bois-des-Bel peat bog

Resources, time and money

Estimation of the time and resources required for the creation of pools can only be based on the experience of the Bois-des-Bel peat bog. At this site it took one hour per pool with a small excavator.

Monitoring

Monitoring is a necessary step in the restoration process because it is the only way to assess the success or failure of restoration and to determine if the objectives are met. It is best done by collecting data on measurable elements at different periods of time to evaluate the evolution of a restoration site. Although objectives of peatland restoration are defined mainly in terms of hydrology and vegetation in the short term, monitoring focuses on vegetation. Plant establishment reflects the general conditions of a site because plants depend on factors like hydrology and nutrients for their survival and growth. Nonetheless, collecting data on hydrology or other elements is very helpful for the interpretation of vegetation data and should not be ruled out.

Over the long term, monitoring can improve peatland restoration methods by contributing to a national database that can help identify factors responsible for the success or failure of restoration by comparing different sites. To do so, consistent and standard information on site conditions and restoration procedures must be collected. It is important to use the same monitoring method to ensure that data from different sites can be compared. Consistency is the key for reliable monitoring data and the principal cause of irregularity is the human factor. It is paramount to allow the most appropriate resources for monitoring. This means having the same people doing it year after year and that they be trained to identify plant species and properly evaluate the percent cover of plants in plots. It is often worthwhile to hire a specialist to do the monitoring. This part presents the methodology used by the PERG to monitor plant establishment in experimental sites. It also shows how to measure the water table level and peat water content.

Vegetation

Specific objectives regarding vegetation in peatland restoration are twofold: 1) rapid establishment of a peat bog vegetation cover and 2) presence, and eventually complete coverage of a moss carpet composed of *Sphagnum* species. To determine if objectives are reached, the most important variables to consider are plant species, the proportion of the ground they cover and their evolution through time. The recommended procedure describes vegetation at three levels: the site level, the permanent plot level and the ground level. These levels are complementary and allow a good assessment of the vegetation of an entire site.

The vegetation should be monitored at different time periods after the implementation of restoration procedures to determine if the new plant cover evolves toward a peat bog plant community or not. Experience shows that it is useless to collect data one growing season after restoration work. Monitoring should start on the second year and be repeated after the third and the fifth growing seasons.

Site level

At the site level, the procedure consists of a general description of the entire site. Examples of the features that should be noted are:

- Uniformity of the site
- Presence and location of non-peatland species

- Presence and location of trees
- Dominant vegetation feature
- Inundation
- Perturbation (all-terrain vehicle tracks, frost heaving, etc.)

Remember that one can never take too many notes. Any comments on the local meteorological conditions may help interpret the results because they influence the development and appearance of vegetation. Photos providing an overall view of a site should be taken prior to restoration and once a year following restoration procedures.

Permanent plot level

The permanent plot level gives a closer look at the vegetation cover for a given sector of a restoration site. To provide a representative image of the evolution of a whole restoration site, a number of permanent plots must be installed at appropriate locations. This number depends on the size and diversity of a site: large and more variable sites need more permanent plots. For instance, a flat homogenous restoration site may require a few scattered permanent plots located strategically: upslope, downslope, near the margin and in the middle of the site. In the case of a more heterogeneous restoration site, for example a site with steep complex slopes or bordered by agricultural fields on one side and forest on the other sides, all habitats (wet, dry, colonized by trees, etc.) that occupy a significant surface should be represented by permanent plots. Larger habitats could have more plots while very small ones may not have any. The higher the number of permanent plots the better the monitoring results. A small area may also be left un-restored and be monitored with a permanent plot to serve as a comparison site to better assess the result of restoration procedures.

A permanent plot consists of an area of 5 m x 5 m delimited by posts in which the vegetation is described. The representativeness of a permanent plot of the sector it represents must be carefully evaluated. The importance of each vegetation strata is evaluated according to the percentage of the ground they cover expressed into classes and their height is noted (Figure 23). Other features such as bare peat, straw mulch and any unusual element are also noted. All plant species must be identified and their percent cover estimated visually except for mosses that are pooled together at this level.

Vegetation strata

The vegetation is often divided into strata based on the height of plants to facilitate its description. The recommended monitoring method uses the following strata:

- *Tree and shrubs strata: composed of trees and non-ericaceous shrubs*
- *Ericaceous strata: composed of ericaceous species*
- *Grass strata: composed of non-woody species*
- *Moss strata: composed of mosses (including Sphagnum) and lichens*

The date of the survey, the surveyor's name, site name and the location of the plot in the bog should be recorded. Ideally, a sketch of the permanent plot is drawn and photos are taken. Examples of forms that can be used to describe the vegetation are presented in Appendix C. These forms greatly facilitate the work and their use is encouraged to help standardize data.

It is important not to walk into permanent plots because the trampling can disturb the plants and damage the vegetation cover.

Percent cover

For non-familiar people, estimating the percentage of ground covered by plants seems like an esoteric and subjective method. However, past studies show that this method is the most accurate. It has the advantage of being simple and not needing specialized apparatus. Moreover, one becomes used to estimating percent cover and can do a large number of quadrats in one day. In the case of many people working together, it is recommended that they standardize among themselves at first by comparing their estimate for the same series of plots or quadrats. Diagrams of known percent cover, like the ones shown in Figure 23, can also be used to calibrate. Everyone comes to develop his or her own trick. For example, five cents and two dollar coins represent percent cover of 0,5 % and 1 % respectively for a 25 cm x 25 cm quadrat.

Lower percentages are easier to differentiate while higher percentages are more difficult. For example, it is easy to differentiate between 1 % and 5 % of cover, but covers of 50 % and 60 % look alike. Percent cover can also be divided into classes.

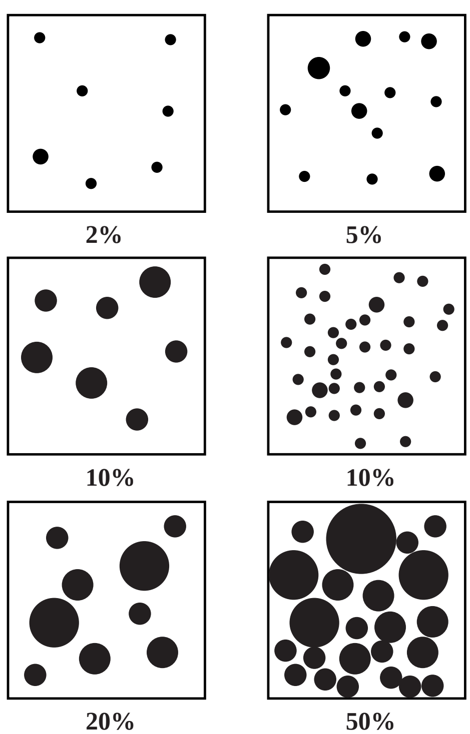


Figure 23. Diagrams of known percent cover.

Ground level

Site and permanent plot descriptions do not allow adequate estimation of the moss carpet. Given the major role of *Sphagnum* and other moss species in peatland restoration, it is important to get a precise estimate of the percent cover and the composition of the moss carpet.

The recommended procedure consists of estimating the percent cover of moss species, liverworts (Hepaticae) and lichens in a series of 20 quadrats of 25 cm x 25 cm located inside permanent plots (Figure 24). Five quadrats are equally distributed on each side of the plot at 50 cm from its margin. If the centre part of the permanent plot differs substantially from the margin, it is appropriate to place quadrats along lines across the plot. Commonly, a frame of the appropriate dimension is used (Figure 25). The straw mulch is removed carefully and the percent cover of mosses and lichens is estimated. It is recommended to evaluate separately the total cover of the vegetation instead of adding the cover of each species. Dead plant parts are not considered as living plants but their presence should be

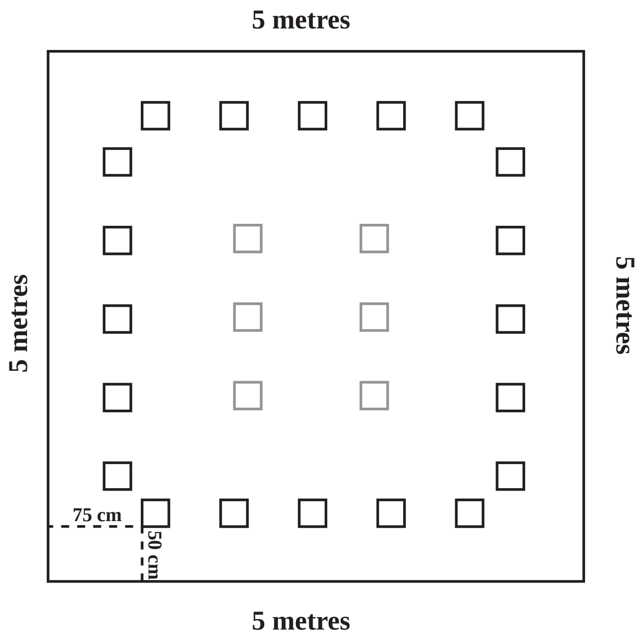


Figure 24. Distribution of vegetation quadrats in a permanent plot. Quadrats in grey are used only when the margin of the plot is not representative of the centre.

Figure 25. Example of a 25 cm x 25 cm frame used to estimate the vegetation in quadrats at the ground level. The straw has been carefully moved and it will be put back after the determination of percent covers. (Photo: F. Quinty)

noted. The straw is put back after the evaluation, and the frame is moved about 75 cm away and so on. An example of forms used for these surveys is given in Appendix C.

Hydrology

An important objective of peatland restoration is the rise and stabilization of the water table close to the peat surface and it can be easily measured using a variety of methods. In the short term, one of the most important factors is the strength by which water is retained by peat particles, or the water tension. When water is bound too strongly to peat particles, it is not available for *Sphagnum*. However, this variable can only be measured with a special apparatus. To simplify monitoring, it is more practical to measure the peat water content that gives a general assessment of the quantity of water that is present in the upper layers of peat.

Water table

The water table can be measured by different methods and for the purpose of peatland restoration it is recommended to use water wells. Water wells are made of PVC pipes, usually 2.5 cm (1 inch) in diameter and about 1 metre long. Pipes must have holes or slots all along except for 20 to 30 cm at the top that will not be into the peat. It is suggested that the bottom perforated section be covered with something that will let water through but not peat (nylons do a great job). The screen or nylon can be held in place and protected from tearing with tape at the bottom and at the top of the perforated section. Pipes are then pushed down into the peat to the top of the holes or until the bottom of the peat deposit is reached. If the peat is dry and stiff, it is better to make a hole with a rod or any instrument prior to pushing down a pipe, but it must be tight in the hole. After one day, the water table in the pipe becomes in equilibrium with the groundwater around it and measurements can be taken.

Various instruments exist for reading the water table level in water wells. They can be bought from scientific instrument dealers or be homemade. A simple way to measure is by pushing down a tube into a pipe and blowing at the same time. When one hears bubbles, the water level is reached, and the length of the tube in the pipe is measured. The water table depth is calculated as follows:

Water table level = Length of the tube into the pipe – Above ground height of the pipe

When a sample point is flooded at the time of measuring the water table, the depth of water should be taken. The more often the water table is read, the better the dataset. Usually, measurements are made once a week during the frost free season. The presence of ice in the pipe should be noted. A frozen layer may well be present until June and July in some cases. An example of a form that can be used to note water table measurements is presented in Appendix C.

Water wells can be installed the year prior to the restoration of a site to characterize the pre-restoration water table. These data will serve as a reference to evaluate the change of water table level resulting from restoration procedures. Water wells can be pulled out during restoration operations and put back afterwards at the same location.

Peat water content

The peat water content is measured by weighing peat samples in their original state and after drying. It is calculated as follows:

$$\frac{\text{Wet weight} - \text{Dry weight}}{\text{Dry weight}} = \text{Peat water content}$$

The result represents the percentage of water that was present in the peat when it was collected and it is also called the gravimetric water content.

The procedure consists of collecting a volume of about 250 ml in the top 5 cm of peat at three locations around each permanent plot or sample point. A cup or any other container can be used to collect the peat. These three sub-samples are put together into an identified sealed bag to form a composite sample representative of the permanent plot. All samples from the same site must be collected the same day, preferably during a dry period.

The wet weight is obtained by weighing peat samples in their original state. It is recommended to weigh the samples as soon as possible after their collection for the wet weight. After that, they can be stored in a refrigerator until they are treated. To measure the dry weight, peat samples must be dried for 24 hours at 105°C. They are weighed again as soon as they come out of the oven.

PH

It is suggested to measure the pH because it is an important element for plants, and especially for *Sphagnum* species that are very sensitive to the level of acidity. Although pH may have been measured in the planning phase of restoration, it is helpful to make additional measurements in permanent plots because restoration procedures, such as surface preparation, may cause some change. The pH data contribute to the interpretation of vegetation data. There are a wide variety of pH meters that can be used in the field or in a lab.

Site conditions and restoration procedures

The monitoring of hydrology and vegetation establishment after restoration work provides data that should show if objectives are to be met, or in other words, if a site really is in the process of being restored. However, these data may not give clear answers and other information is necessary to interpret the results of monitoring. The description of site conditions prior to restoration work, as it is recommended to do in the planning section, as well as an account of the procedures that were applied to restore a site, should become part of the monitoring and be incorporated into a database.

Forms that can be filled in easily to describe site conditions and restoration procedures are presented in Appendix C.

- Monitoring of the vegetation should be conducted two, three, and five growing seasons after restoration work
- Evaluate the general state and describe the vegetation at the site level
- Identify homogenous sectors and install a number of permanent plots representative of their size
- Identify plant species and their cover at the permanent plot and ground levels

Troubleshooting

Research on peatland restoration only started in 1993. At that time there was only one problem: restoring harvested peatlands. The development of the Canadian approach to restoration provided a method to establish peat bog plant species and raise the water table, thus starting a process leading to restoration. But new problems arose: what gave interesting results on a few square metres had to be scaled up and mechanized. Solutions to these problems have been found and now restoration procedures are being conducted at a large scale. Difficulties that now have to be addressed occur during the restoration process, after restoration procedures have been applied.

The scaling up of restoration techniques is at its beginning, and few large-scale sites have been restored so far (see Appendix A). Consequently, few problems have yet arisen. The research of solutions is only beginning, and what is proposed in this section should be considered as informal because it has not been tested experimentally.

Invasive plant species

Restoration sites can be colonized rapidly by a large population of one or few species. Because dominant vascular plant species establishment differs from what is expected, that is a moss carpet, these invasions appear to be a major problem. However, the two most common invasive species, cottongrass and birch, do not necessarily represent such a problem.

- **Cottongrass:** Cottongrass, especially the tussock forming species (*Eriophorum vaginatum*) is an aggressive colonizer of bare peat surfaces. It can spread spontaneously or be introduced by restoration procedures. Recent studies show that cottongrass may have a positive effect on plant establishment because it creates sheltered sites where the microclimate allows better survival and growth of mosses. When it spreads following restoration work, no measure should be taken to remove it. When cottongrass is already present before restoration work, tussocks can be left only if they do not cover a substantial portion of a site. Too dense tussocks should be removed because a large amount of introduced plant fragments will never reach the ground and they will dry and die. In many cases, cottongrass will be partly removed during surface preparation. It is not known if cottongrass seeds can contaminate the peat on currently harvested fields, but studies show that massive seed production by cottongrass only last a few years.

- **Birch:** Birch is another species that can rapidly colonize bare peat surfaces or appear in colonies after restoration work. Very little is known on the effect of birch on the restoration process. It has been observed that birch seedlings can form large colonies but they rarely grow to mature trees if the site is well rewetted. A negative effect may be the production of litter that could bring nutrients and favour non-peatland species. Also, by pumping water through evapotranspiration, small birch trees may contribute to lowering the water table.

Low plant establishment

Low plant establishment is a common problem and it can be caused by different factors.

- **Time:** One factor that has to be considered for plant establishment is the recovery time. One is often deceived by seeing little recolonization of a site the year following restoration work. Experience shows that one year is too short a period for proper evaluation and that any monitoring of plant establishment must be done only after two growing seasons.

- **Quality of plant material:** As stated in this *Guide*, the quality of plant material is a major factor responsible for the success of plant establishment (see Plant collection). An experiment comparing plant material coming from two sites clearly shows that the choice of the collection sites becomes very important and that the right plant communities must be selected. The equipment used and the depth of collection also influence the quality of plant material.

- **Frost heaving:** Frost heaving can cause a lot of damage by degrading newly established vegetation carpet (see Planning the restoration). Frost heaving rarely occurs during the first two years after restoration work because straw mulch limits its occurrence by changing the microclimate. Frost heaving usually takes place once straw mulch no longer provides protection against climate. Rapid colonization of ground by mosses favoured by fertilization is the best way to prevent damage by frost heaving. Adding straw mulch a second time, or after two years of the initial work has been tried, but it is not a practical solution because it is not always possible to go back to a site with machinery after rewetting.

- **Straw mulch:** In all experiments comparing straw to other treatments (irrigation, other protective devices, etc.), it always turned out that straw had the greater positive effect on plant establishment. The need for straw is imperative. However, it is important to apply straw as soon as possible after spreading the plants and to apply the right quantity of straw (see Straw spreading). Not following these rules may result in low plant establishment.

- **Plant disturbance:** Plant disturbance by passage of machinery often reduces plant establishment locally. It may even create patches of bare peat that are slowly colonized by plants.

Water

An adequate supply of water is necessary for the return of *Sphagnum* species, but managing water is not an easy task, especially in a climate characterized by cold winter. Thus, problems are often associated with an excess or lack of water.

- **Inundation:** Recent studies suggest that flooding for a short period is not harmful to mosses and may in fact help their establishment. When it lasts for a long period of time (> 1 month) or when water is too deep (> 30 cm), flooding becomes a problem because it may cause physiological or physical perturbation of plant fragments. Inundation over large areas allows wave action that can cause erosion and the breakup of berms as well as displace straw mulch and plants. If such situations are likely to occur periodically, it is necessary to do something to achieve a better water distribution (see Surface preparation). Construction of berms or other management solutions adapted to site conditions must be applied. However, once a new plant carpet has formed, these problems are less likely to occur.

- **Breakage of berms**: Berms made of peat often break under the pressure of large masses of water and wave action. They can also be eroded by surface runoff, sometimes following heavy rainfalls. Unless more efforts are made in surface preparation at the beginning, the only solution to this problem is to repair them (see Surface preparation). Other water management strategies adapted to site conditions should be considered if the problem is recurrent.

- **Drought**: Drought and low water levels are common in restoration sites because of the large water deficit in summer associated with the North American climate. This situation can be counteracted by stocking more water into restoration sites, by reducing water loss or by adding water to a site. Stocking more water means building berms that will limit water loss at snowmelt and prevent extensive inundation (see Surface preparation). The presence of a straw mulch substantially reduces water loss, but it is also essential that berms and blockage are impervious (see Blocking drainage). Finally, water can be added to a site provided that its chemical characteristics are adequate and that it can be distributed over large areas.

Wind

Most harvested peat bogs offer large open areas with nothing to slow down wind, especially in the coastal bogs of New Brunswick. Many people worried about the use of straw mulch because it could be blown away on fields currently harvested and contaminate the peat. Surprisingly, very few problems of windblown straw mulch have occurred so far, except for very localized displacement of straw. It seems that after straw has been exposed to a rainfall event, it settles down and straw pieces stick together. At one site, straw mulch was covered by a degradable net at more exposed places, but there was no difference between sections covered by the net and sections without the net.

Cost of restoration

It is difficult to precisely calculate the cost of restoring a milled peat bog because it is influenced by many factors. The operating costs for tractor and equipement as well as the cost of manpower vary for each company and may even vary for each site. Hence, these costs are expressed in terms of the hours required for implementing procedures (Table 15). Site-specific conditions cause the greatest variation of the cost because they dictate the different options that need to be applied. Actually, surface preparation and plant collection are the two steps that are the most likely to vary and have an effect on the cost of restoration. Surface preparation options are numerous and must fit site characteristics. Some sites require few interventions while others necessitate more work, as in the case of dome-shaped fields combined with complex slopes. Distance and access to an appropriate collection site have a direct impact on the cost of restoration, because transportation is time consuming and poor access can cause problems such as the sinking of machinery.

Once a site is prepared and plant material is piled up close to the fields, very few problems can arise. The time required for plant and straw spreading, fertilization and blocking drainage varies little. One exception is the time for straw spreading, which can be longer due to the handling of straw bales.

The total cost for restoration is estimated at 25 hours of machinery and operator time and at $800 per hectare (Table 15). It is important to note that the time required for each operation was estimated based on large-scale experiments and trials conducted in Québec and New Brunswick. Numbers represent averages, so the real cost can be either lower or higher than that presented. Numbers in money are expressed in Canadian dollars and they reflect the cost for 2002. The cost of renting machinery is based on the rental price of $150 and $200 per day for a manure spreader and a straw spreader respectively, and it does not include transportation if necessary. The price for the straw is based on 4' bales at $18/bale, and at 30 bales per hectare. The cost of fertilizer is estimated at $500/ton of granulated rock phosphate applied at a rate of 150 kg/hectare plus $10/hectare for rental of a fertilizer spreader.

Table 15. Summary of time, ressources and money required for peatland restoration

	Hours/hectare*	$/hectare
Surface preparation	3.5	0
Plant collection	9	0
Plant spreading	4	75
Straw spreading	7	640
Fertilization	0.5	85
Blocking drainage	1	0
TOTAL	25 hours	$800

* Hours represents the total number of hours of machinery and operator required for conducting any intervention. For example, 9 hours may correspond either to 9 hours for 1 tractor and 1 operator, or 3 hours for 3 tractor and 3 operators.

4 Other options

Under certain conditions, restoration to a *Sphagnum* dominated peatland is not possible. In the case of fully developed peat bogs, there may be no source of suitable vegetation to be collected as plant material for restoration. Sections of peat bogs, especially those located at the margin, may have adverse conditions for restoration because of too shallow peat left and influence from nearby uplands. Until recently, research on fen restoration focused on rewetting, and active fen species introduction is at its very beginning. Such sites can be restored to other types of wetland or be reclaimed to non-wetland uses. This section briefly presents an approach to restoration that is commonly used in Europe as well as an overview of agriculture and forestry reclamation options.

Flooding and water management

Germany and The Netherlands were pioneers in peatland restoration in Europe. The approach they developed focuses on rewetting and water management instead of trying to reintroduce living plants. Plant material, as it is used in Northeastern America is hardly available in these countries given the rarity of natural peatlands. Their primary goal is to stabilize the water table not less than 40 cm from the surface to provide suitable conditions for spontaneous colonization by *Sphagnum* and prevent invasion by non-peatland species.

This approach aims to counterbalance water table instability caused by the reduction in water storage capacity of the peatland due to the loss of the acrotelm. Efforts are directed at increasing the storage of water from precipitation by building berms. This often results in the creation of large basins that are flooded in winter and where the water table can drop below the surface in summer. This approach allows spontaneous recolonization by *Sphagnum* species adapted to open water (*Sphagnum cuspidatum*) in a number of sites. However, further development toward peat accumulating conditions has not yet occurred in any of them. Frequent problems are associated with wave action that breaks berms and disturbs the establishing vegetation. Invasion by non-peatland species is common and, in some cases, no colonization by vegetation occurs, thus producing large, poor, unproductive basins.

This rewetting approach was tested at a small scale with little success in Northeastern America, likely because of climatic reasons. Northeastern America and the prairie region have a much more continental climate than Western Europe, characterized by a large summer water deficit. This means that despite a positive water balance over a year, high summer evaporation rates lead to fairly dry conditions at peat surfaces that impede spontaneous establishment of *Sphagnum*. On the other hand, winter conditions do not favour this approach. The large amounts of water that are stocked as snow, become suddenly available within a short period of time, making it difficult to manage. One example of a depressed area that is permanently flooded exists in Eastern Québec, and no spontaneous colonization by peatland species has been observed.

Agriculture

Peatlands, mostly fens, have been intensively used for agriculture in Canada, especially in the southern, more intensively inhabited area. However, few post-harvested peat bogs have been used for this purpose. In general, low pH and nutrient content are negative factors in peatlands, but they have a potential for agricultural uses because peat has a high cationic exchange and water holding capacity. Appropriate cultural methods have to be implemented to grow commercial crops on peat deposits.

Cropland

Harvested peat bogs can be reclaimed to cropland provided some conditions are met and appropriate soil preparation is performed. A major prerequisite is adequate drainage conditions. The soil must have good drainage and provide a sufficient water supply to plants. Reclamation to culture on organic soil should be chosen only for sites with a substantial layer of peat because subsidence and decomposition result in a loss of about 1 cm of peat annually, and shallow peat does not provide good drainage. It is suggested that a layer of peat of less than 25 cm should be mixed with the mineral substrate. However, in many cases the mineral substrate is impervious leading to poor drainage conditions. The optimal water table for most crops is 70 to 80 cm below ground.

Soil preparation depends on the characteristics of the site and on the crop. It typically comprises liming and fertilizing. Liming is required because of the acidic conditions of peat bogs. It aims to raise the pH to a level between 5 and 7. However, the culture of small fruits like blueberry and cranberry needs low pH. Fertilization is also necessary to improve the nutrient status of peat soils. Although it must be adapted to each crop, low levels of potassium and phosphorus in peat must be compensated for as well as boron and copper that are often lacking. It is recommended to thoroughly mix lime and fertilizers with the soil because they generally have a low mobility in peat. In a first phase, fibric peat decomposes and nutrient content, pH and biological activity increase. It takes a few years before the new soil develops, stabilizes and produces commercial yields.

The production of various crops has been tested experimentally in harvested peat bogs in Canada. Experiments were principally conducted in New Brunswick and gave satisfying results with beans, Chinese cabbage, cauliflower, celery, lettuce, peas and radishes. Potatoes received special attention in a study conducted with the participation of the Peat Research and Development Centre and they produced yields comparable to commercial crops. Carrots were commercially grown for a number of years at St. Charles bog in New Brunswick. Onions, potatoes and corn were grown experimentally in a collaborative project with the PERG at the Saint-Bonaventure peat bog in southern Québec, and proved to have commercial potential.

In the study conducted at the Saint-Bonaventure peat bog, low and high bush blueberry and black chokeberry (*Aronia melanocarpa*) were planted. The site was characterized by variable peat depth and acidic conditions. Soil preparation was restricted to mounding for some blueberry plants but all plants were fertilized. A majority of blueberry plants survived but they did not establish well. Weeds rapidly colonized the site and mounding prevented mechanical weed control. Better results were obtained with black chokeberry. They showed a good growth for the first two years and fruit yield seems to be promising. The culture of lingonberry (*Vaccinium Vitis-Idaea*) was tried on small plots in New Brunswick but results were unsatisfactory.

Pasture land

Harvested peat bogs are commonly converted into pasture land in Ireland and Eastern Europe. At least two examples of this type of reclamation exist in Canada — Sugden bog, Alberta and East bog, Saskatchewan. The Sugden bog site had only shallow peat left and it was considered too dry for restoration. Fertilization along with seeding of grass species was tried experimentally recently and results look promising so far. The East bog site was simply abandoned in the late 1980s and it now serves as grazing land.

Cranberry farming

Cranberry farming received a lot of attention recently as the demand for this fruit increased significantly. Cranberries naturally grow in peat bogs and hence are well adapted to conditions found in harvested peat bogs. They have been farmed in peatlands for close to two centuries and site conditions, preparation, as well as cultural practices are already described in detail in numerous publications (see References). For the purpose of this *Guide*, an overview of site requirements and preparation is presented.

Site condition requirements for cranberry farming are:

- **Soil:** Acidic soil with a pH of 4.0 to 5.5. The soil must have good drainage in its upper layer and be impervious at about 1 to 1.5 metre below the surface. In general, a layer of 60 cm of poorly to moderately decomposed peat (von Post > 6) is adequate. The impervious layer is necessary for flooding; otherwise water would be lost through the substrate. Thus the deeper the impervious layer, the larger the quantity of water needed for flooding.

- **Water:** Sufficient supply of water represents 2 to 3 metre-hectare/hectare/year. In other terms, for each hectare in production, an equivalent surface in reservoir with 2 to 3 metres of water is needed. Water must be acidic (pH 4.5) and nutrient poor.

- **Sand:** An application of 10 cm of sand is required for cultivation on peat beds the first year and 1 to 2 cm must be added every 2 to 4 years for better rooting of cranberry vines. It is advisable that a cranberry farm be no farther than 10 km from the nearest sand pit.

- **Slope:** The fields must have a very gentle slope to facilitate flooding and drainage. It is estimated that it is not economical to level a slope greater than 2 %.

Cranberries are cultivated in basins that must be flooded at certain periods. Cranberry vines usually grow on almost flat fields bordered by a peripheral ditch about 50 cm deep and surrounded by a dike. The peripheral ditch must have an input and an output blocked by dams to allow flooding and drainage. Reservoirs are necessary to stock a large amount of water. Cranberries can be grown on peat or on sand beds. Peat beds must be covered by a layer of sand of 7 to 10 cm to favour better rooting of vines and avoidance of weeds.

It is estimated that it costs $75,000 to $100,000 per hectare to establish a cranberry production, and it takes about 5 years before full production is reached.

Forestry

Forestry appears to be an advantageous reclamation option for harvested peat bogs because it has commercial and aesthetic values. A lot of studies have been done on ways to increase growth and yield of existing tree stands in peatlands, but plantation on harvested peat bogs has received little attention. Most research on the potential of harvested peat bogs for commercial forestry has been done in Ireland and Finland and prospects are good. In North America, trees were planted on a few hectares at Pointe-Sapin, New Brunswick in 1990, 1991 and 1994, and more recently, from 2000 to 2002 in Baie-Sainte-Anne and Bay-du-Vin, New Brunswick and Saint-Bonaventure, Québec. The most important factors responsible for the success of tree plantation on harvested peat bogs are fertilization, peat depth, soil preparation and tree species.

Fertilization: Fertilization is an absolute requirement because peat lacks phosphorus, potassium and oligo-elements such as boron. Slow release fertilizers rich in these elements are usually used. The way fertilizer is applied has a major influence on success. The use of pills buried in the peat is recommended because in broadcast and spot fertilization methods, fertilizer is present at the surface and it favours growth of weeds. Competition from weeds is a major problem in the first years following plantation.

Peat depth: Peat depth influences drainage and access to the mineral substrate. In most harvested peat bogs, drainage is already present and will prevent water logging conditions. Problems of drainage may occur in the presence of shallow peat overlying clay deposit. In such a case, it is proposed to leave a minimum of 60 cm of peat. However, in some cases, such as in New Brunswick, ditches were blocked to counteract dry summer conditions. Shallow peat deposits have the advantage of facilitating rooting into mineral soil and access to nutrients. Studies suggest that trees planted on a peat deposit less than 30 to 35 cm deep does not require long-term fertilization.

Soil preparation: Soil preparation aims primarily at facilitating root penetration mainly by ploughing. Discing and rotovating have also been used for soil preparation. In Europe, rotovating is used along with broadcast fertilization to mix fertilizer with the peat. Ploughing may also be used to mix peat with the underlying mineral substrate when the peat depth is adequate.

Tree Species: Tamarack and Black spruce are the most common species planted in harvested peat bogs in Canada. Satisfying survival and growth rate were obtained for these two species in New Brunswick. Jack pine, Scotch pine, Red maple and hybrid Poplar were also planted in southern Québec.

The major problem in tree plantation in North America is the competition from aggressive colonizers. This problem occurs especially when fertilizers or minerals are present at the peat surface. Yearly weed control is necessary at least until the trees reach a sufficient height. In Southern Québec, seedlings of deciduous species like hybrid Poplar and Red maple did not establish well and some plantations were seriously affected by deer grazing. Grazing by rabbits is also a major problem in Ireland. Finally, the cost of tree plantation was estimated at $1,250 per hectare in New Brunswick.

5 Quick reference sheet

Objectives of peat bog restoration

- **Raise and stabilize the water table close to the peat surface all over the site**. This involves avoiding as much as possible the probability of flooding and drought events.
- **Establish a new plant carpet composed of peat bog species and especially *Sphagnum* mosses**. This involves collecting plant fragments in natural areas, spreading them on restoration sites, and protecting and fertilizing them to accelerate the establishment process.

Restoration procedures

Objectives	Operation*	Must do/avoid	Resources	Time required per hectare**	To plan in advance
Surface preparation					
- Keep as much water as possible within the site - Favour an even distribution of water - Provide appropriate peat surfaces	- Build berms according to site characteristics - Flatten dome shaped fields - Scrape loose surface peat - Remove or use existing vegetation	- Never reach the mineral soil - Compact berms thoroughly - **Once ditches are filled or blocked, the water table can rise rapidly and create soft ground conditions**	- Any equipment that can push and compact peat - A leveller is recommended	- **3.5 hours in total** for a leveller or other equipment - Varies a lot according to site preparation options needed	- Visit the site to determine site preparation options - Position berms according to site characteristics - Mark the location of berms for the machine operator
Pool creation					
- Increase biodiversity and site value	- Create pools with permanent standing water	- Pool specifications are as follows: • Size: 75 - 100 m^2 • Depth: 1 – 2 m • One gentle slope • Presence of emergent structures - Do not reach the mineral substrate	- Excavator - Branches or small trees for emergent structures	- **1 hour in total** per pool	- Locate pools regarding requirements and mark pool locations
Plant collection					
- Collect the right amount of appropriate plant material	- Carefully select a collection site with appropriate vegetation and mark it - Shred the top 10 cm of	- **Suitability of plant community of the collection site is paramount** - The site must be about	- Rotovator or other equipment to shred the surface vegetation - Equipment to pile up and load the plant	- 1 hour for shredding surface vegetation*** - 8 hours for pick up and transport - **9 hours in total**	- Determine the area of the restoration and collection sites - Select and mark the the collection site

Restoration procedures cont'd

Objectives	Operation*	Must do/avoid	Resources	Time required per hectare**	To plan in advance
Plant collection (suite)					
	surface vegetation - Pick up and transport the plant material to the restoration site	1/10 the size of the restoration site - Do not collect plant material deeper than 10 cm in average	material into peat wagons - Peat wagons to transport the plant material	- Varies a lot according to distance and access to collection site	- Select storage areas for plant material if needed - Refer to spring plant collection procedures if appropriate
Plant spreading					
- Cover peat surfaces of restoration site with plant fragments to establish a new plant carpet	- Spread the plant fragments all over the restoration site with a manure spreader	- The layer of plant material should be 1 – 2 cm thick and cover the entire surface - **Avoid passing over the plant material after it is spread** - **Apply straw as soon as possible after spreading the plant material**	- Manure spreader (estimated rental cost $75/hectare) - Front end loader or other equipment to load plant material	- 1 hour for a front end loader - 3 hours for a tractor with a manure spreader - **4 hours in total**	- Rent a manure spreader
Straw spreading					
- Improve growing conditions for plant fragments with a mulch that creates a wetter and cooler air layer at the peat surface	- Apply straw mulch over plant fragments	- **Avoid passing over the plant material while spreading straw mulch** - **Apply straw as soon as possible after spreading the plant material** - Apply the right quantity of straw: • Too much straw does not allow light to reach plants • Too little straw does not provide enough protection to plants - Do not chop straw	- Straw spreader (estimated rental cost $100/hectare) - Straw: 25 to 30, 4' round bales or 18 to 20, 5' round bales per hectare (estimated cost $540/hectare)	- **7 hours in total**	- Buy straw in advance especially in regions where agriculture is less intensive - Transport straw bales on each field or close to the restoration site - Rent a round bale straw spreader - Plan dry storage areas for straw bales

Restoration procedures cont'd

Objectives	Operation*	Must do/avoid	Resources	Time required per hectare**	To plan in advance
Fertilizer application					
- Provide adequate nutrients to favour a rapid establishment of a moss carpet	- Apply phosphorous fertilizer	- The rate of phosphate (P_2O_5) to apply is 19.5 kg/hectare - In the case of rock phosphate apply 150 kg/hectare - Correctly calibrate the fertilizer spreader - Avoid spills of fertilizer in watercourses	- Fertilizer spreader – a conic spreader that fits on a three point hitch is recommended (estimated rental cost $10/hectare) - Fertilizer: granulated phosphate rock is recommended (estimated cost $75/hectare)	- **0.5 hour in total** for a tractor with a conic fertilizer spreader	- Buy fertilizer and store in a dry place - Rent a fertilizer spreader
Blocking ditches					
- Keep as much water as possible within the site - Favour an even distribution of water	- Clean both sides of ditches for better sealing - Block ditches by filling with wet decomposed peat on a width of 2 m - Compact peat thoroughly	- Block ditches at the end of operations if the water table is likely to rise rapidly - Ditches should be blocked every 50 to 75 m and closer in the case of sloping fields - Well decomposed peat makes stronger, more impervious blockages - Avoid the presence of wood or other material in the peat - Never reach the mineral substrate	- Backhoe or clamshell are recommended because they can clean ditches and reach wet more decomposed peat	- **1 hour in total**	- Evaluate the risk of a rapid rise of the water table after blocking ditches to determine the best time to block them

* Operations are presented in a chronological order.
** The time required includes the overall time for operator and machinery. For example, 2 hours may represent 1 hour for a tractor with a manure spreader and 1 hour for a front end loader and 2 hours for the operator.
*** Hours for plant collection represent the time required per hectare of area to be restored.

6 Key to identification of collection sites

Find the situation that best describes the natural site in order to assess its suitability as a collection site. Note that this key cannot provide precise assessment and that it applies only to peat bog plant communities in Northeastern America.

1. **It is a wet site where water shows up under our feet when we walk across in normal summer conditions.**

Suitable collection site

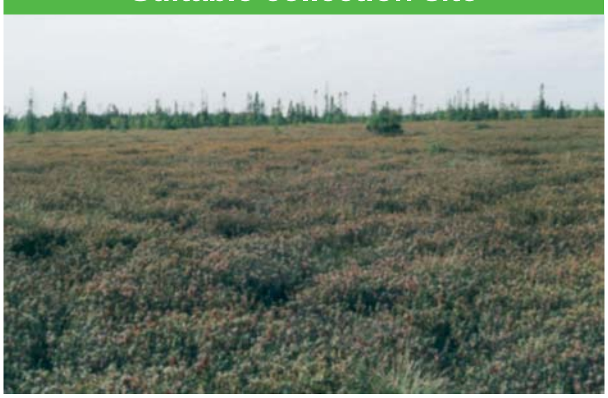
A.- The plant carpet is dominated by *Sphagnum rubellum* with low sparse shrubs < 40 cm or graminoids (i.e., grass-like plants). (Photo: M. Poulin)

Inappropriate

B.- The plant carpet is dominated by other *Sphagnum* species mostly green or yellowish; presence of pools or black pool-like depressions. (Photo: M. Poulin)

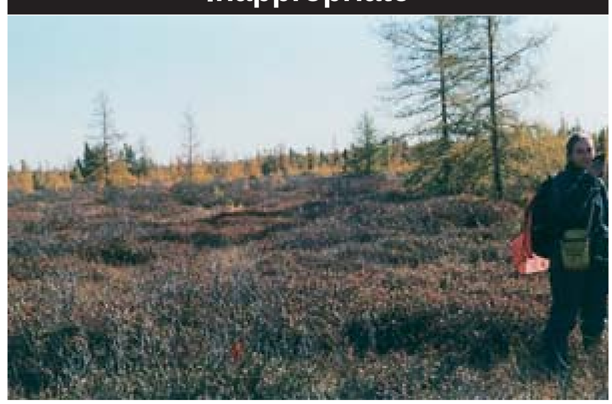
2. **It is a dry site where water comes only when a handful of *Sphagnum* mosses is squeezed or no water at all.**

Suitable collection site



A.- The plant carpet is dominated by *Sphagnum fuscum* or *Sphagnum rubellum* or by other mosses (Hair-cap moss and/or *Dicranum*), with or without lichens and with ericaceous shrubs more or less dense about 20 to 50 cm high. The topography can be bumpy or not. (Photo: M. Poulin)

Inappropriate



B.- The moss carpet is sparse or there is no moss at all, bare peat or litter may be dominant with a dense strata of high (> 50 cm) ericaceous shrubs. (Photo: M. Poulin)

Description of a few peat bog plant species

It is necessary to be able to identify a few plant species for restoration purposes. *Sphagnum* mosses and Hair-cap moss (*Polytrichum strictum*) play an important role in peat bog restoration and other plants like Ericaceous shrubs may help in selecting a good collection site. Although most of these species can be found worldwide, they reflect peat bog vegetation of Northeastern America.

Sphagnum

Sphagnum represent a group of mosses usually associated with peat bogs where they form most of the moss carpet. *Sphagnum* have a unique structure that differentiate them from other mosses. They are composed of a stem with groups of branches covered by leaves (Figure 4). The most significant element is the capitulum or head that forms the tip of the stem. Around 60 species of *Sphagnum* are present in Canada and they are difficult to differentiate for non-specialists. However, two of them are particularly important in peatland restoration because they have the best potential for establishing a new moss carpet. They are *Sphagnum fuscum* and *Sphagnum rubellum*.

Sphagnum fuscum: Small species that forms compact hummocks. It is usually brown but it can be green in shadowy habitats (Figure 26). The stem, which is always dark brown, is a good characteristic to identify this species. *Sphagnum flavicomans*, a similar brown but larger species occurs in the maritime region, and may also be suitable for restoration purposes.

Figure 26. Photo of *Sphagnum fuscum*. (Photo: L. Rochefort)

Sphagnum rubellum: Small species that can be found in hummocks or in more depressed or flat areas (Figure 27). It is usually partly or totally red, but it can also be green in shadowy habitats. Its red colour and its size are the best characteristics to identify this species. It often grows along with *Sphagnum fuscum*.

Figure 27. Photo of *Sphagnum rubellum*. (Photo: R. Gauthier)

Polytrichum (Hair-cap Moss)

Figure 28. Photo and sketch of *Polytrichum strictum*. (Photo: F. Quinty)

Polytrichum or Hair-cap moss is another group of mosses present in peat bogs, especially the species *Polytrichum strictum*. These mosses play a significant role in restoration since they propagate rapidly after fertilization and improve conditions for the establishment of *Sphagnum* species.

Polytrichum can be easily distinguished from *Sphagnum* by the **absence of capitulum** and the presence at certain times of a long stem ending with a capsule (Figure 28). Many other moss species have similar characteristics, but few of them can be found in peat bogs, except for *Dicranum* species. In general, *Polytrichum* has darker and thicker leaves than *Dicranum* and characteristic whitish woolly hair at the base of the stem.

Dicranella cerviculata

Dicranella cerviculata is a very small moss, 1 to 6 mm in height. It often spreads rapidly and forms a velvet-like carpet on restoration sites (Figure 29). It plays a role in peat substrate stabilization.

Figure 29. Photo of a carpet of *Dicranella cerviculata*. (Photo: F. Quinty)

Eriophorum (Cottongrass)

Eriophorum or cottongrass are common pioneer plants in abandoned peat bogs. *Eriophorum vaginatum* and *Eriophorum angustifolium* are the most common species. They are graminoid plants from the sedge family and their principal characteristic is the presence of white cotton balls.

Eriophorum vaginatum forms tussocks or clumps of stems. Each stem has only one erected cotton ball at its end (Figure 30).

Figure 30. Photo of *Eriophorum vaginatum*. (Photo: F. Quinty)

Eriophorum angustifolium grows in the form of individual stems coming up from a rhizome (horizontal root) rather than in tussocks. Stems of this species usually have 2 to 3 hanging cotton balls (Figure 31).

Figure 31. Photo of *Eriophorum angustifolium*. (Photo: S. Boudreau)

Ericaceous shrubs

Ericaceous is a group of shrub species from the blueberry family. They are commonly found in peat bogs where they form a more or less dense cover 10 to 100 cm high. These shrubs keep their leaves in winter. Leaves are often thick and hardy. The most common species can be differentiated easily.

Chamaedaphne calyculata (Leatherleaf) is one of the most common shrub species growing in natural bogs and restoration sites. It seems to establish easily from plant material used in peatland restoration. It can be identified by its erected leaves with white dots and its flowers that are like white bells hanging under branches (Figure 32).

Figure 32. Sketch of *Chamaedaphne calyculata*.

Ledum groenlandicum (Labrador tea) is also common in peat bogs and restoration sites. It is characterized by leaves rolled at their edges with brownish woolly hair beneath. It has clusters of white flowers at the end of branches (Figure 33).

Figure 33. Sketch of *Ledum groenlandicum.*

Kalmia angustifolia (Sheep Laurel) is widespread in natural peat bogs, but it does not establish as easily as *Chamaedaphne calyculata* and *Ledum groenlandicum* from plant material in restoration sites. Its leaves are in groups of three, and they are dark above and pale beneath. It has clusters of pink saucer-shaped flowers located below the tips of branches (Figure 34).

Figure 34. Sketch of *Kalmia angustifolia.*

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Appendix A
Large-scale restoration and reclaimed sites in Canada

Large-scale restoration sites in Canada

Site/Company*	Year	Area (hectares)	Site conditions**	Interventions	Results	Comments
Rivière-Ouelle, Québec/Lambert Peat Moss - PERG	1997	5	Site abandoned for 11 years before implementation of restoration procedures. Very dry site at the margin of the bog, bordered by a large main ditch. Flat topography and acidic conditions with peat depth about 120 cm.	Fields flattened and berms built across the slope. Application of the Canadian approach, except for the fertilization tried experimentally along strips in 1998.	Good results after 3 years except for damage by frost heaving. Less damage in fertilized strips. More *Polytrichum* and vascular plants in fertilized strips.	Experimental site with sections restored in 1993. Degradation of establishing vegetation and return of dry conditions after re-opening of ditches in 1999.
Inkerman Ferry, New Brunswick/Fafard Peat Moss - PERG	1997	5	Site characterized by a strong slope (1-2 %) and dry conditions. More than 175 cm of peat left. Acidic conditions. The site was harrowed periodically until restoration work to clear establishing vegetation.	Fields flattened and ditches filled with peat. Four berms built along contour lines. Application of the Canadian approach except for fertilization. Fertilizer applied in the fall of 1998 in large plots.	Good establishment of plants in the first two years with invasion by cottongrass.	Problem with frost heaving in the second and third year. Second application of straw and fertilizer locally for remediation.
Bois-des-Bels, Québec/PERG	1999-2000	8	Site abandoned for about 20 years before implementation of restoration procedures. Flat topography with 1 to 3 m of peat left. Dry conditions with pH of 3.5 to 4. Possibilities of contamination by enriched water in the ditches. Site partly colonized by vegetation.	Fields scraped with a leveller and the top material along with the vegetation put in the ditches and used to build berms. Application of the Canadian approach and 4 berms built along contour lines. Creation of 8 pools.	Vegetation establishment was rapid from the beginning. Rapid and successful rewetting after all ditches were blocked. Successful return of fauna in created pools.	Experimental site with long term monitoring of the restoration including carbon cycle.
Sainte-Marguerite, Québec/Johnson & Johnson - Planirest environnement	1999-2002	162	Site used for vacuum harvesting and block cutting abandoned for less than 5 years before implementation of restoration procedures. Relatively wet conditions with spring flooding. Flat topography with more than 1 m of peat left. Acidic conditions.	Application of the Canadian approach. Block cut fields harrowed to be flattened prior to other interventions. Peripheral berms built.	Plant and *Sphagnum* establishment favoured by wet conditions. Mosses dominate new plant cover.	General conditions vary depending on the type of extraction. Block cut fields wetter than vacuum-harvested areas.
Pit Bog, Saskatchewan/Premier Horticulture	1999	43	Site harvested until 1997. Average peat depth is 50 cm and peat pH varies from 4.8 to 5.5. Very dry site.	Application of the Canadian approach except for fertilization. Second application of straw done over bare areas in 2000. The entire site restored at once.	Establishing vegetation dominated by moderate to rich fen species at the periphery and bog species in the centre. Almost no *Sphagnum* grows on the site.	Very dry site. Results partly reflect characteristics of the collection site located in the forested transitional zone around the bog.

Large-scale restoration sites in Canada cont'd

Site/Company*	Year	Area (hectares)	Site conditions**	Interventions	Results	Comments
Maisonnette, New Brunswick/ Sungro Horticulture - PERG	2000	12	Site comprising the extremity of a series of fields toward the margin of the peat bog. Peat depth 15-100 cm with pH of 3.9 to 4 and scattered mineral material along ditches. Flat topography and dry conditions.	A new main ditch dug to isolate the site from currently harvested fields. Application of the Canadian approach except for fertilizer that was applied at different periods for experimental purposes. Straw mulch applied in the following year on some fields.	Low plant establishment during the first two years with generally less than 12 % cover.	Experimental site used to test the timing of fertilizer application. Rapid rise of the water table delayed straw and fertilizer application.
Kent, New Brunswick/Fafard Peat Moss	2001	4.5	Site with two levels separated by a relatively steep slope. Peat depth varies from more than 100 cm to less than 50 cm. Acidic conditions. The site is bordered by a main ditch.	Fields flattened and berms built. Application of the Canadian approach. Fertilizer spread manually.	No results available.	
Baie-Sainte-Anne, New Brunswick/ Berger Peat Moss	1998, 2000	6.5	Site harvested until 1998. Ditches very shallow and not functioning. About 50 cm of peat left. Peat pH of 3.5 to 4.	The surface flattened and ditches blocked at regular intervals. Only plant material spread in 1998. Plant material spread again in 2000 along with straw mulch. No fertilizer used.	Plant fragments died after the 1998 introduction. Low plant establishment after the 2000 introduction.	Plant establishment is better close to ancient ditches because of wetter conditions. Field are still convex and this does not favour good rewetting.
Chemin-du-Lac, Québec/Premier Horticulture	1995, 1997, 1999, 2000, 2001, 2002	15.5	Very dry site with complex slopes on short fields. Acidic conditions with pH 4.0. Peat depth varies between 30 and 100 cm. Mineral substrate is clay.	Application of the Canadian approach. Undulating topography was created in 1995 and 1997 sites. Chessboard — like berms built in the sections restored in 1999, 2000 and 2001. Ditches were filled except for 1995 site. No fertilizer was applied in 1999, 2000 and 2001 sites.	Good plant establishment in all sites. Cover is more than 80 % after 7 years.	
Saint-Henri, Québec/Premier Horticulture	1997	18	Site abandoned for about 10 years before implementation of restoration procedures. Dry peat surfaces slowly colonized by trees. Peat depth varies from 30 to 50 cm.	Peripheral and across slope berms built. Plants and *Sphagnum* moss thrown manually in the site. No mulch and fertilizer application.	Site characterized by very dry sectors with little plant establishment and wet area with *Sphagnum* and wetland vegetation.	Mammals break through berms every year.

Large-scale restoration sites in Canada cont'd

Site/Company*	Year	Area (hectares)	Site conditions**	Interventions	Results	Comments
Saint-Charles, Québec/Nirom Peat Moss - PERG	1999	1	Site abandoned for about 25 years before implementation of restoration procedures. Residual peat depth 35 to 125 cm with mineral material along drainage ditches. Dry site with flat topography. Acidic conditions. Colonized by sparse vegetation.	Application of the Canadian approach. Straw spread by hand.	Very good plant establishment with more than 50 % of the surface covered by plants. High species diversity due to mineral enrichment.	Shallow spring flooding, but very dry conditions in summer.

* Company and/or organization responsible for the restoration work
** All sites, unless specified, were vacuum-harvested.

Large-scale reclaimed sites in Canada

Site/Company*	Year	Area (hectares)	Site conditions**	Interventions	Results	Comments
Baie Ste-Anne, New Brunswick/Berger Peat Moss	2001-2002	14.5	Site harvested until 2000. Peat depth varies from 20 to 180 cm. Dry and acidic conditions. Sandy mineral substrate.	Tree plantation of Tamarack and Black spruce. Seedlings 15 cm to 100 cm high, fertilized with a pill (20-10-5) that lasts 2 years. Plantation density is 2400 plants/hectare, with a distance of 2 m between plants. Ditches were blocked.	Survival rate of 80 % in average in fall 2002.	
Baie du Vin, New Brunswick/Berger Peat Moss	2001-2002	8	Peat depth 30 to 145 cm with pH of 3.2.	Tree plantation of Jack pine, Tamarack and Black spruce. Seedlings 15 cm to 100 cm high, fertilized with a pill (20-10-5) that lasts 2 years. Plantation density is 2400 plants/hectare. Ditches were blocked.	Survival rate between 90 and 100 % for all species in fall 2002.	

Large-scale reclaimed sites in Canada cont'd

Site/Company*	Year	Area (hectares)	Site conditions**	Interventions	Results	Comments
Sugden bog, Alberta/Sungro Horticulture	2000	133	Site considered too dry for restoration. Shallow peat.	Various combinations of fertiliztion and grass seed mixes to convert the site into a grazing land.	Good results so far despite dry conditions.	
Saint-Bonaventure, Québec/ Fafard et frères - PERG	2000	11	Milled peat fields. Dry conditions except for spring. Peat depth varies from 60 to 120 cm peat and pH around 4.0. Mineral substrate is clay.	Tree and small fruit plantation of Red maple, Tamarack, Black spruce, Scotch pine, Green alder, Hybrid poplar, Black chokeberry and low and high bush blueberry. Field levelled prior to planting and different doses of PK rich fertilizer added. Additional ditches dug to test ditch spacing.	Interesting results with Black chokeberry and conifers only with fertilization. Hybrid Poplar grazed by deer.	Problem with weeds because of proximity to agricultutal fields and spot fertilization at the peat surface.
Pointe-Sapin, New Brunswick/ASB Greenworld	1990, 1991, 1994	3	Peat depth varies between 15 and 115 cm on acidic sand. Peat pH is 3.5.	Tree plantation of Tamarack (1994) and Black spruce (1990 and 1991). Ploughing and tilling prior to 1990 plantation. Spot fertilization during the first years for 1990 plantation. Tilling and liming for 1991 and 1994 plantations.	Growth rate of Tamarack comparable to commercial plantations.	
Pokesudie, New Brunswick/Lamèque-Quality Group	1990, 1997	4	Abandoned site, opened to seaward wind.	Creation of basins on 2 hectares and an equivalent surface for water reservoir. Experimental site to test varieties and harvest methods, pest management and winter protection.	Successful establishment of 2 out of 5 varieties confirms that cranberry can adapt to harsh conditions on depleted peatland surfaces.	Two fields are still being monitored and protected from winter freezing.

* Company and/or organization responsible for the restoration work.
** All sites, unless specified, were vacuum-harvested.

Appendix B
von Post scale

von Post scale

Degree of decomposition	Nature of water expressed on pressing	Squeeze test	Nature of plant residues	Description
H1	Clear, colourless	Very spongy Springs back after pressure Holds no shape No peat extruded between fingers	Living layer	Undecomposed
H2	Almost clear, brown-yellow	Spongy Springs back after pressure Holds almost no shape No peat extruded between fingers	Almost unaltered Entire structure	Almost undecomposed
H3	Slightly turbid, yellow-brown	Slightly spongy Holds a fairly definite form of handprint with rounded edge No peat extruded between fingers	Most remains easily identifiable but breaking into piece	Very slightly decomposed
H4	Turbid, brown	Not spongy Forms a distinct replica of handprint No peat extruded between fingers Very slightly soapy	Most remains identifiable	Slightly decomposed
H5	Strongly turbid, contains mixture of plant debris and amorphous material	Very little peat extruded between fingers Slightly soapy	Bulk of remains difficult to identify Some amorphous material present	Moderately well decomposed
H6	Muddy, much peat in suspension	One third of sample extruded between fingers Soapy	Bulk of remains unidentifiable Nearly half sample in amorphous state	Well decomposed
H7	Very small amount, strongly muddy	Half of sample extruded between fingers Somewhat pasty	Relatively few remains identifiable	Strongly decomposed

von Post scale cont'd

Degree of decomposition	Nature of water expressed on pressing	Squeeze test	Nature of plant residues	Description
H8	Thick mud, little or no free water	Two thirds of sample extruded between fingers Pasty	Only resistant roots, fibres and bark identifiable	Very strongly decomposed
H9	No free water	Almost all sample escapes the hand Pudding-like	Practically no identifiable remains	Almost completely decomposed
H10	No free water	All sample escapes the hand	Completely amorphous	Completely decomposed

Adapted from Puustjarvi, V. and R. A. Robertson (1975). Physical and chemical properties. In: D. W. Robinson and J. G. D. Lamb (eds.), *Peat in Horticulture*. London, Academic Press, pp. 23-38.

Appendix C
Monitoring forms

Planning - Site conditions (1)

Site name: ______________________________

Location (Town, prov. lat. and long.) **:** ______________________________

Contact name: ______________________________

Surface: Surface of restoration site in hectares and/or acres.	
Abandon date: Last year of peat harvesting or harrowing.	
Site characteristics prior to peat extraction: Presence of trees, type of vegetation, water table level, pools, etc. Notes on any other reference ecosystem.	
Hydrological environment: Possibility of water loss. Potential source of water. Dry or wet conditions.	
Topography: General slope of fields. Presence of dome shaped fields. Site survey.	
Peat characteristics: **- Peat thickness** **- Type of peat** (Sedge peat, *Sphagnum* peat, etc.) **- Degree of decomposition** (von Post scale) **- Peat pH** **- Mineral** (Presence of minerals at or near the surface. Type of mineral: clay, sand, etc.) **- Surface peat** (Presence of loose peat, frost heaving or crust at peat surface.)	
Chemical aspects: **- Water pH and electric conductivity** (Restoration site and potential source of water). **- Sign of enrichment** (Presence of non-peatland species).	

Planning - Site conditions (2)

Site name: ______________________

Location (Town, prov. lat. and long.)**:** ______________________

Contact name: ______________________

Existing vegetation: **- Dominant species** (Peatland or non-peatland species.) **- Percent cover** (Percent cover of vegetation including percent cover of ground by mosses.) **- Potential invasive species** (Presence of colonies of non-peatland species at peat bog margins.)	
Source of plant material: **- Area of collection site** (Must be 1/10 the area of the restoration site.) **- Plant community/ *Sphagnum*** (Make sure the right plant community is present and that *Sphagnum* moss covers most of the ground.) **- Access to collection site** (Make sure the collection site is accessible for heavy wagons.)	
Surrounding landscape: **- Land use change** (Some changes in nearby land use may influence possibilities for restoration.) **- Drainage** (Note any drainage that may affect rewetting.) **- Other peat bogs** (Nearby peat bogs can serve as possible source of plant material.)	
Photos: Photos of restoration site prior to restoration operations (photos should be numbered and their location and date specified.)	

Planning - Objectives (3)

Site name: ______________________________

Location (Town, prov. lat. and long.) **:** ______________________________

Contact name: ______________________________

Potential for rewetting: Assess the potential for rising and stabilizing the water table. (Is the restoration site likely to be wet or dry?) Assess the variations of the water table spatially and in time.	
Potential for plant establishment: Evaluate the possibilities for the establishment of peat bog vegetation, specially *Sphagnum* moss, based on site conditions and plant material quality.	
Potential problems: Assess the possibility of colonization by non-peatland species or any other problem.	

Restoration procedures

Site name: ______________________________

Location (Town, prov. lat. and long.)**:** ______________________________

Contact name: ______________________________

Surface preparation: Description of surface preparation options accompanied by a map of the restoration site locating berms, blockages, pools, etc., and equipment used.	**Date**	
Plant collection: Notes on plant communities, depth of collection, size of collection site, quality of plant material, conditions/damage to the collection site, and equipment used.		
Plant spreading: Thickness of plant material, weather during plant spreading, and equipment used.		
Straw spreading: Notes on quality and thickness of straw, and equipment used.		
Fertilization : Type and rate of fertilizer, notes on the creation of ruts, spill or possibility for fertilizer to reach watercourse.		
Blocking drainage: Notes on the raise of water table after blockage.		
Pool creation: Size and depth of pools, water level, and vegetation introduced.		
Other operations:		
Site visit/Monitoring:		

Permanent Plot

Site: ____________________ **Permanent plot #:** ____________________

Name (s): ____________________ **Representativeness:** ____________________

Date: ____________________ ____________________

Percent cover classes

0 = 0
+ = <1%
1 = 1 - 10%
2 = 11 - 25%
3 = 26 - 50%
4 = 51 - 75%
5 = 76 - 100%

	Percent cover classes	Average Height (cm)
Trees/shrubs strata	☐	☐
Ericaceous strata	☐	☐
Grass strata	☐	☐
Moss strata	☐	☐
Total plant cover	☐	
Bare peat and litter	☐	
Perturbation	☐	
Straw mulch	☐	

Photos

____
____
____

Comments

____
____
____
____
____

Plant list with percent cover

(cover of mosses is evaluated in quadrats and noted on the Ground level form)

____________________	☐
____________________	☐
____________________	☐
____________________	☐
____________________	☐
____________________	☐
____________________	☐
____________________	☐
____________________	☐
____________________	☐
____________________	☐
____________________	☐
____________________	☐
____________________	☐
____________________	☐
____________________	☐
____________________	☐
____________________	☐
____________________	☐
____________________	☐
____________________	☐
____________________	☐

Ground level
Percent cover of mosses in quadrats

Site: ______________________________ **Date:** __________________________

Permanent plot #: ____________________ **Name (s):** __________________________

Quadrat	Total Moss cover	*Sphagnum*					Mosses				*Hepaticae*	Lichens
		Total	*Fus**	*Rub**	*Mag**		Total	*Poly**				
1												
2												
3												
4												
5												
6												
7												
8												
9												
10												
11												
12												
13												
14												
15												
16												
17												
18												
19												
20												

Notes:

* Fus = *Sphagnum fuscum*, Rub = *S. rubellum*, Mag = *S. magellanicum*, Poly = *Polytrichum strictum*

Water table measurements

Site: ____________________

Date	Name	Permanent Plot #	Distance to water table	Above ground height	Water table depth

Distance to water = Distance between top of pipe and water table

Above ground height = Distance between ground and top of pipe

Water table depth = Distance to water table   Above ground height

Peat Water Content

Site: ____________________

$$\frac{\text{Wet weight - Dry weight}}{\text{Dry weight}} = \text{Peat water content (\%)}$$

Date	Name	Permanent Plot #	Wet weight (g)	Dry Weight (g)	Water content (%)

Notes:

Glossary

Acrotelm: The acrotelm is the superficial layer of the peat column in peat bogs where the water table fluctuates.

Anaerobic: Conditions of an environment characterized by a lack of oxygen.

Anoxic: Conditions of a low level of oxygen in plant cells.

Bog: A peatland fed in water exclusively by precipitation, dominated by *Sphagnum* mosses and characterized by acidic and nutrient-poor conditions.

Catotelm: The catotelm is the peat layer underneath the acrotelm which stays permanently below the water table.

Chopper: Device used to prepare the soil made of a horizontal shaft with loose blades.

Collection site: Site usually located in a natural area of a peatland that serves as a source of plants for peatland restoration.

Diaspore: Any plant part (seed, fruit, branch, root, etc.), that can grow as a new plant.

Fen: A peatland fed by precipitation and runoff water that is enriched in contact with the mineral substrate. Fens are often dominated by a mixture of sedge, grass and mosses and with variable pH (4-8) and mineral status (poor to rich).

Hummock: Small mound made by the accumulation of peat.

In-kind restoration: Restoration of a site to the same ecosystem type that existed prior to a perturbation.

Loading conveyor: Conveyor used to pick up roots also called a root picking conveyor.

Out-of-kind restoration: Restoration of a site to an earlier stage of development of the ecosystem that existed prior to perturbation. For example, the restoration of a bog to a fen.

Paludification: Process by which mineral soil is converted to wetland by the accumulation of peat.

Plant material: Name given to the mixed plant fragments that are spread on abandoned peat fields in order to establish a new plant carpet. Plant material is a mix of all species present at the collection site.

Polytrichum: Genus of mosses to which belongs *Polytrichum strictum* or Hair-cap Moss; a species that is common in peatlands and that can play an important role in peatland restoration by colonizing rapidly and stabilizing bare peat substrates.

Reclamation: Transformation of a site to a type of ecosystem or a use different from the original ecosystem.

Reference ecosystem: An ecosystem that serves as a model for planning an ecological restoration project, and later in the evaluation of that project.

Rotovator or rototiller: Device used to prepare the soil that has a horizontal shaft with fixed blades.

Screw leveller: Horizontal endless screw used to shape fields.

Sphagnum: A group of mosses that dominates the moss carpet and forms most of the peat in peat bogs. *Sphagnum* mosses have unique characteristics that allow them to play a major role in peatland formation and functions.

Terrestrialization: Process of accumulation of organic matter leading to the infilling of open water.

Vegetation community: A group of plant species growing together in a particular habitat.

Water tension: Strength or suction that retains water to peat particles.

Canadian Sphagnum
Peat Moss Association

New Brunswick Department of
Natural Resources and Energy

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