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Department of Horticultural Science
University of Minnesota, St.Paul, MN

Techniques for *Sphagnum* restoration in Canadian peatlands

Matt McCue

Ombrotrophic bogs are nutrient poor environments that are almost entirely dependent on the atmospheric inputs for nutrients and water. These areas are rather limited in plant and animal species, when compared to other wetland ecosystems (Rubec 1996). Several unique and rare plant species also inhabit ombrotrophic bogs such as *Sarracenia* spp., *Pinguicula* ssp. and *Drosea* ssp. and several species of orchids. Many of these species are only adapted to the nutrient poor conditions of ombrotrophic bogs. The dominant species in bog ecosystems is *Sphagnum* moss, which is the major component of peat moss. Peatlands are important in the filtering of water, serving as collection basins for precipitation, in the accumulation and storage of carbon and in providing habitat for wildlife (Rubec 1996).

In Canada the primary threat to peatlands is from the extraction of peat for horticulture use. Peatlands may be harvested for a period of 15 to 50 years, depending on the depth of the peat deposit (http://www.peatmoss.com/pm-me3htrm.). The surface peat that is harvested is only slightly decomposed. Lower layers in the peat profile are unsuitable for use as horticulture peat because of the more decomposed composition. After the surface peat supply has been exhausted, the field is abandoned to revegetate naturally. This process may take as little as 3 to 7 years on minerotrophic (nutrient rich) peatlands. On ombrotrophic (nutrient poor) peatlands in which vacuum harvesting has been used, this process may take 25 to 30 years (http://www.peatmoss.com/pm-me3htrm.). The harvested site is typically barren and devoid of vegetation with exception of a few vascular plant species that can tolerant dry and acidic soil conditions (Bugon et al. 1997). On post-harvested peatlands there is very little natural recolonization by *Sphagnum* moss. In Quebec only 10% of the abandoned bogs have some *Sphagnum* regeneration. (Price 1996).

In Canada reclamation of peatlands after harvesting has not been clearly defined. Many of the European countries have greater experience in the reclamation of post-harvested peatlands (Rubec 1996). Several of the reclamation options for post-harvested peatlands in Canada include the creation of wetland habitat for waterfowl. These wetland areas would be different than the original bog ecosystem. Other options for post-harvested sites are as afforestation projects or for land used for the production of agriculture crops (Rubec 1996). In contrast, several restoration techniques have been developed in Canada to return post-harvested peatlands as close as possible back to their original state as a functioning wetland.

Several studies have been conducted in Canada by the University of Laval in Quebec, the University of Waterloo in Ontario, and the University of Alberta in Edmonton on developing techniques in the restoration of peatlands to make *Sphagnum* moss a sustainable resource. Most of these experimental studies have been on a small to medium scale. Some of these techniques include re-establishing the hydrological cycle to the site, methods of propagation of *Sphagnum* moss, providing wet and humid conditions for the regeneration of *Sphagnum* moss by the use of mulches, companion species and changing the topography of the post-harvested site. Methods for rewetting the peat surface and the hydrological and chemical changes that have occurred due to drainage of the site during harvesting have been studied. Some of these techniques are now currently used in the restoration of post-harvested peatlands. As with many reclamation and restoration programs, successful plant recolonization may take long periods of time.

Another organization involved in the reclamation and restoration of peatlands is the peat harvesting industry. In 1990 the Canadian *Sphagnum* Peat Moss Association (CSMPA) and its companies have adopted a policy concerning the restoration and the management of peatlands called The Preservation and Reclamation of Policy. Some of the CSPMA's goals are to identify bogs for preservation, reducing environmental impact by implementation of careful harvesting techniques so these areas can be restored after harvesting is complete, and leaving at least 3 feet of peat on the bottom of the bog. The CSPMA has invested 1 million dollars on research and in developing techniques on peatland restoration by its own research team and in conjunction with studies and research conducted by Canadian Universities (http://www.peatmoss.com/pm-me 3htm.).

The majority of the peat harvesting is done in the bog and poor-fen classes and peat extraction occurs mostly in the less populated boreal regions of Canada. Peat harvesting operations are found in parts of southern and southeastern Quebec and eastern and northeastern New Brunswick. Production also occurs in central Alberta, southern Saskatchewan and eastern Manitoba, Nova Scotia, Prince Edward Island and New Foundland (Rubec 1996).

In Canada there are several methods by which peat is harvested. Two of the most commonly used methods of peat extraction are block harvesting and vacuum harvesting. Block harvesting is one of the oldest methods of peat extraction and has been used in European countries for centuries. Before the site is harvested, drainage ditches are constructed to lower the water table. After the site has been drained the peat is harvested by cutting blocks of peat from the peat profile either by hand or by a simple extractor (Nyronen 1996).

Today the most commonly used method of peat extraction is vacuum harvesting. Before the site is harvested drainage ditches are excavated, which are usually 20 meters apart. The relatively close spacing of the drainage ditches is to lower the water table and because of the high water holding capacity of the peat. After the site is drained the vegetation on the surface of the bog is completely removed (http://www.peatmoss.com/pm-me 3htm).

During harvesting a tractor drawn a plow is used to harrow the upper surface of the peat profile. This process loosens the peat from the peat profile and to break the capillary action of the peat to increase the drying process (http://www.peatmoss.com/pm-me 3htm). The harrowed peat is allowed to dry naturally by the action of the wind and sun for a period of two to three days. After this period, vacuum harvesters are used to the collected the peat. The collected peat is then loaded on to trucks and transported to be processed. Vacuum harvesting is done from May to mid-September. Peat harvesting is dependent on the weather conditions. During a wet season peat harvesting is delayed (http://www.peatmoss.com/pm-me 3htm).

The rate of revegetation depends on what harvesting method was employed. On bogs in which vacuum method harvesting was used, the abandon field has a relativity flat topography. Studies on natural revegetation at these sites show that revegetation is rather sparse with only a few species such as *Eriophorum* ssp. and *Betula papyrifera* and *Betula poplifolia* (Lavoie and Rochefort. 1996). On sites in which block harvesting has been employed, the topography consists of alternating trenches and ridges referred to as balks (Wind-Mulder et al. 1996). Twenty to thirty years after these sites have been abandoned, 50% revegetation has occurred. Both the balks and trenches are colonized by *Larix larcinia*, *Picea mariana*, *Betula populifolia*, *Ericaceae* spp. and *Cyperaceae* ssp.. Some recolonization by *Sphagnum* moss has occurred on the balks, but most of the recolonization is restricted to trenches. *Sphagnum* moss regeneration is very limited (Wind-Mulder et al. 1996).

The main challenge in the restoration of peatlands is overcoming the chemical and hydrophysical changes that have occurred due to the drainage of the bog and the loss of vegetative cover. The slow rate of natural revegetation on vacuum harvested peatlands is caused by several factors. The drainage of the peatland alters the natural hydrology of the bog ecosystem by lowering the water table. The peat remaining in the bog after harvesting is more decomposed and is subject to shrinkage, oxidation and compression due to exposure from anaerobic to aerobic conditions (Price 1996). The more decomposed peat layers also have smaller pore spaces, which reduce the available water, which is required by *Sphagnum* moss. The water table on post-harvested sites is more variable and fluctuates more than on natural sites (Price 1996). The flat topography on vacuum harvested fields is easily eroded by wind and water.

On post-harvested peatlands the upper layer of vegetation is completely removed during the harvesting process. In natural bogs this upper layer or acroletm layer serves several functions. This upper most porous layer is composed of living and slightly decomposed *Sphagnum* moss and has a high water holding capacity that helps regulate the water level of the bog (Price 1996). Another function of this layer is as a viable seed bank. The seed rain that occurs in this layer helps in revegetation. Because in cutover peatlands this layer is completely removed, the viable seed bank and water holding capacity of the bog are lost (Ferland and Rochefort 1996).

The chemical composition of the peat found in the lower peat profile and which is now exposed at the surface because of harvesting activities is typically higher in nutrients than in natural bogs. In a study by Wind-Mulder et al (1996) water and peat samples were analyzed to determine what nutrient changes had occurred on post-harvested sites that were compared to the nutrient levels that occur on natural sites. Several bogs in different regions of Canada were used in this study. The amount of nutrients can vary from bog to bog or in the regions in which they occur (Wind-Mulder et al. 1996). In some cutover bogs the nutrient levels may be similar to conditions found on natural bogs. Peat samples that were analyzed on cutover sites were found to contain higher levels of Na, K, Ca, Mg, SO_4, NO_3 and NH_4 . Water samples that were also analyzed contained higher levels of nutrients than on natural sites. The peat in harvested bogs in maritime regions contained higher levels of sodium than bogs in continental regions (Wind-Mulder et al. 1996).

Phosphorus was more abundant on the surface of natural sites than on post-harvested sites (Wind-Mulder et al.1996). On a site that was rewetted in Alberta the pH. changed from 4.5 to 6.1 over a two-year period. The increase in nutrients may be caused by the combination of several factors such as an increase in pH., aeration, an increase in microbial activity and the lack of vegetation to remove the nutrients from the soil (Wind-Mulder et al.1996).

The nutrient conditions found on some post-harvested peatlands may resemble conditions, which are found on moderate-rich fens (Wind-Mulder et al. 1996). These earlier successional stages contain different plant species than those that occur in ombrotrophic bogs. In the restoration of post-harvested peatlands a soil and water analysis should be done prior to the reintroduction of vegetation to determine what type of nutrient conditions are present (Wind-Mulder et. al 1996). Many of the ombrotrophic bog plant species are adapted to acidic and nutrient poor conditions. These changes in the nutrient status may require the establishment of plant species that are found on moderate-rich fen sites, rather than ombrotrophic bog species. Another alternative to attempt re-establishment of living *Sphagnum* moss to help acidify the site before the introduction of other bog plant species (Wind-Mulder et al.1996).

One of the most important considerations in the restoration of post-harvested peatlands is restoring the hydrological conditions by increasing the water table. *Sphagnum* moss is a ectohydric species and is dependent on high atmospheric humidity and wet conditions for growth and survival (Ferland and Rochefort 1997). In the re-establishment of *Sphagnum* moss the water level should not drop 40 cm below the peat surface, especially during the summer months (Ferland and Rochefort 1997). The most common method of rewetting the peat surface is by either blocking or filling the drainage ditches, which run parallel along the edge of the harvested field (Larose et al. 1997). The ditches should be blocked 1 to 3 years before the reintroduction of *Sphagnum* moss to thoroughly rewet the peat surface (Bugon et al. 1997).

Changing the topography or the microrelief of the vacuum harvested fields produces conditions similar to those found on block harvested sites. By creating hummocks and hollows these areas produces microclimates. The hummocks act as windbreaks and the hollows act as collection basins for rain water and snow, which provides wet and humid conditions in which *Sphagnum* moss can become re-established and later spread to the hummocks (Rochefort et al.1997).

Another technique is reprofiling or changing the topography of the vacuum harvested peat surface. The topography of vacuum harvested field is slightly crowned in the center, which runs parallel to the two drainage ditches which are located on each side of the field. The edges of the drainage ditches are slightly rounded. This shape could be described as cambered in form or convex in cross-sectional form (Bugon et al. 1997). This form is to promote drainage of rainwater and snow melt into the two ditches, which run parallel on each side of the field. The ditches are usually spaced 20-30 meters apart. In a study by Bugon et al. (1997) post-harvested fields were reprofiled to invert the cambered form into a v-shape. A bulldozer was used to reprofile the peat surface. The v-shape was excavated down the of center the field and running between the two drainage ditches which were filled in. The v was excavated at a 3% slope. Two fields were excavated with this profiling technique and another field was excavated with a completely flat topography, which was used as a control. One of the reprofiled fields was lined with sheets of plastic on the upper slope and one was not. Living *Sphagnum* moss fragments were applied to the bare peat surface and straw mulch was used on the control site. The plastic helped to reduce evaporation and drained rainwater and snow melt to the center of the field. The field in which sheets of plastic were used had a slightly higher soil moisture content than the other reprofiled field. This technique or reprofiling the peat surface by excavation, improved the soil moisture by lowering the position of the field closer to the water table and the channeled runoff from rain and snow melt to the middle of the field (Bugon et al. 1997). The best regeneration by *Sphagnum* moss occurred on the reprofiled field in which sheets of plastic were used, compared to the other site in which only reprofiling was used. The control site had the least amount of regeneration by *Sphagnum* moss (Bugon et al. 1997).

Post-harvested peat surfaces are easily desiccated by wind and sun. In natural bogs the acroletm layer replenishes water lost by evapotranspiration and the effects of wind and solar radiation. The acroletm's porous surface absorbs water from the underlying layers of peat to replace, water which is lost. Several methods have been used to maintain wet and humid conditions on bare peat surfaces and to help reduce water loss. Overhead irrigation systems are often used to maintain wet and humid conditions on restored peatlands. The problem with this system, especially on fields that have recently been "reseeded" with *Sphagnum* fragments, is that the water droplets hitting the peat surface tend to bury and displace diaspore fragments (Rochefort et al. 1997).

The use of protective mulches and the use of windbreaks have also been tested to maintain moist soil conditions on the soil surface. The use of wooden snow fencing has been tested as a windbreak and in accumulating snow during the winter months. This method helped in the accumulation of snow, but offered little protection to diaspores from desiccation during the growing season (Rochefort et al. 1997). Plastic snow fencing was tested as a protective mulch. This resulted in very little protection from desiccation. On post-harvested sites straw mulch improved the survival rate of *Sphagnum* diaspores and provided the best protection against desiccation, especially during the summer months, since there is no acroletm layer to maintain and restore water which is lost. In a study by Rochefort et al. (1997) straw mulch was applied at a rate of 1500-kg ha^{-1} and, after three seasons, 50% cover by *Sphagnum* moss occurred on a post-harvested site. Protective mulch application is now a commonly used practice in the restoration of post-harvested peatlands and, unlike other mulches that need to be removed, straw can be left on the site and allowed to decompose naturally.

Sphagnum moss is able to regenerate vegetatively or asexually from leaf, stem and branch fragments referred to as diaspores. Little is known about the propagation of *Sphagnum* moss by sexually produced spores (Bugon et al.1997). In the restoration of peatlands diaspores are applied to the bare peat surface and should not be buried. Most of the research on the restoration of peatlands has been done on a small to medium scale and the diaspores or individual plants are usually applied by hand. On a larger scale the *Sphagnum* is put through a shredder and applied with a manure spreader at a ratio 1:8 or $1m^2$ of *Sphagnum* moss to $8m^2$ of bare peat surface (Rochefort et al. 1997).

The material that is used for restoration of peatlands is living *Sphagnum* moss, which is collected from natural bogs referred to as borrow sites (Rochefort et al. 1997). The material collected from the upper 0-10 cm layer of acroletm has a greater regeneration capacity than lower layers. *Sphagnum* moss that was collected from the lower layers 10-20 cm and 20-30 cm of acroletm resulted in very little regeneration. On borrow sites in which *Sphagnum* moss was removed and natural revegetation was allowed to occur, the recovery rate depended on the species. After one season *Sphagnum fuscum* regenerated to 40% cover and *Sphagnum angustifolium* only had regeneration of 5%. This slower rate of regeneration could be due to this species more loose growth habit (Rochefort et al. 1997). Different sites were mulched with straw and without straw.

The rate of regeneration was greatest on sites in which straw mulch was applied (Rochefort et al. 1997).

Under greenhouse conditions most *Sphagnum* species regenerated most rapidly when water levels were maintained at .5 cm below the peat surface (Rochefort et al. 1997). Diaspore fragments at a density of 450 plants per m^2 resulted in 50% cover in 3 months and 100% cover in 6 months. Under field conditions it would be more difficult to maintain and regulate high water levels (Rochefort et al. 1997).

In the restoration of peatlands the of nutrient amendments and the use of companion species also improved conditions for both *Sphagnum* moss and other bog species. The nutrient that is most limiting in post-harvested peatlands is phosphorus. The highest levels of phosphorus occur in the upper acroletm layer, which is removed when the bog is harvested. In a study by Ferland et al. (1997) conducted in a post-harvested bog in New Brunswick, several plots were studied in which phosphorus was applied and in other plots no nutrients were applied. Both these areas were planted with companion species. The companion species were used to provide protection to the diaspores by reducing transpiration, preventing desiccation from wind and solar radiation and by providing shade (Ferland and Rochefort 1997). Companion species are plant species such as brown mosses, sedges and ericaceous shrubs that commonly occur in bogs. The companion plant species were introduced one year before the *Sphagnum* diaspores are applied. Triphosphate (0-46-0) was applied at a rate of 50 g/m^2 to the bare peat surface when the companion species were planted. Phosphorus at this concentration is detrimental to many bryophytes such as *Sphagnum* moss and a more diluted concentration was applied the following season, when the diaspores were reintroduced (Ferland and Rochefort 1997).

Eriophorum ssp. had the best results in re-establishment and in providing protection to the diaspores. The fibrous root system of this species also helps to reduce soil erosion. Other species such as the brown mosses and ericaceous shrubs did not provide much protection to the diaspores. Many of the ericaceous shrubs did not transplant very well, due to damage to their root systems during collection from natural sites (Ferland and Rochefort 1997). It was also observed that the ericaceous shrubs, which flowered, after transplanting, had a larger percentage of seedlings on fertilized plots, than on plots in which no fertilizer was applied. *Sphagnum* moss on fertilized plots also appeared to be larger and greener in color, when compared to plots in which no fertilizer was applied (Ferland and Rochefort 1997). The application of nutrient amendments improved the survival rate of transplants and increased plant growth.

The restoration and reclamation of peatlands is a relatively new field in Canada. The majority of the research and the development of techniques on restoration of peatlands have been conducted in the 1990s. Further research is required in the re-establishment of other bog plant species, other than *Sphagnum* moss. Removal of plant species from natural bogs is disruptive to the natural bogs and some species do not survive transplanting. Another alternative in the restoration of peatlands may be the propagation of other bog plant species by seeds, cuttings or rhizomes or the moving of plant material from a newly harvested site to a post-harvested site in the same area. Restoration techniques such as these improve the likelihood that post-harvested peatlands may no longer remain as barren wastelands for decades, but may be used as a sustainable resource. By reintroducing *Sphagnum* moss and other bogs species and improving conditions for plant growth on post-harvested peatlands, the process of revegetation can occur at a more rapid rate than by the slow natural process of revegetation which occurs on vacuum harvested bogs. The natural accumulation of peat will take hundreds of years to replace the layers that were removed by harvesting and before harvesting can be done again. (http://www.peatmoss.com./pm-me3htrm.)

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