Sphagnum Farming in Canada: State of Knowledge

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OBJECTIVE AND BACKGROUND

In light of the many potential benefits of Sphagnum farming and interest from the Canadian horticultural peat industry, some research projects to test small-scale Sphagnum farming approaches were launched in the early 2000s, in partnership with the Peatland Ecology Research Group (PERG), the Research and Development Institute for the Agri-Environment (IRDA), VALORĒS, and the Canadian Sphagnum Peat Moss Association (CSMPA). The encouraging results of these projects led to a first experimental Sphagnum farming site being set up in New Brunswick, from 2006 to 2012, with industry partners. Subsequently, two other experimental sites were established, one in Quebec and one in New Brunswick, in 2013 and 2014. These included an optimized irrigation system and improved hydrological controls.

This document aims to review the knowledge that has been acquired since the first Sphagnum farming sites were created, bring together the expertise developed during that time, and summarize all the concepts needed to establish and operate a farming site. Given that experience with certain aspects of Sphagnum farming is still limited in Canada, we will also present some of the knowledge gained by German teams. The information presented here will need to be updated as research and practices move forward.

This document first introduces basic concepts about Sphagnum farming, including its benefits and the potential uses of *Sphagnum* fibres. This is followed by the various aspects to consider when planning a farming site, namely, the site characteristics and the sources of plant material. We will address the preparation of the farming site, encompassing all aspects of basin development, such as implementing the irrigation system and reintroducing plant material. Then, maintenance and monitoring of the farming site will be presented, followed by harvesting, *Sphagnum* fibre conditioning, and the various resources needed. The conclusion will provide an overview of the key elements along with some useful references.

1. INTRODUCTION

Growing Interest in Sphagnum Farming

In modern horticulture, blond peat or *Sphagnum* peat is the main ingredient in growing media, due to its unique characteristics: high water- and nutrient-retention capacity, low density, high porosity and its structural stability.

The biomass of non-decomposed *Sphagnum* has been proposed as an alternative to blond peat and could be used in a variety of contexts. Since *Sphagnum* makes up the base of blond peat, their physical and chemical properties are very similar. *Sphagnum* forms from two types of plant cells: the chlorophyllose cells (chlorocysts) responsible for photosynthesis and the empty hyaline cells (hyalocysts) for water storage. Because of this unique feature, *Sphagnum* has a very high water-retention capacity, up to 90% of its volume. It also emits humic acid, and can absorb and retain nutrients and cations.

Figure 1. Non-decomposed *Sphagnum* fibres.

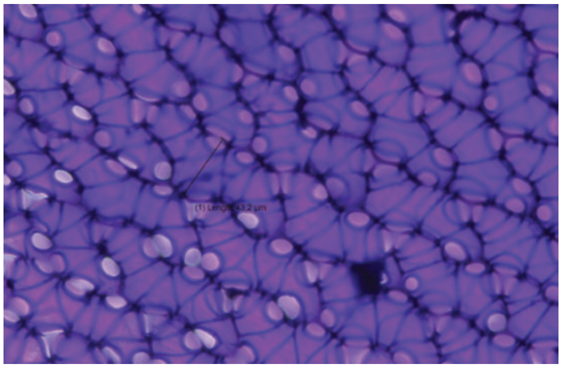

Figure 2. Cellular structure of a *Sphagnum* branch leaf.

Sphagnum farming is defined as the sustainable production of non-decomposed *Sphagnum* fibre biomass, on a cyclical and renewable basis. The efforts made to restore peatlands in Canada in the last three decades have confirmed the feasibility of large-scale multiplication of non-decomposed *Sphagnum* fibres. However, it has been shown that hydrological conditions must be controlled to optimize *Sphagnum* biomass production. This is why, on the field, Sphagnum farming is practised in irrigation basins. The design and implementation of irrigation systems and the reintroduction of plant material will be discussed in section Steps in Site Implementation (p. 20).

Potentials Uses of *Sphagnum* Fibres

I. Growing Media

Cultivated *Sphagnum* fibres could be used as a new ingredient in growing media, to decrease their environmental footprint. For instance, two Canadian studies[1] have shown that *Sphagnum* can replace some or all the perlite and vermiculite used in growing media, without altering their chemical or physical properties. Other studies have suggested that *Sphagnum* fibres can at least partially substitute the peat content in growing media, or that it can improve the structure of peat substrates with a more advanced degree of decomposition (e.g., von Post H6 to H7[2]). Indeed, *The* principles for *Wise Use of Mires and Peatlands*[3] recommends optimizing peat extraction once a peatland has been opened for production. The principle of wise use states that it is better to use a peat deposit as much as possible rather than opening up a new one, while making sure to leave at least 50 cm of residual peat (with the appropriate characteristics) to facilitate restoration. Consequently, adding *Sphagnum* fibres as a value-added ingredient in peat-based growing media, taken from a extraction site nearing its end of life, can contribute to wise management of this resource. A lot is still not known about these mixes, however, since the proportion of *Sphagnum* in growing media can change according to a number of criteria, including the targeted horticultural production, the grade of peat used, and the *Sphagnum* species.

Sphagnum is already used as a growing media in orchid propagation and cultivation. The species of this family are particularly well adapted to the characteristics of *Sphagnum* as a growing media, and this market is well established.

II. Donor Material for Peatland Restoration

In areas with limited numbers of donor sites for restoring *Sphagnum*-dominated peatlands, the biomass of *Sphagnum* produced in farming sites can be used as donor material. As compared with material from natural peatlands, the use of material from farming sites has led to a similar establishment of *Sphagnum* and vascular plants, and the same plant diversity.[4] For this to be successful, the *Sphagnum* carpet harvested from the farming site must be at least 5 cm thick, which, in our experience in Canada, can be generated in about 3 to 4 years.

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[1] Aubé et al. (2015) and Jobin et al. (2014)

[2] See Appendix C of the Peatland Restoration Guide (Quinty and Rochefort, 2003) to assess the degree of peat decomposition.

[3] Joosten et Clarke (2002)

[4] Hugron and Rochefort (2018)

III. Other Potential Uses

Sphagnum fibre can have a number of other uses. Some have already been commercialized, while others should be assessed beforehand. For instance, it can be used as a filtration agent for wastewater. In the animal care industry, *Sphagnum* is used as terrarium bedding. Some companies manufacture hanging flowerpots using *Sphagnum*. Its fibres could also be incorporated into the manufacture of pots made of peat. Given *Sphagnum's* high absorbency, it could be used to make hygiene products such as diapers, sanitary napkins, paper towels, or as an absorbent material for use with toxic product spills. Lastly, due to its high porosity, *Sphagnum* fibre has the potential to serve as insulation for building construction.

Environmental, Economic, and Social Benefits

Sphagnum farming is a form of **paludiculture**, which is defined as the production of agricultural biomass in natural or rewetted wetlands. As an approach to sustainable peatland management, activities related to Sphagnum farming preserve the carbon deposit and have little or no impact on the ecological goods or services.

Sphagnum farming is in line with the United Nations' Sustainable Development Goals (SDGs)[5] (mainly goal 12 "Responsible consumption and production," goal 13 "Climate action," and goal 15 "Life on land"). It keeps carbon in the peatland soil supporting the crop. In addition, as the *Sphagnum* carpet becomes established, the Sphagnum farming basins actively sequester carbon. However, when we also take into account the methane emissions from irrigation canals and the carbon export during the harvesting of *Sphagnum* biomass, Sphagnum farming sites are generally considered to be carbon neutral.[6] Promoting the return of peatland plants maintains a certain level of biodiversity in Sphagnum farming basins.[7]

Cultivated *Sphagnum* fibres could replace floral moss as well as the donor material used in restoration, which is currently being harvested in natural peatlands. This would reduce the impacts of harvesting and help preserve peatland ecosystems. By minimizing the amount of peat required in growing media, Sphagnum farming could reduce the environmental impacts of drainage during peat extraction, namely, peat oxidation, soil subsidence, and CO_2 emissions. Besides, it is now widely recognized that keeping peatlands moist is an effective way to reduce CO_2 emissions and fight climate change. Under Canada's Greenhouse Gas Pollution Pricing Act, a company producing *Sphagnum* through farming could obtain carbon credits, due to the CO_2 sequestered during plant growth. However, some aspects of the carbon balance of Sphagnum farming sites should be studied more in depth.

[5] Hyperlinks are only available in the online version of the document.

[6] Beyer et Höper (2015) and Günther et al. (2017)

[7] Muster et al. (2020)

Wetlands generally have the capacity to hold a large volume of water and this quality is preserved when peatlands are used for Sphagnum farming. This is because it does not require net drainage of the area, merely that drains and canals be installed to control irrigation. Activities relating to Sphagnum farming are safe for the environment and do not alter the health and safety conditions of citizens living nearby, and in fact, it can potentially create jobs for them.

International Advances

Considerable progress has taken place in the research on Sphagnum farming in the last two decades, including small-scale testing in several countries and larger-scale trials in Canada and Germany.[8] Aside from the work done in Canada, it is mainly German expertise that has most advanced since the 2000s, due to the scarcity of *Sphagnum*-dominated peatlands there and strong pressure from the European community to reduce or even eliminate peat extraction. Research[8] has been conducted at several levels of Sphagnum farming development: vegetative propagation of *Sphagnum*, storage and conditioning of *Sphagnum*, species selection, types of cultivation (e.g., on floating mats), hydrological controls, *Sphagnum* harvesting, post-harvest regeneration, and more.

However, it is important to account for the differences between the German and Canadian contexts before making direct comparisons. Notably, Sphagnum farming sites in Germany (specifically in Lower Saxony) are generally established on former peat bogs that have been used for agricultural purposes for decades or even centuries. As a result of peat subsidence, these peatlands are now located below sea level. Therefore, water management in these farming sites requires a totally different approach than in Canada. In Germany, pumping systems are used to drain excess water from the site. And German peat deposits are generally more decomposed (von Post H6 to H10), thinner, and characterized by very low permeability.[9] The peat and the irrigation water are higher in nitrogen, phosphorus, and potassium, for a number of reasons including the history of peatland use in Europe (e.g., for grazing and agriculture) and higher atmospheric nitrogen deposition. This higher nutrient content favors fast-growing *Sphagnum* species such as *Sphagnum fallax*, of the *Cuspidata* subgenus, as compared to *Sphagnum papillosum*[10], which was initially reintroduced. What's more, in Canada, a lower annual productivity is to be expected, compared to the results obtained in Germany, due to our shorter growing season.

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[8] Gaudig et al. (2018)

[9] Grobe et al. (2021)

[10] Gaudig et al. (2017)

2. PLANNING

There are two steps involved in planning a Sphagnum farming site: defining the purpose of the cultivation and planning the work. Different parameters must be taken into account depending on the objective for farming *Sphagnum*, for instance, to integrate it into growing media or to produce donor plant material for restoration.

But regardless of objective, the following questions must be answered during the planning stage: Is the selected site suitable for cultivation? Are all the necessary resources available, such as general installations with a power source, water, and plant material? The work planning step includes details on the methods and resources to be used, a time line, and a cost assessment.

Farming Site Characterization

I. General Aspects to Consider

The environment surrounding the site may have a major impact on the project. It is therefore essential to carefully examine the components of this environment and to be able, insofar as possible, to anticipate possible changes over the medium and long terms. For instance, a conventional farm located nearby could affect the Sphagnum farming. Any drainage near the site must also be taken into account because peripheral drainage can influence water level and movement. Natural elements can also impact Sphagnum farming, notably proximity to the ocean, which can cause salt water infiltrations. In the Maritime provinces, coastal erosion is also a long-term factor to consider when selecting a location.

In western Canada, regional climate conditions must be factored in when planning, especially annual precipitation, given its important water contribution. For instance, overlong dry periods could be problematic for this type of project, even with an irrigation system.

Several other general aspects must be studied during the planning stage, to minimize risks and facilitate operations. Site selection and structuring must also be rigorously thought out before work begins. Some of the elements to consider are the accessibility of the site to heavy machinery, storage for harvested material, power source, the source of irrigation water, the proximity of various installations (such as the irrigation control point), and the space for basin development for future expansions. These elements must work together and be practical for the planned operations.

Establishing a Sphagnum farming site remains an activity in a wetland and consequently there are laws and regulations that apply to operations in this type of environment. It is therefore important to contact provincial government authorities to analyze the laws that could impact the project. The government departments responsible for natural resources and the environment are definitely the most likely to be able to provide pertinent information. In some cases, municipal governments may have some jurisdiction over the wetlands on their territory.

The project's profitability must also be assessed before launching a Sphagnum farming site. Since each project has its particular features, it is important to use profitability analysis tools and make sure the level of financial risk is acceptable before development work begins.

II. Potential Sphagnum Farming Sites

Sphagnum farming basins can be established in various types of sites, each with its own advantages and disadvantages. Old trenches created during block-cut peat extraction have a great deal of potential for Sphagnum farming because they generally require very little land redesign, due to the presence of alternating trenches and baulks. However, there is a limited number of sites that were used for block-cut peat extraction in Canada, and this type of peat harvesting has practically disappeared in the industry. Sphagnum farming sites can also be developed in peatlands where peat was vacuum extracted towards the end of the operations. There are many more of these sites in Canada. To date, however, few projects have been conducted in this type of site, so the know-how is rather limited. Lastly, Sphagnum farming basins can be established in natural or restored peatlands. This type of site requires a fairly extensive level of redevelopment, which can decrease the environmental benefits that these sites offer, mainly due to the frequent passage of machines.

III. Hydrological and Topographic Features

When selecting a site for Sphagnum farming, the hydrological and topographic features should be considered, to maximize the natural water supply and minimize losses, in accordance with groundwater circulation. It is also important to pay attention to the type and porosity of the underlying mineral soil, as there may be underground flow that causes water loss from the basins through a subterranean vein.

First, the site's natural drainage basin and nearby streams should be studied. Hydrological wells are a simple but practical tool for assessing water level and movement. They should be situated at several locations on the site being targeted for Sphagnum farming and monitored over time, especially during floods and droughts. Additionally, drones, LiDAR data, and topographical surveys can be used in preparing a high-accuracy digital site model (figure 3). These models can be beneficial, for instance, for indicating water movement and, later, for basin development and levelling. Characterizing underground water movements can also be very useful in determining the optimal position of the basins and the irrigation network during the subsequent site preparation stage (see section Building the basins, p. 20).

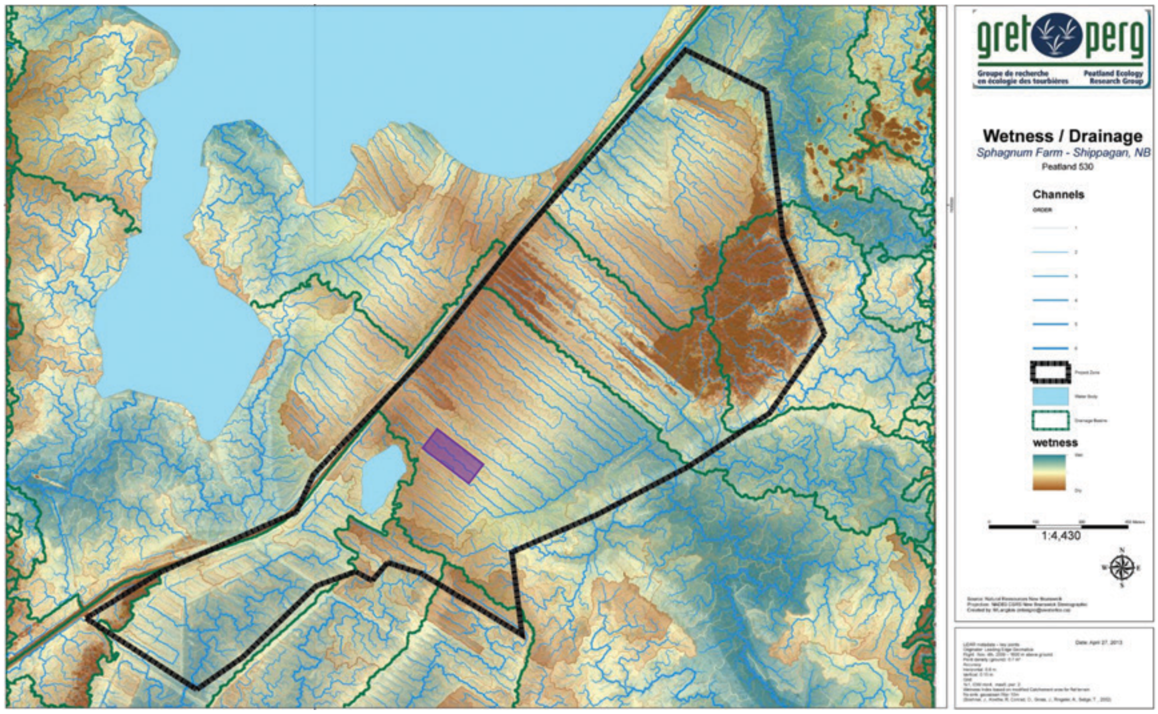

Figure 3. Example of a LiDAR map that helped researchers select the location of the Sphagnum farming site at the Peatland 530 in Shippagan, New Brunswick (in purple).

IV. Peat Characteristics

A detailed description of the peat's physicochemical characteristics is essential to determine whether a given site is suitable for Sphagnum farming.

From a chemical point of view, characterizing the pH and the electrical conductivity of the peat at the surface helps establish whether the peat deposit is appropriate for *Sphagnum* growth. Similarly to the recommended thresholds for *Sphagnum* peatland restoration, the peat pH values should ideally not exceed 5.5 to 5.8, and the electrical conductivity values should be below 100 to 140 μS/cm. However, these benchmarks are flexible, especially since a lower pH value (e.g., 4.8) can be combined with a higher conductivity (e.g., 300 μS/cm), and vice-versa. As regards the major cations, i.e., calcium, magnesium, and potassium, their concentrations should, as much as possible, not exceed, respectively, 5–9 mg/L, 4–8 mg/L, and 0.5–2 mg/L. Contrary to the belief that high levels of calcium are harmful to *Sphagnum*, it is rather higher concentrations of bicarbonate that are harmful since they increase alkalinity. The bicarbonate concentration should absolutely not surpass 500–2000 μM, which represents an alkalinity of 800–2000 μeq/L. Below these thresholds, it is possible for a *Sphagnum* carpet to develop because, unlike with conventional agriculture, *Sphagnum* does not require a mineral- or nutrient-rich substrate.

As for the physical aspects, determining the type of peat found on the surface makes it possible to assess the substrate's effectiveness as a sponge, i.e., at absorbing water and letting it circulate easily. *Sphagnum* peat moss is the most suitable substrate, as its low level of decomposition (von Post H1–H5) enables it to transport and retain water easily. Also to be considered is the residual thickness of the peat deposit; however, it is difficult to set a minimum thickness. Generally speaking, Sphagnum farming sites in Canada have been established on thicknesses of at least one metre of fairly undecomposed peat (von Post H3–H4). It is possible for *Sphagnum* to become established on more decomposed (von Post > H6) and thinner peat deposits, but this increases the risk of hitting the underlying mineral substrate when digging irrigation canals. This can enrich the water in the canals via direct contact and promote the spread of vascular plants whose roots are capable of reaching the mineral substrate. It is recommended that Sphagnum farming sites be established on fairly undecomposed peat (von Post H1–H5). Furthermore, the peat deposit should have a minimum thickness of 50 cm to 1 m, depending on the selected irrigation structure, while avoiding going down to the mineral substrate when constructing the basins.

SPHAGNUM FARMING ON DECOMPOSED PEAT IN GERMANY

In Germany, Sphagnum farming has been tested and successfully established on peat deposits that are highly decomposed (> H6) and as thin as 30 cm. However, during dry periods, the peat on the surface hardens and forms a crust that prevents water from rising via capillary action up to the *Sphagnum* (figure 4). And if these dry periods are followed by significant rainfall, the crust then also hinders water penetration into the peat, leading to considerable erosion problems. Therefore, in such environments, it is critical to avoid any failure in the water supply from ground reserves. However, since more decomposed peat is less permeable, it is much more difficult to maintain a stable, high water table throughout the basins.

Figure 4. "Crusty" peat surface and displacement of plant material, resulting from dry periods followed by abundant rain.

V. Quantity and Quality of Water Available for Irrigation

The amount of water needed depends on the targeted water level, the total area of the basins, and the type of irrigation selected for the cultivation basins. Depending on this target, the water volume required to irrigate the basins can be quickly estimated from the dimensions of the irrigation canals. Relative to the overall water volume, only a minimal amount is lost to evaporation in the canals or evapotranspiration in the basins.

The water source should be as local as possible to minimize the resources needed for water delivery to the site and to ensure that the water quality, in terms of chemical makeup, is suitable for Sphagnum farming. For instance, the water source used for the Sphagnum farming site at the Peatland 530 in Shippagan (New Brunswick) is a peatland lake, located under 100 m away, whose pH and electrical conductivity are, respectively, 4.6 and 97 μS/cm. For the Saint-Modeste site (Quebec), the water comes from a sedimentation basin supplied from an onsite water tank, and its pH and electrical conductivity are 6.7 and 190 μS/cm. However, setting up a Sphagnum farming site near a natural peatland water source can be complicated, especially given the need to obtain an environmental authorization for water withdrawal and to monitor water levels frequently. It may also be possible to dig a water retention basin to collect drainage water from the extraction fields as well as rainwater and snowmelt. Provincial laws and regulations should be checked beforehand.

It is possible to cultivate *Sphagnum* using water with thresholds higher than those mentioned above for peat's chemical characteristics. According to current knowledge, the pH and electrical conductivity of the irrigation water should not exceed 7 and 200 μS/cm.

IRRIGATION WATER ENRICHMENT IN GERMANY

In Germany, irrigation water generally comes from retention basins that collect drainage water from nearby agricultural fields along with rainwater. In addition to a high phosphorus and potassium input from the irrigation water, nitrogen from atmospheric deposition has also been observed. Yet, this enrichment does not limit *Sphagnum* growth. However, these rich conditions favour faster-growing and highly competitive *Sphagnum* species, such as *Sphagnum fallax* of the subgenus *Cuspidata*, which may even completely overtake *Sphagnum papillosum*, the species being targeted for cultivation.

Plant Material Source

For cultivation, enough initial *Sphagnum* biomass must be available to be spread in the basins. Given that the germination of *Sphagnum* spores in the field is complex and unlikely, it is advisable to take advantage of vegetative propagation, that is to say, *Sphagnum's* ability to regenerate from any part of the plant. This merely requires a donor site of a sufficient size (according to the reintroduction ratio; see section Reintroducing plant material, p. 29) containing the targeted species. It can be in a natural peat bog or from the previous production cycle of a Sphagnum farming site.

I. Selection of Sphagnum Species for Cultivation

Selecting what species of *Sphagnum* to farm will depend on their intrinsic properties and what the final use of the produced biomass will be. *Sphagnum* species generally share similar intrinsic properties within a same subgenus (*Acutifolia*, *Sphagnum*, *Cuspidata*).

Sphagnum moss of subgenus *Acutifolia* (figure 5), such as *Sphagnum rubellum* and *Sphagnum fuscum*, are found on hummocks and lawn of natural peatlands, where they form dense, matted carpets that easily transport water via capillary action. Therefore, these species are more drought resistant and tolerate lower water levels. *Acutifolia* are the slowest growing, but they also have the lowest decomposition rates, making them appealing for cultivation.

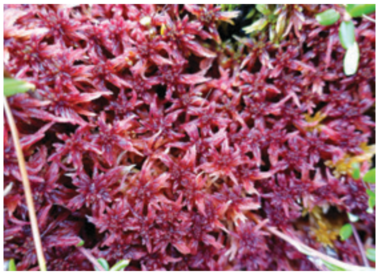

Figure 5. *Sphagnum* moss of subgenus *Acutifolia.*

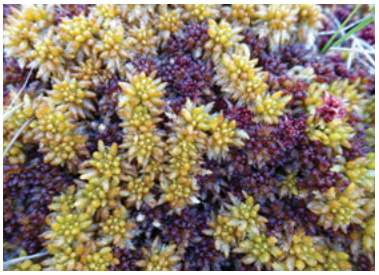

Figure 6. *Sphagnum* moss of subgenus *Sphagnum.*

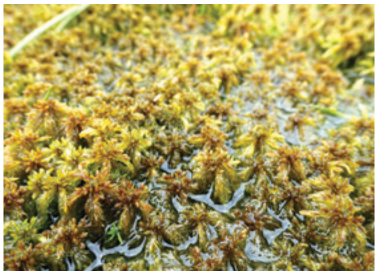

Figure 7. *Sphagnum* moss of subgenus *Cuspidata.*

SPHAGNUM FLAVICOMANS: AN INTERESTING SPECIES FOR SPHAGNUM FARMING

Sphagnum flavicomans is a species of the *Acutifolia* subgenus that is endemic[11] to the Atlantic maritime regions of North America. It has promising potential for farming, since it is a large species compared to other *Acutifolia* mosses, giving it high porosity, which is an interesting characteristic for growing media.

Figure 8. *Sphagnum flavicomans.*

Sphagnum moss of the subgenus *Sphagnum* (figure 6), such as *Sphagnum medium* and *divinum* (formerly both identified as *Sphagnum magellanicum*) and *Sphagnum papillosum*, are larger and highly porous, which makes them interesting for use as growing media. Because of their larger size, they create carpets that are less dense than *Acutifolia*, but they can accumulate a great deal of biomass per unit area. *Sphagnum* moss of subgenus *Sphagnum* also decompose slowly but are less drought resistant than *Acutifolia* because of their less-dense carpets. They are found in the lawn of natural peatlands, where they are tolerant to variable water levels.

[11] Endemic: species found exclusively within a defined geographical region.

Species of the *Cuspidata* subgenus (figure 7), such as *Sphagnum cuspidata* and *Sphagnum fallax*, are typical mosses found in the hollows of natural peatlands. They make loose carpets that don't allow for good water conservation at the surface. Therefore, even though *Cuspidata* have the highest growth rate, they frequently dry out in summer, which greatly affects their biomass yield. Furthermore, their leaves decompose quickly, resulting in a peat essentially made up of stems and poor-quality biomass with low porosity.

These differences in terms of leaf and pore sizes, production and decomposition rates determine the different species' potential for use in growing media. If the cultivation goal is to produce *Sphagnum* for use as horticultural growing media, then several *Acutifolia*, *Sphagnum* and *Cuspidata* species can be selected. It has been shown in growth tests[12] that these subgenera can be incorporated into growing media while maintaining its quality. However, less consistency is shown in some results with the subgenus *Cuspidata* than with *Acutifolia* and *Sphagnum*. For cultivating floral moss, we do not know of any studies identifying the most suitable type of *Sphagnum*, but have observed that *Sphagnum* subgenus is most often used. If, however, the goal is to use *Sphagnum* fibres to manufacture an absorbent product, then the species of the subgenus *Cuspidata* should be avoided. And lastly, in order to produce donor material for peatland restoration, the *Sphagnum* species cultivated should be from the subgenera *Acutifolia* and *Sphagnum*. In addition, bog haircap moss (*Polytrichum strictum*) should be included, as recommended in the Peatland Restoration Guide: Plant Material Collecting and Donor Site Management.

Key Elements to Check During Planning

It is possible to establish a Sphagnum farming site if the following key elements are found to be available during the planning stage:

- Access to a power source
- Access to an irrigation water source of suitable quality
  - pH ≤ 7 and electrical conductivity ≤ 200 µS/cm
- Suitable-quality peat substrate in the basins
  - pH ≤ 5.5 to 5.8 and/or electrical conductivity ≤ 100 to 140 µS/cm
  - Low decomposition rate (von Post H1–H5)
  - Minimum thickness ≤ 0.5 to 1 m
- Availability and suitability of plant material to start the farming site
  - *Acutifolia* and *Sphagnum* subgenera

[12] Gaudig et al. (2018)

3. RESEARCH HISTORY

Rewetting Method

The various research projects conducted by the Peatland Ecology Research Group (PERG) have demonstrated that, in combination with plant introduction, it is necessary to rewet the residual peat deposit in post-extraction peatlands in order to restore hydrological conditions that can allow a carpet of *Sphagnum* to establish itself. Given the need to have a water table close to the surface to optimize the establishment and growth of *Sphagnum*, knowledge of the different rewetting approaches for post-extraction peatlands is highly relevant for Sphagnum farming.

Various methods of rewetting peatlands have been tested in the past, and not all have proven effective. In particular, surface irrigation that uses sprinklers to keep *Sphagnum* moist was shown to have a negative impact, since the peatland water, which is rich in dissolved organic carbon, created peat deposits on the *Sphagnum* capitula (figure 9). Additionally, during the *Sphagnum's* establishment stage, the water drops hitting the ground continuously moved the newly reintroduced propagules. Mist-type sprinklers were not an option either, because the system quickly clogs up due to the fine particles present in the water. What's more, this type of irrigation system is very expensive. Thereafter, the creation of closed basins (without irrigation or drainage canals) measuring 20 cm deep was considered (figure 10). Indeed, cultivation in basins does give the *Sphagnum* better access to the water needed for growth, but it is difficult to maintain the optimal conditions. Also, the *Sphagnum* was frequently submerged by flooding in the basins, which is harmful during the establishment stage; however, this is less problematic once the *Sphagnum* carpet is completely formed. When the goal is to establish a *Sphagnum* carpet and optimize its yield, for instance when cultivating *Sphagnum*, **the best option is actively managing the basins' hydrological conditions.** The water level is kept just below the peat surface via lateral irrigation from reservoir canals (figure 11). During dry periods, the water in the canals is delivered laterally to the adjacent peat according to the peat's hydraulic conductivity. In times of water surplus, the canals are used to evacuate excess water to prevent flooding.

Figure 9. Surface irrigation via sprinklers.

Figure 10. Irrigation via surface flooding.

Figure 11. Irrigation via lateral water supply.

Controlling Hydrological Conditions

One of the first larger-scale (1.26 ha) Sphagnum farming sites in Canada was established in a former block-cut peat extraction site in New Brunswick (Peatland 527). This site took advantage of the existing topography of alternating trenches and baulks, and the production basins were established in the trenches. The water level in the basins was controlled manually: the level of the dams was set to maintain a maximum water level of around 5 to 10 cm below the surface. This system made it possible to evacuate surplus water in the fall and spring, but did not prevent significant drops in the water table level in summer, since precipitation was the only source of water.

The water level thus varied greatly between basins and even within any given basin. The result was significant variations in *Sphagnum* biomass production (figure 12 – yellow bars). Optimizing water access in Sphagnum farming basins **through active irrigation doubled the biomass production, on average**. Therefore, installing an active irrigation system is strongly recommended when setting up a Sphagnum farming site.

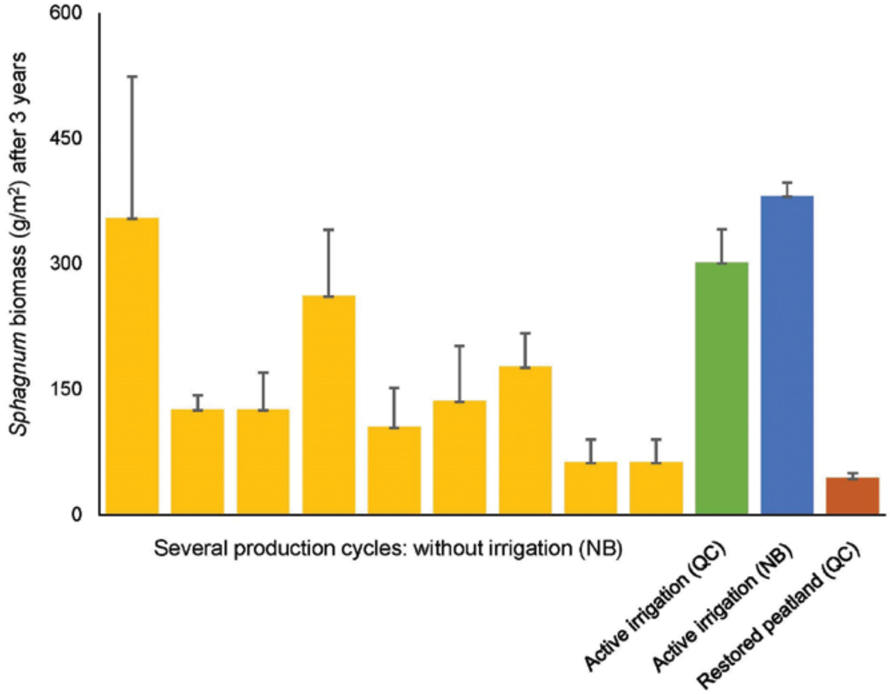

Figure 12. Average three-year *Sphagnum* biomass accumulation after their reintroduction in different Sphagnum farming sites, with or without irrigation, in New Brunswick and Quebec, as compared with a restored *Sphagnum*-dominated peatland.

GREENHOUSE PRODUCTION AND MICROPROPAGATION

Several studies[13,14] have demonstrated that it is also possible to cultivate *Sphagnum* in a hydroponic greenhouse setting. This type of cultivation significantly prolongs the *Sphagnum* growth period. Micropropagation tests have also been successful; however, these methods can be complex since they only work from spores, which are rather difficult to obtain due to scarcity.

[13] VALORĒS (2022a)

[14] Unpublished data, PERG

4. STEPS IN SITE IMPLEMENTATION

Developing a Sphagnum farming site begins with setting up the basins and installing the irrigation system. It may be a good idea to test the irrigation system to make sure it is operating effectively before introducing the plants. Once the plant material is in the basins, the irrigation system can be turned back on.

Most of these steps are done with machinery. The operations should be done from the outside (from the borders of the basins) to minimize any disturbances and compacting of the peat. Altering the profile of the peat will modify its properties, notably its hydraulic conductivity. Where machines must move around inside the basins, you can reduce the risks of them sinking and getting stuck by draining the basins beforehand. Inside the basins, it is preferable for machinery to move around on floats, plywood boards, or on the plant layer before it is removed, and for mini-crawler excavators to be used. It is also an option to work on frozen ground; however, the window of operation may be difficult to target, since the ground must be partly thawed but still frozen underneath. Finally it is important to remember that the risk of machinery sinking varies according to the situation. Operating machines on former peat fields is less risky than in a natural peatland, since the peat in the peat fields is more decomposed, compacted, and contains less water.

Building the Basins

The first steps in building the cultivation basins is to demarcate the boundaries, remove the surface vegetation where necessary, excavate the basins to the desired depth, and level them out. These last three steps can be done simultaneously using an excavator equipped with an adapted bucket. While digging the basins, special care must be taken not to dig down to the underlying mineral soil. Making contact with this soil can cause significant problems: water loss through an underground vein, depending on the porosity of the mineral, and contamination of the peat by the mineral soil. Reaching highly decomposed peat (von Post > H6) should also be avoided because this can promote the growth of competing species. This is why it is important to characterize the site conditions beforehand.

An excavator bucket with a levelling edge can be used for grading. This should be done while using a laser level or total station. This allows a person located in the basin to check the level, give the excavator operation instructions, and make minor adjustments with a hand shovel where needed. If the basin is humid, the person going inside should wear snowshoes. The level of precision to target in the basin is **plus or minus 5 cm**, to allow for even water distribution and ensure an optimal *Sphagnum* yield.

Basin Size

Ideally, the basin width should make it possible for the excavator boom to reach the centre, so the excavator can reach the entire basin surface from the sides. This basin size makes most operations easier, from digging the basins to harvesting the *Sphagnum*. Basin width also has an impact on how effective the irrigation system can be. In dry periods, lateral irrigation is less effective farther away from the irrigation canals (figure 13). Thus, the wider the basins, the more difficult it will be to achieve the desired water levels at the centre. As for basin length, it depends on the slope of the site. The steeper the slope, the more complex and difficult it will be to achieve the targeted level of precision across the whole length of the site. In such cases, it is best to make several shorter basins.

The size of basins at Sphagnum farming sites in Canada vary. Irrigated basins measuring 10 x 50 m and 20 x 50 m have been put in place successfully; however, the latter require the addition of **transverse micro-channels** to improve water distribution all the way to the centre.

Installation of the Irrigation System

I. Type of Irrigation

During the Sphagnum farming experiments carried out in Canada, different irrigation devices were tested to determine the optimal irrigation methods. For instance, the use of reservoir canals was combined with subsurface drains and micro-channels. And, the irrigation structures were used at various positions. Five different devices have been implemented to date (figure 13): a) peripheral reservoir canals; b) a central longitudinal reservoir canal; c) a lateral longitudinal reservoir canal with transverse subsurface drains; d) a lateral transverse reservoir canal with a central longitudinal subsurface drain; and e) a lateral longitudinal reservoir canal with transverse micro-channels. When selecting the appropriate irrigation device, it's important to take the site conditions into account, especially the depth and characteristics of the peat and the natural flow of water (see text box, p. 26). If the thickness of the residual peat does not permit digging reservoir canals, then an irrigation approach using micro-channels should be given priority, to avoid reaching the underlying mineral substrate. If the peat is fairly decomposed, micro-channels also allow for better water distribution within the basins.

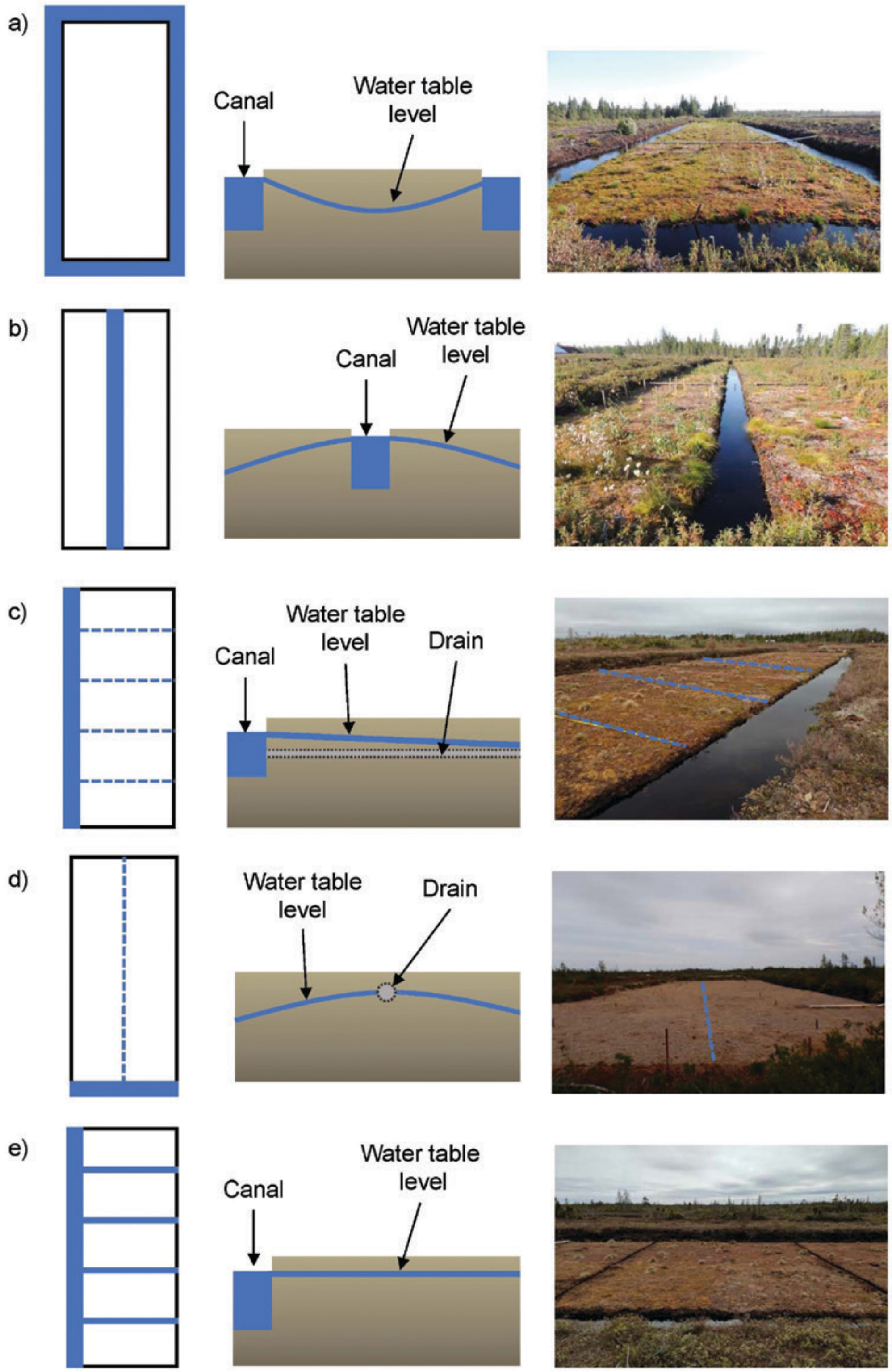

Figure 13. Aerial view and cross-section of the different type of irrigation structures: a) peripheral reservoir canals; b) a central longitudinal reservoir canal; c) a lateral longitudinal reservoir canal with transverse subsurface drains; d) a lateral transverse reservoir canal with a central longitudinal subsurface drain; and e) a lateral longitudinal reservoir canal with transverse micro-channels.

With reservoir canals, water is supplied via diffusion into the peat located near the excavated canals. The level of the water table in the basins varies according to the position of the reservoir canals (peripheral, central, or lateral; figure 13): it is higher near the canals and gets lower farther away. The efficiency of the water diffusion also depends on the peat's decomposition level, which influences hydraulic conductivity. The more decomposed it is, the weaker the hydraulic conductivity, and therefore, the less easily water will flow. On the different Sphagnum farming sites in Canada, the canals are 65 to 85 cm deep, and 60 to 130 cm wide (table 1). However, it has been observed that the deeper the canals, the more they tend to drain the basins rather than irrigate them, and that the canals tend to widen after excavation. Furthermore, large reservoir canals can increase potential water losses via underground flow, runoff at the dam, or evaporation. Large canals will also emit more methane into the atmosphere, negatively impacting the site's carbon footprint. Therefore, it is preferable to use shallower canals, to benefit from flow in only the first 30 to 50 cm, where the most permeable peat is located, which is characterized by higher horizontal hydraulic conductivity than the deeper peat horizons. The excavation of canals should be done when the peat is not water-saturated, since its structure can be damaged at that time.

The use of subsurface drains was considered with a view to reducing water losses via evaporation and methane emissions from the reservoir canals. The efficiency of irrigation with subsurface drains is directly dependent on the peat's hydraulic conductivity at the depth where the drains are installed and on the distance between drains. This form of irrigation is not recommended for peatlands with moderately decomposed peat (von Post > H5). The subsurface drains used were perforated agricultural drains, 4 inches in diameter and made of polyethylene. The perforations are slits measuring about 2 cm long. The drains are hydraulically connected to one end of the reservoir canal. When subsurface drains are installed laterally, they are spaced about 10 m apart. Installation is complex because the drains must be level across their entire length and must then be covered. After they are covered, the basin level must be readjusted. Practically, the use of subsurface drains does not appear optimal since it is possible, and even likely, that they will fill with peat over time. And, since they were installed at a depth of 75 cm in more decomposed peat, their efficiency is not optimized.

Micro-channels can be used to distribute water more efficiently to take advantage of the permeability of the surface layer peat (first 30 cm), as compared to deeper horizons, which are more impermeable. Since micro-channels run crosswise, they can be dug and cleaned from outside the basins, using an excavator with a sufficiently long boom and a shovel about 20 cm wide. Micro-channels are easier to put in place and maintain than subsurface drains. And, because of their small size, micro-channels are not as operationally challenging as reservoir canals. For instance, they are easy to cross on foot or with machinery and may be less of a hinderance to groundwater flow (see text box, p. 26).

Table 1. Dimensions of irrigation structures currently used in Sphagnum farming sites in Canada

Irrigation type	Position	Dimensions
Reservoir canal	Peripheral, central longitudinal, lateral longitudinal, lateral transverse	60–130 cm wide by 65–85 cm deep
Subsurface drain	Transverse, central longitudinal	4-in. pipe buried about 75 cm deep
Micro-channel	Transverse	20 cm wide by 15 cm deep

The optimal number of micro-channels and the distance between them depend on the peat's decomposition level at the basin surface and on the amount of precipitation during the growing season (May to October). Since water circulates less well in highly decomposed peat, which has low hydraulic conductivity, it is recommended that the number of canals be increased and that they be spaced closer than in a basin with less decomposed peat. Saturated hydraulic conductivity can be measured using the auger hole method in stratified locations. Finally micro-channels can be spaced out more in regions that receive more precipitation during the growing season (table 2).

Table 2. Approximate recommended spacing of micro-channels[15] according to the equivalent hydraulic conductivity[16] of *Sphagnum* peat moss and according to the cumulative May-to-October precipitation for the Québec/Bas-St-Laurent region (350 mm) and the Atlantic region (500 mm). Micro-channel spacing can be adjusted according to basin size. The symbol "-" is used when conductivity is so low that using micro-channels for irrigation is physically not recommended.

Hydraulic conductivity (K_e; m/jour)	Micro-channel spacing (m)	
	Québec/Bas-St-Laurent	Atlantic
24	50	75
2	15	18
1.5	12	15
1	10	13
0.8	9	12
0.6	7	10
0.4	5	8
0.18	2.5	4
0.034	-	0.5
0.017	-	-
0.009	-	-

The *Sphagnum* biomass yield results indicate that there is little difference between the various types of irrigation structures, even if they do not all result in a uniform water level inside the basins (figure 13). Therefore, selecting a type of irrigation is more dependent on practical considerations. The combination of a lateral reservoir canal and micro-channels seems to offer the best prospects for large-scale Sphagnum farming. Subsurface drains are not recommended, even though they give similar *Sphagnum* production results, because their long-term effectiveness is not certain. And basins with peripheral canals are definitely less practical at the operational level.

[15] The values in table 2 are the result of a simulation for a micro-channel with a rectangular cross-section of 20 x 20 cm, which will always have a water level of -2 cm (i.e., 18 cm full).

[16] Equivalent hydraulic conductivity (K_e) is an "average" of the saturated hydraulic conductivity (K_{sat}) measured for the different horizons identified, weighted by horizon thickness.

IMPORTANCE OF CONSIDERING NATURAL WATER FLOW

It has been observed that, depending on their position and depth, reservoir canals can intercept natural water flow and thus hinder the natural water supply in the basins (figure 14). At the Shippagan Sphagnum farming site (Peatland 530), some peripheral basins naturally receive more water than others due to their position. The basins receiving less water require more artificial irrigation to maintain the water table at the desired level. The use of micro-channels could potentially decrease this effect. And the orientation of the basins and channels can be selected to diminish or avoid this phenomenon where possible.

Figure 14. Interception of natural water flow by reservoir canals. Blue arrows indicate natural water flow intensity, and orange arrows show where the flow is intercepted by canals (image: 2022 CNES/Airbus).

II. Types of Dams

To control the water level in the basins, dams are placed at the canal exits. To date, two types of dams have been tested: (1) fixed dams and (2) mobile automatic dams.

Fixed dams are very simple systems to control the water level (figures 15 and 16). They are adjusted to maintain a maximum water level in the canals in summer, and then, if needed, opened in spring and fall to drain excess water. For instance, steel plates about 1 m high, driven almost entirely into the peat, have been used. They have an opening for inserting wooden planks as a way to determine the maximum level of the water table (figure 16).

Figure 15. Fixed dam with manually adjustable level.

Figure 16. Fixed dam where the maximum water level is adjusted by adding or removing boards in a steel plate with a bracket.

For more control over the level of the water table in summer, a device was put in place to make the dams mobile and automatic. It has been observed that in periods when water is being pumped into the basins, the canals have an irrigation effect, while in times of rainfall, they have a draining effect (figure 17). Thus, in times of rainfall, the level of the water table will be higher at the centre of the basin, while the opposite will occur during droughts. Given this, it is desirable to lower the water level during times of precipitation and to raise it in dry periods. This is what mobile dams can do.

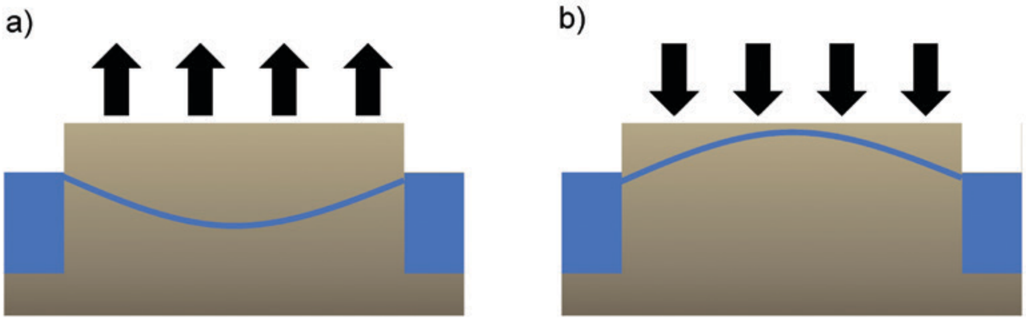

Figure 17. Behaviour of the water table in the basins, according to weather conditions: a) In periods of artificial irrigation, the canals have an irrigation effect and the water table is lower as it gets farther away from the canals; b) During times of precipitation, the canals have a drainage effect and the water table is higher as it gets farther away from the canals.

A mobile dam is in fact a system of pipes equipped with a valve installed on the downstream side of the dam (figures 18 and 19). A hole must be made at the bottom of the dam so the water can enter the pipe system. The valve is ordinarily in the closed position to keep water in the canal. If the water level must be decreased, the valve is simply opened, in one of two ways: The first is through a remote-control system. A sonic sensor (MaxBotix MB 7389) measures the water height upstream of the dam. When the water level goes too high, a program sends the signal to activate a linear actuator (Firgelli Automations, FA-PO-150-12-12), which opens the valve, allowing the water to drain. The second system is automatic and is equipped with a float. When the water level in the canal gets too high, the float simply triggers the opening of the valve. This system helps prevent surprise flooding in the basins, even in the event of system failure.

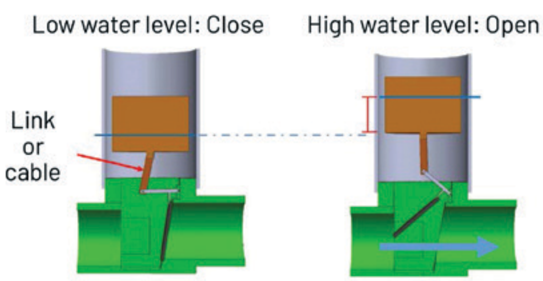

Figure 18. Operation of mobile dams. The dam valve is naturally closed and can open via either the linear actuator or float, when the water level is too high in the reservoir canal (illustration taken from the MSc thesis of Guillaume Goulet, 2019).

Figure 19. Mobile dam operating with a sonar that measures the water level in the reservoir canal, and with a linear actuator and a float (in the grey pipe) to open the dam valve.

In addition to fixed or mobile dams, it is recommended to add peat dams downstream. These should be well compacted using an excavator. The main goal of these peat dams is to protect the metal and wooden dams from the force of the ice in winter, by allowing for a similar water level on both sides of the dam. The peat dams can stay in place in summer, so long as they are slightly shorter than the first dams. In fact, peat dams can even help keep more water in the basin and create additional protection in the event of a leak at the first dam.

III. Targeted Water Table Level

Water is, without a doubt, *Sphagnum's* greatest need. However, *Sphagnum* mosses are not aquatic plants and do not tolerate being submerged for extended periods of time. Therefore, the optimal water table level would be as near the surface as possible, without creating flooding. In addition to threatening the *Sphagnum's* survival, frequent flooding can encourage fungus growth and can also move the *Sphagnum* and straw after reintroduction, ruining the site development work. If the water table is too low, this can have a considerable impact on the *Sphagnum's* growth and even survival. It is particularly critical to maintain a **high and stable water level** during the *Sphagnum* establishment stage, i.e., the first two years. After the *Sphagnum* carpet is established, variations in water level are less of a problem in terms of survival, but they can still have a negative effect on yields. Finally, a high water level minimizes frost heaving and its impacts on *Sphagnum* establishment and also keeps tree and shrub establishment to a minimum.

Sphagnum biomass yield results show that water at 10 cm below the peat surface generally yields more biomass than at – 20 cm, regardless of *Sphagnum* species. Furthermore, it has been observed that the stability of the water level is an important factor controlling *Sphagnum* growth and carbon sequestering. However, depending on the type of irrigation structure and dams used, the water level in the basins is not always on target throughout the growing season. An approach that combines a reservoir canal, micro-channels, and a mobile automatic dam has the best potential for uniform water distribution in the basin and for effective water level control.

Reintroducing Plant Material

Plant material is reintroduced into cultivation basins in a very similar way as in peatland restoration, that is, using the Moss Layer Transfer Technique (MLTT). Therefore most of the recommendations found in the Peatland Restoration Guide: Plant Material Collecting and Donor Site Management also apply to Sphagnum farming sites. Some technicalities are presented in the following sections.

I. Harvesting Plant Material

Selecting a Donor Site

The donor site should be dominated by *Sphagnum* moss of subgenera *Acutifolia* and *Sphagnum*, or more specifically, by the species targeted for cultivation (see section Plant material source, p. 14). It is not necessary that bog haircap moss be found in the donor site, though it is needed for peatland restoration. This is because, in restoration, bog haircap moss acts as a nurse plant, facilitating the *Sphagnum's* establishment and limiting frost heaving. But frost heaving is not usually an issue in Sphagnum farming, since maintaining a high water table lessens the phenomenon. Depending on the use that will be made of the *Sphagnum* fibres produced, the presence of bog haircap moss can affect the purity of the plant material.

Plant material can come from a sector of an undisturbed peatland that will be developed in the future or from a natural peatland. Another option is to harvest the material from a Sphagnum farming site whose carpet is thick enough. Collecting just a 5 cm carpet from basins is enough to relaunch a subsequent production cycle. This option is interesting because it reduces the amount of material needed for plant spreading, decreases the impact of harvesting in natural peatlands, and limits the need to transport the harvested material. Lastly, the donor site selected should be large enough for the selected spreading ratio.

Harvesting Donor Plant Material

Harvesting is generally done mechanically, with machinery selected according to the type of donor site (figures 20 to 23). For instance, to harvest in former block-cut extraction trenches that have been recolonized by *Sphagnum* mosses, it is effective and minimizes damage to use a crawler excavator with a mechanical fork or bucket attachment to scrape off the thawed surface layer of *Sphagnum* in the spring. Harvesting in a natural peatland can be done with the same machinery as used for peatland restoration. If the purpose of cultivation is to maintain a certain level of purity in the material being reintroduced, then harvesting can be done manually, with rakes and pitchforks. This however is only practical on a small scale, as it is quite time consuming.

Figure 20. Harvesting plant material in a former block extraction site using a crawler excavator with a fork attachment.

Figure 21. Harvesting plant material in a former block extraction site using an excavator with a bucket to scrape the thawed surface layer of *Sphagnum* in spring.

Figure 22. Shredding plant material with a rotary tiller, in an undisturbed peatland.

Figure 23. Collecting material after the rotary tiller has passed.

The plant material should be harvested at a time that will minimize the machinery's impact on the donor site, as recommended in the Peatland Restoration Guide: Plant Material Collecting and Donor Site Management. If the plant material must be stored before being reintroduced into the cultivation basins, it can be piled outdoors for a maximum of six months. Beyond that, the material's regeneration potential is greatly reduced, especially for vascular plants. Pre-treating the piled plant material to reduce the presence of vascular plants may be an option, but this requires further investigation. It is still recommended to use fresh plant material to establish Sphagnum farming basins.

II. Spreading Plant Material

Spreading Density

While it may be tempting to reintroduce more *Sphagnum* fragments by reducing the reintroduction ratio, in order to obtain a higher yield faster, it is important to remember that, even with farming, the same recommendations apply as with *Sphagnum*-dominated peatland restoration. It is pointless to spread more plant material than the recommended ratio (between 1:10 and 1:12). In a thick layer of *Sphagnum* fragments, those on the surface will dry out from lack of access to water, and those underneath will die off from lack of light.

Spreading Season

The recommendation is to spread plant material once the system controlling the hydrological conditions is operational and outside the dry season, that is, at the end of spring or beginning of summer. This ensures there are favourable conditions for the *Sphagnum* fragments to establish, and it avoids the extreme rains of autumn and the flooding after spring snowmelt (figures 24 and 25). Establishing the *Sphagnum* carpet at the start of the growing season makes it much more resilient to poor weather in fall or the following spring. It is not recommended to spread plant material in the summer, as the repercussions of any failure in the irrigation system would be too severe.

Figure 24. Flooding of plant material spread in fall, after a significant rainfall.

Figure 25. Displaced plant material and straw after strong winds.

Machinery to Use

In Sphagnum farming sites set up in basins, the machines used to spread plant material cannot move around inside the basins. The machines must be able to spread the plant material in the basins from the baulks, once they have been built. As a result, the canals and micro-channels must be cleaned after the plant material has been spread.

In the past, a side-discharge manure spreader has been used (figure 26). This is not the same machine used in restoration, therefore, a few adjustments are needed. Notably, the presence of roots in the spreader hinder its effectiveness at spreading material evenly in the basins. Therefore, the harvested plant material should, as much as possible, consist of *Sphagnum* only (figure 27). Also, the spreader should not be filled to capacity, to keep the plant material from compacting and blocking the outlet. With these adjustments, a side-discharge manure spreader has proved very effective[17], especially where basins are configured with a lateral canal, so it is possible to spread the plant material from the side without a canal and avoid needing to do canal cleaning after the spreading. Spreading plant material can also be done manually to get a more even distribution; however, this approach takes much longer.

Figure 26. Using a side-discharge manure spreader to spread *Sphagnum* fragments.

Figure 27. Plant material composed mainly of *Sphagnum* in the spreader.

KNOWLEDGE GAP: THE USE OF GEOTEXTILE

Spreading plant material on a geotextile has been considered. However, none of the products tested to date looks promising. They seem to create a hydrological barrier between the substrate and the *Sphagnum* and are easily blown away by wind or displaced through frost heaving, bringing the plant material with them. However, other products to facilitate harvesting should be looked into, for instance, a flexible, nonoxidizable wire mesh.

Figure 28. Plant material displaced by geotextile blown away by the wind.

[17] For more information on using a side-discharge manure spreader, see Landry and Rochefort (2010).

KNOWLEDGE GAP: STRENGTHENING THE ENZYMATIC LATCH

Adding products rich in phenolics (e.g., wood chips) to a Sphagnum farming site has the potential to strengthen the "enzymatic latch."[18] This mechanism is responsible for the accumulation of organic matter in peatlands, and it has been proposed as a geoengineering tool, since it could minimize organic matter decomposition, thereby reducing carbon emissions and even increasing biomass accumulation in the peatlands. A first study[19], conducted in a greenhouse, showed that adding wood chips made from various conifer species to the surface peat made it possible to increase carbon sequestration. Several other experiments on this topic are currently underway.

III. Spreading Straw

In restored sites, adding straw is a necessary step. It ensures a cooler and more humid microclimate at the air-soil interface, which makes *Sphagnum* establishment easier. Our observations seem to indicate that, even if hydrological conditions are actively controlled in Sphagnum farming sites, spreading straw is still essential after the *Sphagnum* fragments have been reintroduced. That said, it is possible that a lesser quantity of straw is needed for Sphagnum farming than for restoration; however, further studies would be needed to confirm this. The same machinery can used be for straw spreading as in the restoration process, i.e., a side-discharge mulcher. It can also be spread manually, although it is more time consuming.

IV. Fertilizing

Phosphorus fertilizer is not needed for Sphagnum farming as it can be when restoring *Sphagnum*-dominated peatlands. In restoration, phosphorus fertilizer is used to encourage bog haircap moss spores to germinate since this plant limits frost heaving. In fact, for Sphagnum farming, adding a phosphorus fertilizer could foster the growth of undesired vascular plants.

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[18] Freeman et al. (2001)

[19] Alshehri et al. (2020)

Irrigation Systems

After plant spreading, it is important to get the irrigation system operational as soon as possible to keep the peat and the spread plant materials from drying out. To date, two irrigation systems have been tested, both mainly solar powered. In the first system, basins are gravity fed, while the second uses direct pumping. In both cases, 2-inch semi-rigid agricultural tubing is used to bring the water to the basins.

I. Gravity Feed

This irrigation system is equipped with a cistern-style tank located higher than the water level in the basins. Two methods for filling the tank have been used. The first used a Honda gas pump, which must be started by an operator when needed. The other is through two low-pressure centrifugal pumps (Jabsco Xylem model 508440024) placed in series. This arrangement raises the water high enough to enter the tank. It is possible to automate these pumps using a floater in the tank, but an electric system is needed to operate them (see section Power Source, p. 35).

The basins are fed via gravity from the tank, simply by opening the valve assigned to the basin needing irrigation. There is therefore one valve per basin, and they can be automated (see section Automation System, p. 36).

II. Direct Pumping

This irrigation system has one pump per basin. Two types of pumps have been tested for this system: low-pressure centrifugal pumps and submersible pumps. The water from each pump travels to its corresponding basin via flexible irrigation pipes measuring 4 inches in diameter. Since each pump is assigned to only one basin, the pump is activated when that basin needs more water. The type and diameter of the pipes were selected to minimize pressure losses and costs.

It is important to note that the type of pump to use may vary according to several site-specific factors, including the power source and the location of the water supply (grade and distance to basins). For these two pump types, it is strongly advised to install a dock on the water source to get as close to it as possible.

The low-pressure centrifugal pumps used were Jabsco Xylem model 50844-0024. These were selected because they require little power but can raise water 2 metres. This is not much, but is enough for current Sphagnum farming sites. These pumps work well, but have the disadvantage of needing to be primed upon installation. Additionally, they sometimes lose their prime over time, requiring that someone go onsite to prime it again. With this pump model, it is important to set an automatic switch off; otherwise, the seals get destroyed quickly.

The submersible pump that was tested is Gol Pump model 01301. It was only used for one summer but worked very well. It is a self-priming pump, which is a considerable advantage in an automated system. However, we do not yet know how durable it is, given the short period in which it has been in use so far. Several models of this type have come on the market in recent years, but their features are not always appropriate for sustained use and their durability is not known.

III. Power Source

For the two types of irrigation system, solar power was used, except with the gas pump. The pumps are equipped with two or three 250-watt Enerwatt solar panels (EWS-250-P), two or four six-volt batteries in series, depending on the device's power needs (GR2C 210 AH), and one Morningstarcorp (TS-MPPT-45) or EPSolar (EPEver XTRA2210N-XDS2) charge controller.

With the gravity irrigation system, the valves (Belimo B248, 2-in.) are the main source of power consumption. The ones used required 110 V of current. Thus, a current of 12 V (two 6 V batteries) is transformed into a current of 110 V via a BESTEK MRI3011BU power inverter. The inverter also uses a significant amount of power, making the system fairly inefficient energy-wise. Valves that use 12 V would be more efficient.

The pumps also use considerable power. As previously mentioned, they are used in the direct pumping irrigation system, but they can also be used to fill the tank for the gravity system. In any case, the electric pumps tested operate with a current of 24 V (four 6 V batteries). Since no inverter is used in the direct pumping system, its power use is more efficient with the equipment tested to date, compared to the gravity-fed system.

Tests have shown that it is possible to eliminate the batteries used between the charge controller and pumps without any impact. However, pumping occurs only when it is sunny, when the *Sphagnum* needs water. This type of system could work jointly with a dynamic pump management algorithm with prioritization. The pumps must be able to withstand voltage variations caused by variations in the intensity of the sun.

IV. Automation System

An automation system requires some way to measure the height of the water level in the reservoir canals and a means of communication to activate the pumps or open the valves (depending on the system) when water is needed. This mechanism also makes it possible to open the valve of the mobile dam via the linear actuator if there is excess water (see section Types of dams, p. 26). Sonic sensors (MaxBotix MB 7389) measure the water level in the canals. Since the speed of sound varies with the temperature, a MaxBotix (HR-MAXTEMP) compensates for this and allows for more accurate measurements. Communication between the sonar and the computer takes place thanks to an Xbee or Xbee Pro module. These could be replaced by the new wireless LORA communications technology, which has a range of 5 to 10 km, up from Xbee's 250 m. It is important to note that the MTEM system now has a better performance.[20] Also, a LiDAR sensor would be better suited for Sphagnum farming as it is far less expensive and does not require temperature readings.[21]

An Arduino microcontroller is used in the modules measuring the water level and controlling water levels in the ditches. This microcontroller handles power management; determines the times when the water level is measured, thanks to the integrated clock; and records the data. A BeagleBone Black nanocomputer was used for the 24 V system, and a Campbell SCI CrR1000 datalogger was used for the 100 V system with inverter. These were installed in the system's control centre. A program was developed and installed on these computers to manage the water levels in the basins. The computers receive data from the microcontrollers, analyze it, and, as needed, give instructions to the pumps or valves, or to the linear actuators of the mobile dams. A modem/router can be installed to use a Wi-Fi or cellular network for remote communication if necessary. Nanocomputers are much more economical and flexible and perform better than dataloggers.

[20] Goulet (2019)

[21] Laberge-Grégoire et coll. (2022)

5. MAINTENANCE AND MONITORING

It is essential to visit the farming site frequently during the growing season (May to October) to ensure the installations are operating properly, especially the irrigation system. During the establishment stage, hydric stress caused by flooding or water scarcity can be lethal to *Sphagnum* and ruin the work done to put them in place. For the first two years, the cultivation basins must be visited at least every week or in anticipation of extreme weather conditions. During the growth stage, the visits can be spaced out, as the situation requires. Monitoring is easier if an alert system is connected to the irrigation system, to send the site manager notifications.

To avoid disturbing the *Sphagnum* carpet during site visits for maintenance and monitoring, it is recommended that visitors wear snowshoes or that wooden sidewalks be built for frequently visited structures (e.g., observation well).

Maintaining and Winterizing the Irrigation System, Dams, and Infrastructure

A Sphagnum farming site generally requires little yearly maintenance. The reservoir canals rarely need maintenance because they are usually stable over a long period. However, it is possible for the species *Sphagnum cuspidatum* to colonize the canals and block the water outlet at the dam. Complications can be prevented by occasionally cleaning the canals to remove this *Sphagnum*. The subsurface drains can be checked for blockage with a long rod (depending on their length). As for the micro-channels, it is difficult to judge what maintenance they will require as they have come into use only very recently. They could potentially fill with *Sphagnum* over a production cycle. We suspect they will need cleaning at the start of the next cycle.

Every year at the end of the growing season and before the first frost (around the end of October), the Sphagnum farming sites must be prepared for winter. Electronic devices (e.g., sonar, water level sensor, communication systems) and batteries must be removed and put in storage. Pumps must be removed from the water source if necessary, emptied of water, and filled with antifreeze, or placed in a heated location. If a tank is used to store irrigation water, it must be emptied. Then, it is necessary to make sure the pipe system is empty enough to allow water to expand as it freezes. Pipe joints must be taken apart to prevent any change in fit due to water expanding as it freezes. The water level of the dams should be brought up in the fall to minimize the risk of frost heaving, especially during the *Sphagnum* establishment stage, i.e., the first two years. All other equipment can be left in place. However, nothing of value should be left behind, especially if the cultivation basins are not on a private site.

It is quite likely that sporadic maintenance will be required during the summer season due to system failures, such as pumps losing their prime or fuses needing to be changed. It is also recommended to do regular maintenance on some components of the system: pump seals should be changed about every five years to maintain their capacity.

YEARLY STEPS FOR SPRING OPENING

The site should be opened in spring, either in May or early June. Here is a list of tasks to make the system operational again for summer:

- Install solar panels
- Plug in batteries and the charge controller
- Install the dock or floating platform if necessary
- Install and prime the pumps
- Verify the irrigation system
- Install mobile dams
- Install the automation system

Hydrological Monitoring

I. Water Level

Water levels must be monitored at three locations: the supply source, the dams, and the basins. At the water supply source, the amount of water available can be checked using a graduated rod. At the dams, the water level gives information relating to the basins' hydrological status; it can be measured with a sonar or ruler. In the basins, the water level is measured via observation wells, which are made from perforated PVC pipes. In summer, the water level in the wells should be checked manually every two weeks, using a bubbler (figure 29) or automatic water level sensors. We recommend installing at least three wells per basin. If sensors are used, a minimum of two per basin should be used, to make sure there is still sufficient data if one of the sensors fails. Choosing manual or automatic measuring instruments and a measurement frequency depends on the objectives of the monitoring and on the resources available. The location of the wells inside the basins depends on their size and configuration.

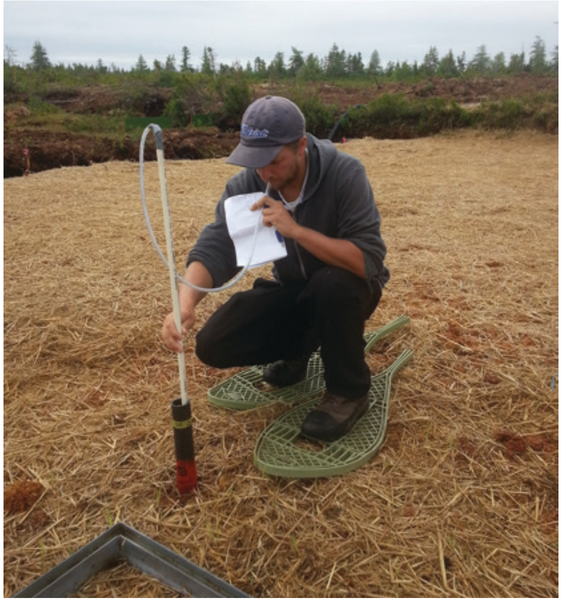

Figure 29. A bubbler is used to assess the water level in a hydrological observation well. The bubbler has two parts: a graduated PCV pipe and a flexible tube. Blowing into the bubbler determines the water level, which is measured on the graduated pipe.

II. Physicochemical Water Quality

Sampling for water chemistry can be done yearly, to maintain the quality of the irrigation water and can be done directly at the water supply source. The following should be targeted in the chemical analysis: N/NO_3^-, N/NH_4^+, P, K, Mg, Ca, along with pH, electrical conductivity, and alkalinity. These last three can simply be measured at the water supply point using a portable pH and conductivity meter. The chemical concentrations should not exceed the average values that has been found for fens [22].

Vegetation Monitoring

Several variables can be measured to monitor the vegetation's establishment and productivity once a production cycle has begun. Choosing the parameters and the frequency of observation depends on the goals of the monitoring, the context, and the duration of a production cycle. For instance, if the goal is to produce fibres from only one species of *Sphagnum*, then assessing the species composition would be relevant to determine the material's purity level. However, regardless of the parameters selected, measurements should be repeated a certain number of times, according to the basins' heterogeneity, to ensure they accurately represent reality. Five repetitions per homogeneous unit are recommended. We also recommend waiting two to three years before performing a vegetation monitoring, because the measurement process would be too disruptive during the establishment stage.

Assessing the cover by estimating the percentage of coverage for each species or group of species by vertical projection is a relatively simple method of measuring the establishment of the *Sphagnum* carpet and to determine its species composition. However, this requires good taxonomic knowledge if applied at the species level and does not provide any information on the *Sphagnum* carpet's yield. This assessment should be done in quadrats of an appropriate size, relative to the size of the stratum being evaluated (e.g., 25 cm x 25 cm quadrats for *Sphagnum*). An assessment of the accumulated biomass makes it possible to know the *Sphagnum* carpet's yield. However, this method is destructive and more time consuming since the samples harvested must be dried and weighed. The thickness of the *Sphagnum* carpet is an interesting variable because it is nondestructive. The carpet's thickness can be connected to its accumulated biomass depending on its density and on the species present, among other factors. An assessment of the vegetation is to be the best indicator to determine if growing conditions are optimal for the *Sphagnum*.

Controlling Undesirable Species

I. Vascular Plants

The presence of vascular plants is **inevitable** in Sphagnum farming basins. They colonize the basins from surrounding areas or can be present in the reintroduced plant material. Vascular plants can act as companion plants for *Sphagnum* and promote their establishment and growth by improving microclimate conditions. However, in Sphagnum farming, where the hydrological conditions are normally optimal, the presence of these vascular plants is not necessary and may even reduce yields. Additionally, depending on the final use intended for the *Sphagnum* fibre, their presence may be undesirable and add an additional step in the conditioning (see section Conditioning, p. 46).

[22] Andersen et al. (2011)

The vascular plants most commonly observed in Sphagnum farming sites are ericaceous and graminoid plants, which are normally found in peatlands. Depending on the farming site's location, it is also possible to find the seedlings of birch or other shrubs that propagate via wind dispersal. In general, the vascular plant cover rarely exceeds 30% and it decreases as the *Sphagnum* carpet grows. Maintaining a high water level also helps keep plants that are not typical to wetlands from invading, and trees and shrubs from growing. A good way to avoid invasive species (e.g., common reed) from colonizing is to not locate a farming site near existing colonies.

In an experiment conducted[23] in a Sphagnum farming station colonized by narrow-leaved cottongrass (*Eriophorum angustifolium*), the cover was reduced from 30% to 10% by mowing with a trimmer three times per summer, for three years in a row (figures 30 and 31). Ericaceous species established at the edge of the baulks were also cut to reduce the amount of shade they cast. However, in this case, cutting the vascular plants had no impact on the *Sphagnum* biomass production; therefore, in terms of maximizing *Sphagnum* yields, controlling the size and density of cottongrass and ericaceous shrubs proved useless.

Figure 30. Experimental Sphagnum farming site where vascular plants were controlled on one side (right) but not the other (left).

Figure 31. Trimmer used to reduce cottongrass density.

However, this recommendation does not apply to all Sphagnum farming sites. Deciding whether or not to control the density of vascular plants will depend on each Sphagnum farming site's dominant vascular species, its growth form, its potential for litter accumulation, and its invasiveness. Also to be considered is the final use planned for the *Sphagnum* fibres.

[23] Guêné-Nanchen et al. (2017)

INVASION OF COMMON RUSH IN GERMAN SPHAGNUM FARMING SITES

In German, invasive species are a common problem, and several methods for controlling them have been tested. These proliferations seem to be fostered by the water sources, which are enriched with nutrients due to their being located in agricultural areas and to the significant atmospheric deposits in Europe that "fertilize" the peat substrate. One such problematic plant is the common rush (*Juncus effusus*). Even when cut regularly, it covers 20% to 30% of the surface of Sphagnum farming basins. Various types of equipment have been used to control it, either directly in the basins or from their edges.

Figure 32. Single-axle mower with cutter bar being used to control the common rush.

Figure 33. Long-reach excavator, equipped with a weed cutter, working from the embankment.

II. Fungi

Parasitic or pathogenic fungus species (figure 34) have been observed at Sphagnum farming sites, though they remain fairly scarce. Notably, fungi tend to grow in flood zones and where the water level fluctuates greatly, leading to necrosis of the *Sphagnum* carpet (figure 35). It is therefore important to be attentive to adjusting the water level as the *Sphagnum* carpet grows. This makes it complex to initiate several production cycles within a single basin, because a given water level can flood a fairly undeveloped carpet but not a thicker one. Since fungus presence in cultivation basins remains marginal, the use of a fungicide is not essential. However, if needed, myclobutanil (Nova 40W; category 3) has been shown to be effective at eliminating these fungus species in a greenhouse environment[24] and in the field. The recommended dose is 3 L/10 m^2 at a concentration of 0.54 g/L. Three applications spaced 10 days apart reduced the infection of the carpet by half. These applications did not have any effect on the *Sphagnum* biomass accumulation.

Figure 34. Fungi (*Galerina sp.*) growing in a *Sphagnum* carpet in a greenhouse.

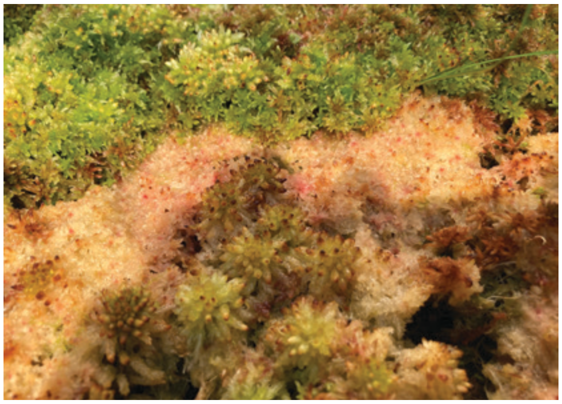

Figure 35. *Sphagnum* carpet affected by fungi.

[24] Landry et al. (2011)

6. HARVEST, STORAGE, AND CONDITIONING

Harvest

In Canada, experts estimate that *Sphagnum* could be harvested after 7 to 10 years of growth. But in reality, the time to harvest should take into account the *Sphagnum's* yield and decomposition rate, which will increase year to year. When the rate of decomposition nears that of the biomass production, it's time to harvest. The goal is to optimize the return on investment. Given the costs involved in setting up a production cycle, it would be unproductive to harvest the biomass too early or too late. For the time being, the productivity of Canadian sites varies between 0.3 and 2 tonnes per hectare per year.[25] Productivity in Germany is 3 to 6 tonnes per hectare per year.[26] This difference may be attributed to the different climatic conditions between the two countries, since Canada has a long snow-coverage period, when no moss growth is possible.

In Canada there has only been some preliminary work done to test *Sphagnum* fibre yields from farming. In fact, to the best of our knowledge, no harvests from basins for commercial purposes have taken place yet. Therefore, a great deal of research and development is still needed to better assess the economic potential. Research work on Sphagnum farming in Germany has made it possible to develop a functional harvesting method that could very well be used in Canada. The text box (p. 44) below presents the methods applied during their experiments.

[25] Pouliot et al. (2015)

[26] Gaudig et al. (2014)

MOWER METHOD

In Germany, a very long-reach excavator able to reach the basin centre is used to harvest *Sphagnum* fibres. The excavator has a weed cutter at the end of the boom to cut the fibres. The excavator and tractor-trailer combos can move around on the embankments that separate the basins.

Figure 36. Aerial view of a *Sphagnum* harvest at a farming site in Germany.

Figure 37. Excavator with a weed cutter at the end of its boom being used to cut *Sphagnum*.

Figure 38. *Sphagnum* fibre being removed for transport.

Figure 39. Transporting *Sphagnum* fibre.

Another type of excavator head, designed by Scotts Canada for block-cut peat, could also be used to harvest *Sphagnum*. This head consists of 12 compartments, which are pushed into the *Sphagnum* (figure 40). When the desired depth is reached, a toothed blade shuts the compartments, cutting the *Sphagnum* fibres. The excavator can then unload the contents at the desired location. With this device, the *Sphagnum* is harvested in blocks.

Using an excavator is an excellent way to harvest *Sphagnum*, however it is not possible to go into the basins with this type of machine without damaging the *Sphagnum* carpet. The embankments must therefore be large enough, which decreases the total area available for Sphagnum farming. Also, an excavator is not a machine that works continuously, but rather is used in alternance with removal equipment, which is not optimal, performance-wise.

Other types of machines have also been used to harvest *Sphagnum* in other situations (crawler forestry forwarder with grapple, bulldozer, excavator with a wide bucket). However, none of these is adapted to operate in wet, unfrozen basins without damaging the *Sphagnum* carpet. Upcoming R&D work on *Sphagnum* harvesting should focus on improving harvesting efficiency.

Figure 40. Device used in Canada for block-cut peat extraction. Tests have shown that this equipment could also be used to harvest *Sphagnum*.

A non-exhaustive list of *Sphagnum* fibre harvesting and removal methods was developed by VALORĒS in 2022.[27] Harvesting can be done manually, by machines operating outside the basins, using a retractable bridge system, by machines operating inside the basins on frozen surfaces in winter, or using robotization. The biomass can be removed via helicopter, through a winch system, with a tractor-trailer combo, using hydrogen balloons, or with the same machine doing the harvesting if it is designed to store the harvested biomass. These methods must be tested and assessed.

It has been determined that the regeneration of residual fragments depends on the age of the production cycle, the depth of cutting, the harvesting method used, the *Sphagnum* species, and the site's post-harvest condition (mainly hydrological conditions).

[27] VALORĒS (2022b)

Storage

After the harvest, the biomass may need to be stored for some time before it can be used or processed. Storage in piles outdoors is an option. However, if the fibre is to be used for peatland restoration, the maximum storage time recommended is six months. After that, the *Sphagnum's* ability to regenerate decreases gradually. Also, since the material is full of water, the piles of biomass may heat up, like compost does. This should be monitored to make sure there is no loss of quality in this valuable product.

Conditioning

The conditioning stage largely depends on the final use that will be made of the *Sphagnum* fibre. For instance, *Sphagnum* to be used in peatland restoration will require less processing than for use in growing media. The different processes it can be subject to are drying, hygienization, grinding, sieving, and packaging, according to need.

Drying can be done in various ways and at different points of the conditioning process. First, a proportion of the water contained in the *Sphagnum* can be removed directly at the farming site, either by leaving the fibres in piles for a few days, allowing the surplus water to flow out, or by pressing the fibres. Heat can also be used to dry *Sphagnum*, using various types of equipment, such as drying chambers, heat lamps, conveyor dryers, or greenhouses. Ventilation, either alone or combined with heat, is also an effective way to dry *Sphagnum* fibres. Given that *Sphagnum* becomes friable, electrostatic, and water repellent when below 20% humidity, care should be taken not to drop below this threshold, regardless of the drying method used. Hygienization means killing vascular plant seeds and parts found in the harvested *Sphagnum*. Water vapour or gamma radiation can be used.

As regards the grinding and sieving of *Sphagnum* fibres, there is still too little scientific data to determine what the best practices are. However, a few experiments[28] of growth in a greenhouse setting, using growing media made of varying sizes of *Sphagnum* fibre, have not shown any difference in yield due to this factor. A great deal of R&D is also required to determine the best practices for *Sphagnum* packaging. We are not aware of any experiments conducted in Canada to date on this issue.

[28] Gaudig et al. (2018)

7. RESOURCES NEEDED (HUMAN, MATERIAL, AND FINANCIAL)

When planning a Sphagnum farming project, it is important to compile a list of the resources that will be needed at every stage and to estimate their costs. An estimate has been made of the total cost of Sphagnum farming (table 3), considering labour and machine use times, and equipment purchases, presented in dollars per hectare ($/ha).

Table 3 shows the costs associated with Sphagnum farming. These amounts were generally established from three experiments conducted in Canada, and based on an implementation in block-cut trenches. Given that Sphagnum farming is very recent, the amounts given are approximate and many can vary greatly. There is still a lot of work to do to facilitate work, achieve economies of scale, and decrease production costs. These amounts should decrease over the coming years, as advances are made in this area. A recent study[29] that looked at various financial scenarios concluded that Sphagnum farming can be profitable in Canada through market diversification (horticultural growing media, substrates for orchid propagation and cultivation, peatland restoration, etc.).

[29] VALORĒS (2021)

Table 3. Estimated time (hr/ha) and cost ($/ha) to set up a Sphagnum farming site, including one harvest after eight years. The total estimated cost does not include the initiation of subsequent production cycles.

Implementation step	Time labour (hr/ha)	Time machinery (hr/ha)	Material and equipment purchases ($/ha)	Total cost[a] ($/ha)	References
Site preparation Access road construction - Bulldozer ($80/hr) - Dump truck ($80/hr) - Excavator ($80/hr)	Variable	Variable	-	Variable	
Culvert installation - Excavator ($80/hr)	Variable	Variable	Variable	Variable	
Basin digging and levelling - Excavator ($80/hr) - Laser level ($8/hr)	700	250	-	36 500	Expert experience
Dam installation - Excavator ($80/hr)	35	15	500	2 200	Expert experience
Digging of canals and micro-channels - Excavator ($80/hr) - Mini-excavator ($250/day)	135	70	-	5 000	Expert experience
Installation of irrigation system[b] - Loaders ($80/hr)	175	5	30 000	37 000	Expert experience
Subtotal	**1 045**	**340**	**30 500**	**80 700**	

Implementation step	Time labour (hr/ha)	Time machinery (hr/ha)	Material and equipment purchases ($/ha)	Total cost[a] ($/ha)	References
Reintroducing plant material Harvesting and transport of plant material - Rotary tiller (rotovator) ($16/hr) - Trailer ($13/hr)	15	15	-	500	Quinty (2012)
Spreading of plant material - Manure spreader ($28/hr)	250	10	-	5 500	Quinty (2012); Expert experience
Spreading of straw - Mulcher ($32/hr)	250	10	700	6 250	Quinty (2012); Expert experience
Subtotal	**515**	**35**	**700**	**12 250**	
Maintenance and yearly monitoring[c] Monitoring of the *Sphagnum* carpet growth	480	-	-	10 000	Expert experience
Water quality monitoring	10	-	2 700	3 100	Expert experience
Irrigation management and water level monitoring	400	-	5 000	8 400	Expert experience
Seasonal installation and take-down	400	-	800	9 200	Expert experience
Subtotal	**1 290**	**-**	**8 500**	**30 700**	

Implementation step	Time labour (hr/ha)	Time machinery (hr/ha)	Material and equipment purchases ($/ha)	Total cost[a] ($/ha)	References
Harvest Cutting *Sphagnum* fibre - Long-range excavator ($80/hr)[d]	50	50	-	5 000	Expérience des experts
Removal of biomass - Loader ($80/hr) - Tractor & trailer ($80/hr)	Variable	Variable	-	Variable	
Conditioning	Variable	Variable	Variable	Variable	
Subtotal	**50**	**50**	**-**	**5 000**	
Initiation of subsequent production cycles Reintroducing plant material	Not determined	Not determined	-	Not determined	

[a] The hourly rate used for machinery operators and technicians is $20.89, which is the average between the hourly rates in Quebec and in New Brunswick for a heavy machinery operator according to Statistics Canada (2018).

[b] The estimated times and costs include the installation of an automatic pumping system and the delivery of a container to the site. The hourly rate for labour used for this activity is the average between the hourly rates in Quebec and in New Brunswick for natural and applied science professionals, according to Statistics Canada, 2018, i.e., $37.19/hr.

[c] Yearly monitoring over eight years.

[d] Purchasing a mower should be considered.

Preparing the Site and Reintroducing Plant Material

When establishing a Sphagnum farming site, the steps that require the most resources are building the basins, deploying the irrigation system, and reintroducing plant material. Depending on the site selected, it may be necessary to build an access road and to install culverts. There can be an enormous amount of variation in the scale of these activities, therefore their costs are not included in the calculation, though they must be factored in when planning a new project.

During the preparation stage, the basins must be dug and levelled, the canals dug, the dams installed, and the irrigation system deployed. The numbers presented in table 3 were determined assuming that the contractor owns the excavators and loaders but that the laser level and mini-excavator must be leased. The finishing stage of the levelling is done by hand.

Reintroducing plant material involves collecting plant material, and spreading the *Sphagnum* and then the straw. In the scenario used for calculation purposes, each step is assumed to be mechanized, but the finishing touches for spreading the *Sphagnum* fibres and straw are done manually.

Maintenance and Monitoring

The aspects to consider in this step are keeping the water level management system operational; assessing the growth of the *Sphagnum* carpet, the water level, and the water quality; and winterizing and installing equipment seasonally. The scenario for assessing the *Sphagnum* carpet yield takes into account harvesting, sorting, drying, and weighing the *Sphagnum* biomass in 50 quadrats of 25 cm x 25 cm per hectare annually. The water level measurement is estimated considering the use of about 12 water level sensors per hectare, while the water quality is assessed on the basis of three samples per hectare per year.

Harvest

Two activities must be considered in *Sphagnum* harvesting: cutting and removing the biomass. In the proposed scenario, an excavator with a mower is used to cut the *Sphagnum*, while a loader and tractors with trailers are used to remove the biomass. However, the amount estimated for the harvest includes only the *Sphagnum* fibre cutting stage, because removal costs are highly variable and must be appraised on a case-by-case basis.

Subsequent Production Cycles

Research to date does not enable us to determine the costs of initiating subsequent production cycles, since no *Sphagnum* harvest has yet taken place on a large scale in Canada. However, it should be noted that the costs will surely be lower than for the initial site development, given that several steps do not need to be done again once the basic installations are in place. Furthermore, the costs of subsequent cycles depend on the *Sphagnum* regeneration strategy. Part of the plant material can be left in place during the harvest, to ensure the *Sphagnum* will come back, or plant material can be reintroduced again. Since neither of these strategies has been tried, it is complicated to assess the costs.

8. CONCLUSION

Like other forms of paludiculture, Sphagnum farming offers a number of environmental, economic, and social benefits. Notably, *Sphagnum* fibre production could partly replace peat from undisturbed peatlands as inputs in the manufacture of growing media. Sphagnum farming therefore aids in the conservation of peatlands and it reduces carbon emissions.

The key element in productive Sphagnum farming is controlling the hydrological conditions to achieve a high water level below the *Sphagnum* surface and to keep it stable throughout the growing season. This requires active and automated irrigation controls. Even though the hydrological controls are not fully developed, the research shows we are advancing in the right direction. The approach to irrigation that uses micro-channels especially shows potential because it makes it possible to take advantage of the properties of surface peat. However, more optimization is required in terms of the irrigation system controls, to improve reactivity to weather forecasts.

The various steps in establishing a farming site were summarized in this document. Planning is an important step, to make sure all the required inputs are available and suited for cultivation (power and water sources, peat substrate, and quality plant material). Then, when preparing the site, regardless of which irrigation structure is selected, it remains critical that machines be operated outside the basins. The plant material reintroduction stage is similar to the one used in *Sphagnum* peatland restoration, though there are subtle differences based on the situation and the cultivation goals. Once the vegetation and straw have been spread, it is appropriate to monitor the carpet's growth. Once it is thick enough, it can be harvested, and then a new production cycle can be launched. Different methods of conditioning the *Sphagnum* fibres produced can be contemplated, depending on their intended use.

In a production cycle, most of the costs are for setting up the site in Year 1. Subsequent production cycles will be less costly than the first, since the installations are already in place. Sphagnum farming can be profitable if the potential markets are diversified.

There are a number of challenges remaining for Sphagnum farming in Canada. Developing methods for the harvest and for initiating subsequent cycles is one of the main ones. It would also be appropriate to look into the optimization of operations in what are sometimes difficult conditions, to reduce production costs. Then, changes to the political and legal frameworks will be needed for this activity to be recognized at the appropriate levels. Sphagnum farming offers a clear opportunity to contribute to solving environmental and social problems. This land use is a nature-based solution to mitigate climate change. It is an opportunity to be seized, by uniting industry, politics, and research, to develop Sphagnum farming on a larger scale.

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