TREE PLANTATIONS WITHIN THE CONTEXT OF ECOLOGICAL RESTORATION OF PEATLANDS:
practical guide

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Photo credits (cover page):

J. Bussières (young tamarack (*Larix*) and height measurement of spruce tree);
S. Hugron (windbreaks and *Larix* plantation);
A. Jacobs (an older spruce plantation);
V. Laroche (natural peatland).

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PHOTO : A. D'Astous

CHAPTER 1
INTRODUCTION

NATURAL PEATLAND

Wetlands are characterized by a high water level during long enough periods during the year to influence the nature of the soils and promote the establishment of plants adapted to saturated conditions, also known as hydrophytes. Wetlands also carry out numerous ecological services including water filtration, flood control, and the recharge of groundwater (according to their location in the water catchment area). Additionally, they provide habitats for diverse fauna, particularly for waterfowl in North America. On the global scale, wetlands provide ecological services of which the annual value is estimated to be 4,900 billion US $ (estimation from 1997).

The characteristic that distinguishes peatland from other types of wetlands is its capacity to accumulate partially decomposed vegetation material, also called 'organic matter.' In fact, in peatlands the annual rate of biomass production is greater than the rate of decomposition. The annual accumulation is however very low (circa 0.5 to 0.6 mm per year) and thousands of years are needed to allow for the development of peat deposits of 1.5 to 2.3 m, which is the average depth of the boreal peatlands. Peatlands naturally release carbon dioxide (CO_2) and methane (CH_4) into the atmosphere, two greenhouse gases (GHG), as well as dissolved organic carbon (DOC) in the water caused by the decomposition of organic material. These quantities are however less than the amount of carbon captured in the form of CO_2 by plants for their growth. This ecosystem is thus considered to be the most efficient carbon sink on the planet. The peatlands only cover 3% of the planet surface, but they store 15 to 30% of the planets carbon in the form of peat or organic matter. Within the context of climate change, peatlands are a extremely important ecosystem to consider when calculating emissions and sequestration of GHGs.

There are two types of peatlands, which can be distinguished by their water source. The minerotrophic peatlands (fens) receive groundwater which is richer in minerals than rainwater (Figure 1). The dominant vegetation of fens is made up of brown mosses and sedges. The ombrotrophic peatlands (bogs) are wetlands whose water source only comes from precipitations, therefore, these ecosystems are poor in minerals. Bogs are dominated by *Sphagnum* (peat moss) and ericaceous shrubs, plants which are well adapted to conditions which are wet and poor in base cations (meaning few nutrients).

A

PHOTO : V. Laroche

B

PHOTO : V. Bérubé

Figure 1 a) Ombrotrophic peatland in the south of Québec and b) minerotrophic peatland in the Bas-Saint-Laurent region of Québec.

A BRIEF EXPLANATION OF THE PEATLAND DEVELOPMENT

During the development of a peatland, a fen becomes a bog when the depth of the accumulated organic matter is so deep that the vegetation no longer has contact with the groundwater (Figure 2). As the peat deposit becomes thicker, the quantity of minerals available for the plants diminishes. The sedges and brown mosses are gradually replaced by *Sphagnum* which has the ability to acidify its environment and thus create conditions which are favorable for its establishment and growth. In bogs, the peat of the deeper layers (sedge peat) often possesses different characteristics (more decomposed and less acidic) than the surface peat (*Sphagnum* peat), because sedge peat is made up of decomposed fen plants.

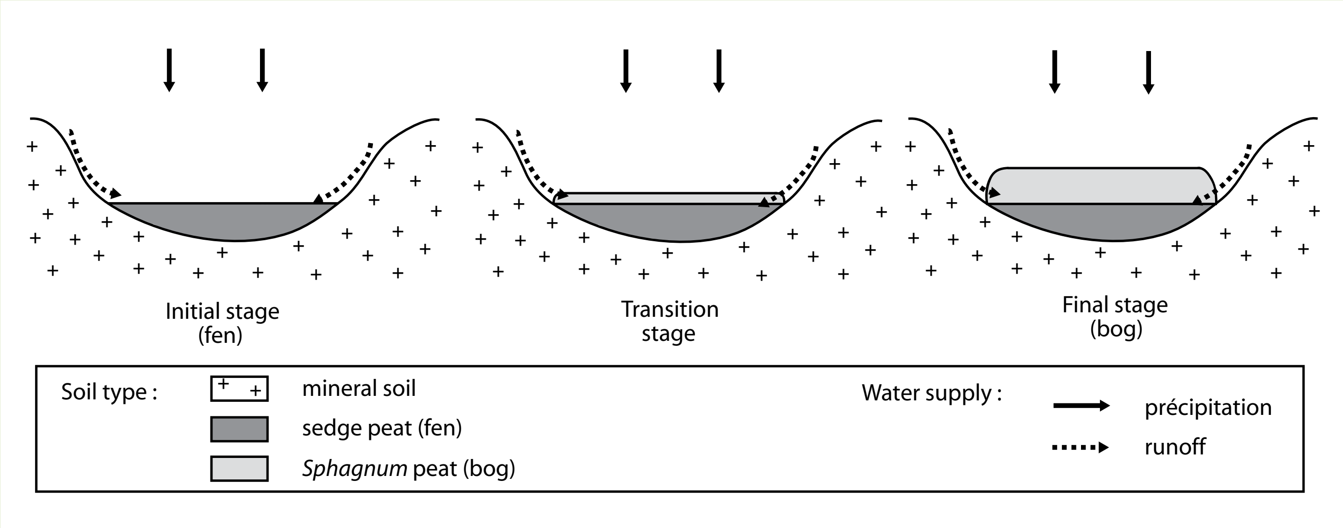

Figure 2 Graphic illustrates the evolution of a minerotrophic peatland (fen) towards an ombrotrophic peatland (bog).

THE PEATLANDS OF CANADA

The area occupied by peatlands in Canada is estimated to be 1,113,280 km² (see Figure 3), which means Canada, along with Russia, are the countries that have the largest area of wetlands. The pressure on peatlands, caused by draining to convert to agricultural lands, urbanisation, forestry, and milling for horticultural peat, is nevertheless concentrated in the south of the country. At a regional scale, the fragmentation and loss of wetlands can reach 80 to 98 % near urban centers, which could have an important impact on biodiversity and water quality.

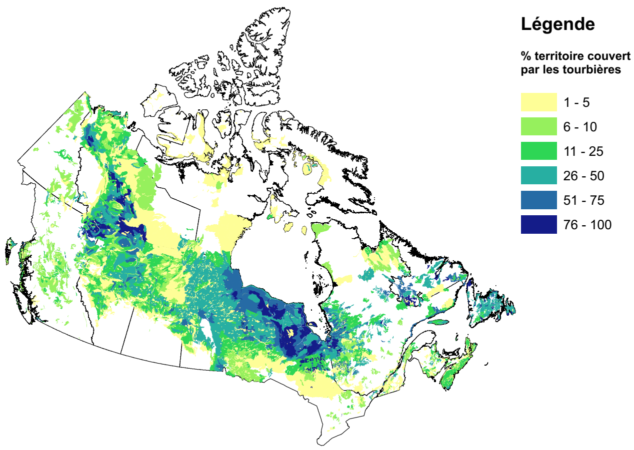

Figure 3 Distribution of peatlands in Canada. Figure was created using numeric files taken from the database Géogratis from the Canadian government (www.geogratis.gc.ca).

In North America, the exploitation of peatlands is mainly for the production of growing substrates for commercial and domestic horticultural needs. The method most commonly used for peat milling is tractor-drawn vacuum machines (Figure 4), but there are other methods which are less frequently used. The vacuum-milling methods require intensive drainage to allow for machinery to remove the peatland's vegetation layer to access the peat deposits underneath. The giant vacuum machines are then used to suck thin layers of peat from the surface of the peatland. As peat milling continues, deeper and more decomposed layers of peat are exposed. If the deep layers of peat are extracted, the sedge peat can be exposed. However, the peat desired by the horticultural industry is the fibric, slightly decomposed peat located on the surface of the deposit.

PHOTO : S. Hugron

Figure 4 Vacuum-machines used for extracting peat.

THE RESTORATION OF MILLED PEATLAND

In North America, exploitation activities usually stop when the quality of the peat is not good enough for use as horticultural peat (indicated by von Post greater or equal to 5) or when impurities are present (gravel, sand, clay, etc.). The depth of the residual peat is generally greater than one or two meters and the residual peat is void of a viable seedbank. The environmental conditions found on peatlands where milling has ceased (milled peatlands) differs greatly from those found in a natural peatland and do not favor the return of typical peatland plants, such as *Sphagnum*. For example, the hydrology of the site is modified because of the presence of drainage ditches and the absence of surface vegetation. Additionally, the peatland surface is instable due to wind and water erosion as well as a phenomenon known as frost heaving where the constant freezing and thawing of the soil leads to the formation of ice crystals which literally heave the soil surface. All of these factors make the conditions difficult for the reestablishment of typical peatland plants and for the return of a functional ecosystem that can accumulate peat. On the contrary, the conditions of the milled peatland favor an accelerated decomposition and oxidation of the peat. Such abandoned milled peatland emit carbon into the atmosphere and become a carbon source.

The Peatland Ecology Research Group (PERG) has developed a restoration technique called the 'Moss layer transfer technique,' which allows for the return of *Sphagnum*, the keystone species in ombrotrophic peatlands. This technique consists of reintroducing *Sphagnum* fragments and then blocking the drainage canals. The efficiency of this technique has been shown since 1990 both in terms of the return of typical peatland species and in terms of the microbial community, which allows the ecosystem to return to a peat-accumulating system (Figure 5).

A

PHOTO : A. D'Astous

B

PHOTO : F. Salvador et J. Monerris

Figure 5 Peatland Bois-des-Bel ten years after restoration: a) restored sector and b) non-restored sector.

THE RECLAMATION OF MILLED PEATLANDS

Peatland restoration after peat milling aims to restore a functional peatland ecosystem which vegetation that is typical to regional peatland. In the long term, the ultimate goal is to recreate a system that is capable of accumulating organic matter in the form of peat. In contrast, the reclamation of a peatland after milling aims to restore an earlier successional stage of the peatland which fulfils different ecosystem function than the peatland which existed before extraction.

The limits of restoration

Some conditions found on sites after peat milling are not optimal for ecological restoration using the Moss layer transfer technique. Conditions are not optimal if the residual peat layer is thin and the mineral soil is close to the surface, for example. In this case, a large quantity of cations (Ca, Mg, Na, and K) from the mineral soils is available. These cations inhibit *Sphagnum* growth because it prefers poor conditions and cannot compete with plants that can grow in a minerotrophic environment.

Additionally, it is possible that certain sectors of the restoration site are difficult to rewet. For example, on old roads the peat compaction due to machinery circulation makes it difficult to raise the water level. Some raised peatland sectors can also remain too dry for *Sphagnum* establishment and growth.

Equally, when the restoration area is close to areas that are still being actively milled, restoring with the *Sphagnum* transfer technique is not possible. The drainage ditches between the restoration site and milling sites must remain active for milling and cannot be blocked for restoration.

Finally, it may prove difficult to find a donor site for collecting plant fragments at a distance which is adequate for restoring the site. In this case, it is preferable to plan a different management option, because to simply abandon a site could lead to the spontaneous invasion (for example by cottongrass, birch, etc.) which could spread to sections still being milled and contaminate the peat with undesired seeds.

The different options for reclamation

Different reclamation options are possible after peat milling has ceased. The choice of the reclamation option is influenced not only by the context of the site and the peatland manager's preference, but also by the social-economic context of the region, notably the laws and rules in effect in the province of the specific country. For example, in New Brunswick the majority of peat milling takes place on public land and the Ministry of Natural Resources who manages this resource prioritizes restoration of the wetland areas. Consequently, a restoration plan for restoring a site after milling operation have ceased must be completed before milling can be authorized on any newly opened site.

Sometimes, the peatlands belong to farmers and are rented by peat producers. To increase the commercial value of his land, farmers may ask the peat producer to return the land with an added value. When the slightly decomposed peat has been milled for horticultural substrate, the underlying highly decomposed organic soil is exposed. This soil has a good potential for growing corn and vegetables.

Another reclamation option of milled peatlands is berry production. In certain European countries and on the East coast of North America, the following berries are commercially produced: cloudberry (*Rubus chamaemorus*), black chokeberries (*Aronia melanocarpa*), blueberries (*Vaccinium corymbosum* and *V. angustifolium*), cranberry (*V. macrocarpon*), strawberry (*Fragaria* sp.), serviceberry (*Amelanchier* sp.), sambucus (*Sambucus canadensis* L.), lingonberry (*Vaccinium vitis-idaea*), and black crowberry (*Empetrum nigrum*).

Managers interested in knowing more about the berry plantation on milled peatlands should consult the guide *Production of Berries in Peatlands* (PERG 2009).

The creation of natural habitats with or without recreation and tourism as a goal is also possible for peatland reclamation. This is the case in Ireland where certain sites were transformed into natural parks with ponds where it is possible to go bird watching or fishing with the family (Figure 6). Certain milled peatlands in Estonia, Peru and Ireland have a pH high enough to allow for the creation of ponds which can sustain fish populations.

Figure 6 Reclamation project for Irish milled peatland. This cutover site was milled for energy production then reclaimed as a site for recreation and tourism. A) The creation of a lake for hikers and bird watchers and B) little house made of peat bricks along a hiking trail created in a forest plantation (See also: www.loughbooraparklands.com)

Among the existing reclamation projects, forest plantation is popular among managers of several North American and European sites. Forestry on natural or disturbed peatlands (mainly disturbed by drainage) has existed for a long time, but forestry on milled peatlands is more recent. This is because industrial peat milling (in a mechanized manner over large areas) is relatively recent. The first forest plantation trials on milled peatlands were carried out in Finland during the 1950s. Scots pine (*Pinus sylvestris* L.) and birch (*Betula pendula* L. and *B. pubescens* L.) showed high yields. In Ireland, the first trials were in the 1980s and tested the growth of Norway spruce (*Picea abies* (L.) H.Karst.). This species is recommended for extensive forestry on cutover peatlands. In Estonia forestry trials on cutover peatlands date to 1972 where birch (*Betula pendula* Roth) and pine trees (*Pinus sylvestris* L.) were tested. Trials in Sweden showed that planting trees is not necessary and that with adequate fertilization natural regeneration is enough for tree establishment. It should be noted, however, that in those sites the peat was milled for energy production which leads to a very deep extraction of the peat deposits. The residual peat on those sites is shallow and is rich in minerals, which favors the spontaneous regeneration of forest species. Finally, other trials were carried out in Lithuania and Czech Republic, but the documentation of these trials is rare and difficult to obtain. On the East coast of North America the oldest forest plantations on milled peatlands date back to the beginning of the 1990s. This guide reports the trials and the results obtained to date.

DID YOU KNOW THAT?

Simply abandoning peatlands after milling is not a desirable option according to the *Strategy for Responsible Peatland Management* published in 2010 by the International Peat Society (IPS).

PHOTO : C. Macabiau

Figure 7 Spruce grouse's habitat is the forested margins of peatlands.

Plantation in the context of ecological restoration

Tree plantations on milled peatlands can complement ecological restoration, especially if it is applied to very large sites. Thus, planting trees in areas which are too dry for *Sphagnum* growth can contribute to recreating a more 'natural' ecosystem, containing diverse habitats. Trees can be planted in groves to favor the growth of forested islands and to act as nesting sites for certain bird species. The plantations can also be placed around the perimeter of the restoration site to create forest margins typical to undisturbed peatlands (laggs) which serve as a transitional corridor fauna between neighboring ecosystems and the peatland (for example for the spruce grouse; Figure 7). Laggs also contain a high diversity of fruit bushes (wild holly, viburnum, serviceberry, etc.). These berries differ from the ericaceous berries of open peatland and can be a food source for diverse animal species. Plantations can also create a wind-break to reduce wind erosion and the spread of weed seeds which can contaminate peat fields still being milled. Finally, plantations can improve the aesthetics of a site and serve as visual barriers for milled peatlands close to human settlements.

Plantations could also be considered as a reclamation option for an entire site, such as for the production of woody material. However, in the North American context, reclamation should not be chosen over ecological restoration. In fact, during the first years after plantations the large amounts of carbon are necessary for tree growth and are accumulated inside this tissue. However, the absence of a *Sphagnum* cover and the lowering of the water level favor the decomposition of the residual peat. When peat decomposes, carbon dioxide (CO_2), a GHG, is emitted into the atmosphere. Unpublished data from PERG showed that 75 years after a disturbance (fire and drainage), which favored the afforestation of a peatland in the Bas-Saint-Laurent region of Québec, the carbon emissions from the decomposition of residual peat and tree mortality was greater than the amount of carbon sequestered by tree growth.

In conclusion, the ecological restoration of peatlands using the *Sphagnum* transfer method, as described by the *Peatland Restoration Guide, 2nd Edition* (Quinty and Rochefort 2003), is preferred for milled peatlands because it allows for the return of the key ecological function of peatlands: the accumulation of carbon. The plantation of forest species is a reclamation method which is complementary and can be used in strategic areas to maximize biodiversity restoration or for sites which are too dry for *Sphagnum* growth.

OBJECTIVE OF THE GUIDE

The idea to create this guide originated from Canadian peatland managers' interest in using tree species to complement the restoration of milled peatlands. There are great examples of this in Europe as well as North America and we now possess enough pertinent information to create a practical guide.

This guide is not an exhaustive review of the work on this subject, but a practical tool for thinking about, planning, carrying out and promoting the use of trees as a complement for restoration projects for peatlands after industrial milling has ceased. We insist on the pertinence of using this guide with the *Peatland Restoration Guide, 2nd Edition* published in 2003 by PERG.

The guide is geared towards the people carrying out the work in the field. We hope to respond to the needs of these peatland managers for each stage of the restoration project. This work also aims to heighten awareness of all stakeholders involved with peatlands and with the integrated management of milled peatlands (i.e. peat industry, environmentalists, governmental decision-makers, town planners, consumers).

In this guide you can find information concerning the all the steps of a tree plantation project which can complement the restoration of milled peatland sites (Figure 8). Finally, you will find at the end of each chapter a list of references which is not complete list of references on the subject, but suggested readings associated with the themes discussed.

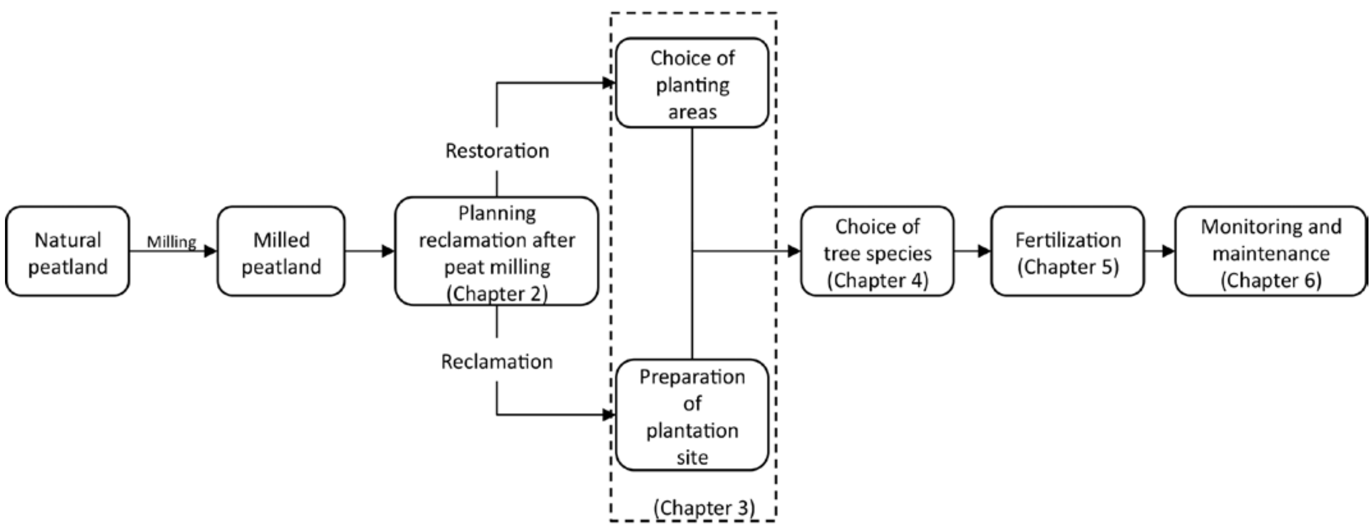

Figure 8 Diagram illustrates different steps of a tree plantation project.

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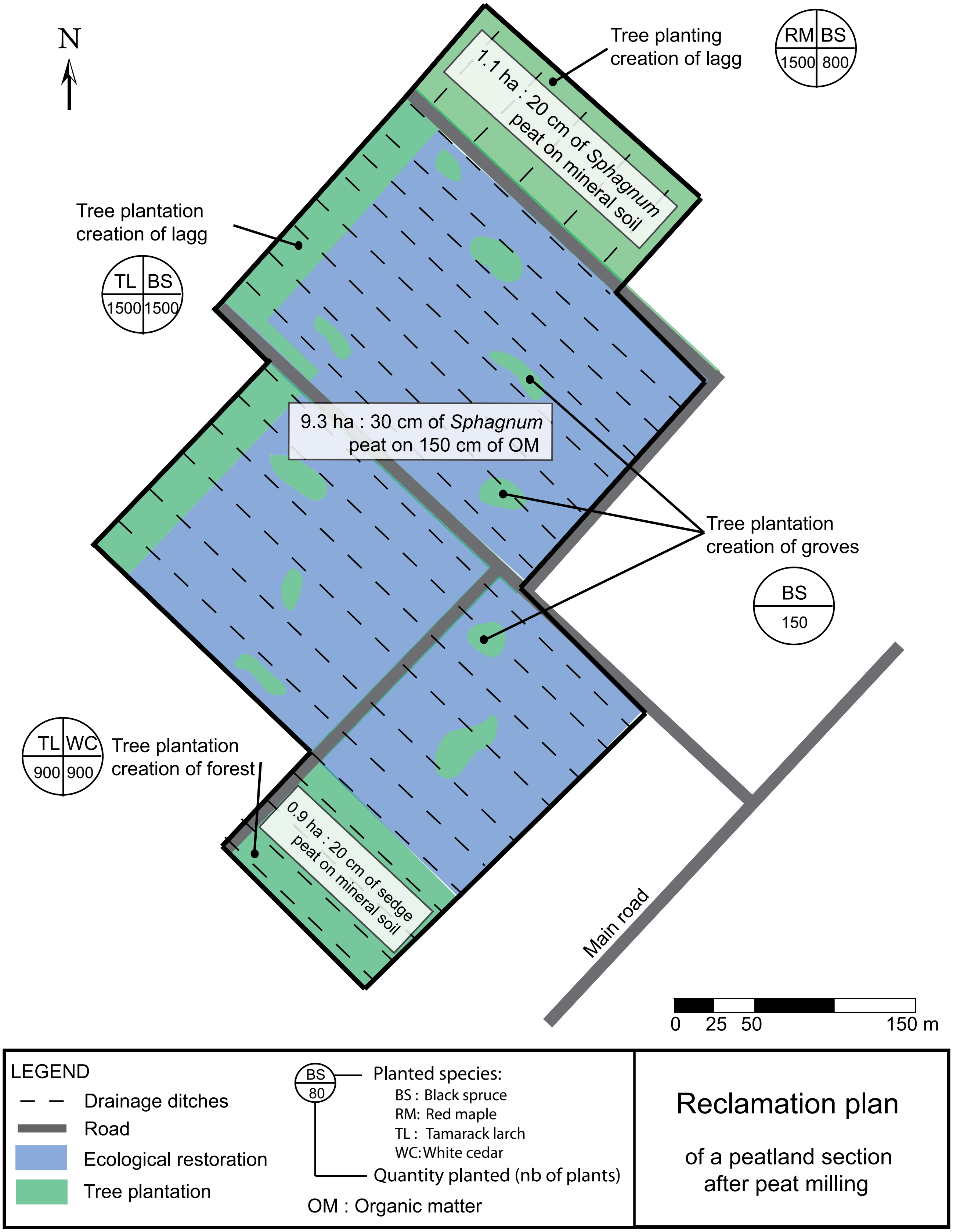

N
Tree planting creation of lagg
RM BS 1500 800
1.1 ha : 20 cm of Sphagnum peat on mineral soil
Tree plantation creation of lagg
TL BS 1500 1500
9.3 ha : 30 cm of Sphagnum peat on 150 cm of OM
Tree plantation creation of groves
BS 150
TL WC 900 900
Tree plantation creation of forest
0.9 ha : 20 cm of sedge peat on mineral soil
Main road
0 25 50 150 m
LEGEND
Drainage ditches
Road
Ecological restoration
Tree plantation
BS 80
Planted species:
BS : Black spruce
RM: Red maple
TL : Tamarack larch
WC: White cedar
Quantity planted (nb of plants)
OM : Organic matter
Reclamation plan
of a peatland section after peat milling

CHAPTER 2

PLANNING RECLAMATION AFTER PEAT MILLING

All reclamation projects should begin with rigorous planning. This stage allows for a choice to be made among all of the reclamation options possible and to evaluate the time and the necessary resources for implementation. When planning the reclamation of milled peatlands, ecological restoration should be given priority because it is the best option for conserving biodiversity and fulfilling the Kyoto protocol. The plantation can be used for consolidating the ecological restoration, for example by creating habitats for fauna or for recreating the vegetation gradient associated with the edges of the peatlands.

However, when the peat layer is thinner than 30 cm, ecological restoration may not be successful because of the presence of minerals coming from groundwater. In this case, other options to restoration, like extensive tree plantation, should be considered (Figure 9)

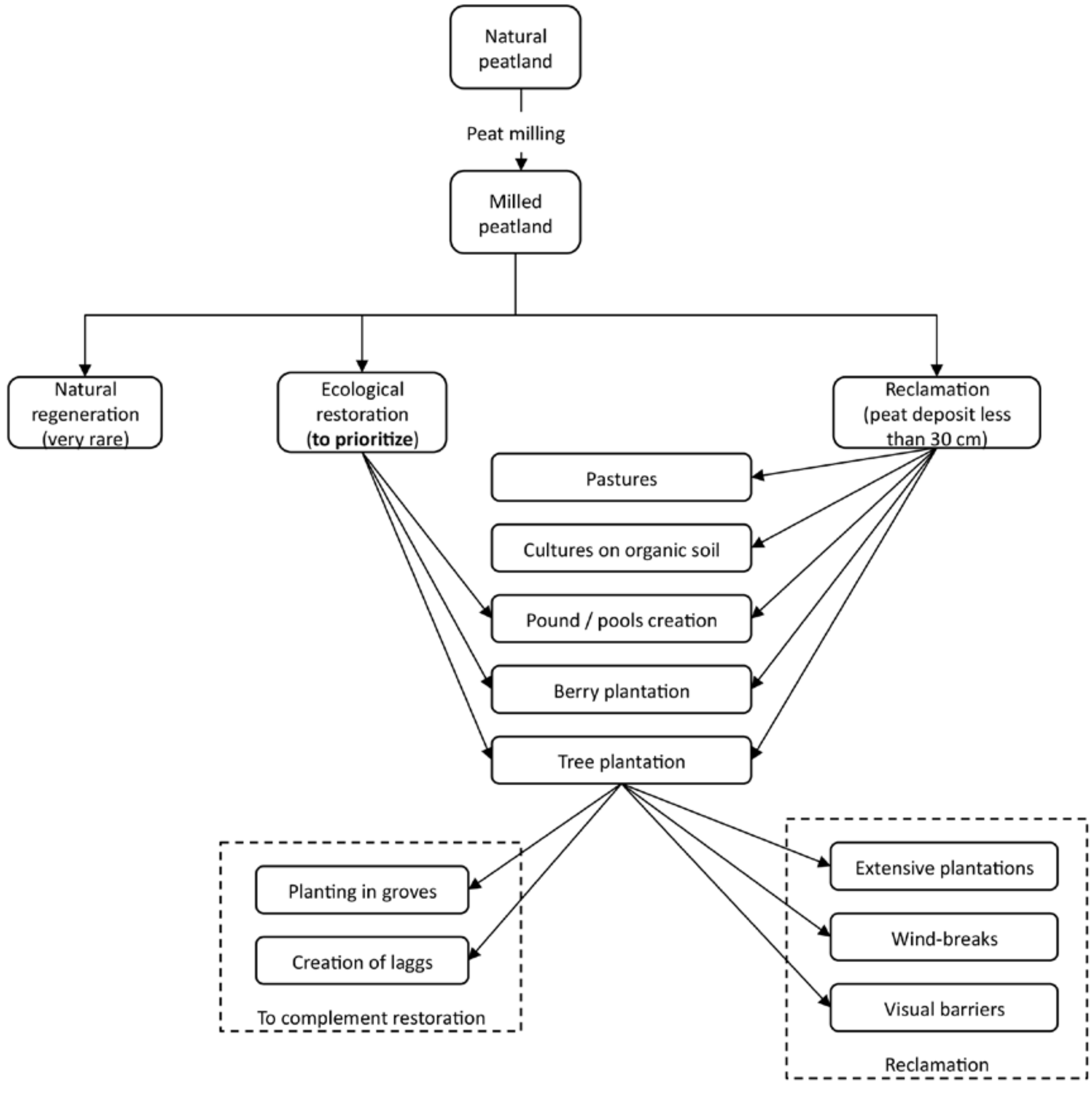

Figure 9 Diagram for choosing among reclamation options.

DEFINING THE OBJECTIVES OF RECLAMATION

It is important to define well the objectives of the reclamation project which will be implemented. The majority of the tasks to be carried out and decisions to be made will be different depending on, for example, a project whose goal is ecological restoration of the site *versus* a project whose aim is to create wind-break hedgerows with trees. The first step is thus to take consensus among the different stakeholders of a reclamation project (managers, owners, foremen, consultants, environmental advisors, etc.) and to define in clear terms the objectives of site management. This should be completed before moving into the reclamation planning stage.

SUGGESTED LITERATURE

Before reaching a final decision, we suggest you consult the books *Wise use of mires and peatlands* (Josten and Clarke 2002), the *Peatland Restoration Guide*, 2nd Edition (Quinty and Rochefort 2003), and the guide *Production of berries in peatlands* (GRET 2009) which could be used to complement this guide.

Importance of a reclamation plan

Before reclamation begins, it is important to prepare a plan in order to have a clear and complete idea of the stages, needs, costs, and schedules to avoid any bad surprises.

A good reclamation plan will include:

- The objective of the reclamation project decided on before project begin;
- An implementation map where the following points appear:
  - The areas to be planted or restored;
  - The species which should be planted;
  - Spacing between plants;
  - The number of plants necessary for each species chosen;
  - The drainage system;
  - The natural and milled sections;
  - The roads, buildings, and the machinery circulation areas;
  - The visual elements which are not aesthetically pleasing and which could be hidden by trees;
  - Dominant winds;
- The name of the person or people in charge;
- A detailed list of the activities needed to prepare the site;
- A medium-term schedule comprising the expected dates for each stage of the reclamation, order for material, preparation of the site, plantation, fertilization, monitoring, etc.;
- A long-term schedule for the milled site comprising the forecast for the next abandoned section with expected dates of abandonment, restoration and plantation;
- A budget comprising a detailed list of labor and material needs (vegetation, fertilization, plantation tools, machinery, etc.);
- A list of suppliers;
- Performance indicators which should be observed during monitoring (monitoring document should be created during the planning stage, see Appendix 3 for a sample document with suggested indicators);
- The adjustments to be made according the outcome of reclamation measures (i.e., replanting, weeding, re-fertilization, etc.).

It is recommended that a reclamation plan be part of the milling plan when a new peatland is opened. In this way, the options and the order in which reclamation is carried out will harmonize with the progression of the peat milling on the site. Thus the management of the site will be more efficient. For example, the vegetation removed when a new site is opened could serve as donor material for restoring sections where milling has ceased, thereby minimizing the costs associated with the transport and collection of donor vegetation. Early planning also allows managers to target areas where forest plantations would be better than ecological restoration. It should be noted that many types of reclamation could be applied to the same site (see introductory figure in Chapter 2). The performance indicators chosen will depend on the types of reclamation chosen and their goals.

PLANNING PLANTATIONS

Once the objectives of a reclamation plan have been well defined, the plantation itself should be planned. This stage should be carried out at least one year in advance to cover the delays necessary for ordering vegetation and preparing the site. Here is an example of a plantation schedule:

At least 18 months before planting:

- Description of the plantation site;
- Complete a plantation map;
- Prepare the site;
- Identify the vegetation to be planted;
- Estimate the number of plants required;
- Order the material (vegetation, fertilizer, etc.);

Some months before planting:

- Description of the site and adjustments if necessary;
- Verification from suppliers (invoice, reception date, etc.);
- Hire a professional planter and verify if additional equipment should be supplied;
- Prepare a site to store the plants when they arrive (if necessary);
- Plan monitoring.

Description of the plantation site

Depth of residual peat

It is important to know, at least approximately, the depth of the residual peat because it could have consequences for drainage (Chapter 3) and could also influence fertilization (Chapter 5).

The depth of the residual peat is general known when milling activities cease. If this is not the case, it is possible to use a threaded rod and survey the fields in different areas in order to estimate the depth of the residual peat (Figure 10). There is also the technique of using radar in the section of the peatland where you want to know the depth (Écho tourbières vol. 15 n° 1 available on www.gret-perg.ulaval.ca, under the PERG's publications tab). This method is the most precise, but is more expensive and requires specialized equipment.

PROTOCOL FOR DETERMINING THE DEPTH OF RESIDUAL PEAT USING A THREADED ROD.

Material needed: A threaded metal rod which has been graduated (using paint) at every 5 cm, GPS and/or a plan of the peatland, tape measure.

How to take samples:

1) Manually insert the metal rod into the peat.

2) When the mineral soil is reached the handler can see a difference in the texture of the soil. For loose sub-soil, you will notice a sudden resistance to the penetration of the rod and for the case of bedrock, the rod will hit it and it will be impossible to penetrate deeper. Be careful that you don't confuse ice, stumps, branches, diverse debris, or big rocks with the sub-soil. In cases of doubts, move your rod some meters and try again.

3) If the sub-soil is deep, i.e. more than 3 m, it might be necessary to add more rods using nuts to connect the threaded rods.

4) Note that the depth of the peat at the right place on a map or a GPS. If you add the sections of supplementary rods or if you did not graduate your rod beforehand, hold onto the rod at the depth which corresponds with the peat surface before you remove the rod and measure the depth with a tape measure.

It is important to foresee many peat depth measurements on cutover and cutaway sites in order to assure a representative portrait of the site because peat depth is not necessarily constant. The sectors situated on the edge of the peatland can be particularly variable and sampling effort in these sectors should be greater than in the center of the peatland.

Tips:

- To help inserting the rod, wear gloves for a better grip or use pliers;
- Rotate the rod as you insert it into the peat to help penetration;
- Kill two birds with one stone when you carefully pull out the rod : you may find at the end of the rod some mineral material which would allow you to confirm the sub-soil was reached and to determine its texture.

PHOTO : J. Bussières

PHOTO : V. Bérubé

Figure 10 Determining the depth of the peat deposit using a threaded metal rod.

Chemical analysis of the peat

We recommend carrying out a chemical analysis on the peat before starting a reclamation project (see Appendix 1 for a sampling protocol). The results of the analysis of the residual peat should be similar to those shown in Table 1 (see Chapter 3) and, in the case of important differences, fertilization advised in Chapter 5 should be corrected. For example, any element truly deficient in the peat should be raised in order to prevent deficiency. On the other hand, any elements present in excess in the peat, quantities should be reduced in the fertilizer because the amount in the soil will be enough for the tree's needs. Adding too much of a nutrient can contaminate the ground water. Adjusting the fertilizer amounts should be done with the aid of a specialist (i.e. agronomist or forest engineer).

The chemical composition of the peat as well as the degree of decomposition will influence the choice of the reclamation option. For example, in the case of ecological restoration for a site, these two characteristics will influence, along with several other factors, the type of peatland to be restored: bog or fen. The degree of peat decomposition is generally known when milling activities have ceased, but, if this is not the case, a von Post test should be carried out (see box below).

ORDINAL VON POST SCALE USED TO EVALUATE THE DEGREE OF PEAT DECOMPOSITION

(based on Payette and Rochefort, 2001)

FIBRIC

H1 Completely undecomposed peat, which, when squeezed, releases almost clear water. Plant remains easily identifiable. No amorphous material present.

H2 Almost entirely undecomposed peat, which when squeezed, releases clear or slightly colored water (brown-yellow). Plant remains still easily identifiable. No amorphous material present.

H3 Very slightly decomposed peat which, when squeezed, releases pale brown water, but from which no peat passes between the fingers. Plant remains still identifiable and no amorphous material present.

MESIC

H4 Slightly decomposed peat which, when squeezed, releases dark brown water. Some peat is passed between the fingers but the plants remains are slightly pasty. The plant remains are still identifiable, but have lost some of their identifiable features.

H5 Moderately decomposed peat which, when squeezed, releases very "muddy" water. The plant residue is very pasty. The structure of the plant remains is relatively distinct; it is still possible to recognize certain features.

H6 Moderately highly decomposed peat with a very indistinct plant structure. When squeezed, about one-third of the peat escapes between the fingers. Very little water can be squeezed out and this water is muddy. The residue is very pasty but shows the plant structure more distinctly than before squeezing.

HUMIC

H7 Highly decomposed peat. Contains a lot of amorphous material with very faintly recognizable plant structure. When squeezed, about one-half of the peat escapes between the fingers. The water, if any is released, is very dark and almost pasty.

H8 Very highly decomposed peat with a large quantity of amorphous material and very indistinct plant structure. When squeezed, about two-thirds of the peat escapes between the fingers. A small quantity of pasty water may be released. The plant material remaining in the hand consists of residues such as roots and fibres that resist decomposition.

H9 Practically fully decomposed peat in which there is hardly any recognizable plant structure. When squeezed almost all material escapes the hand and is a fairly uniform paste.

H10 Completely decomposed peat with no discernible plant structure. When squeezed, all the wet peat escapes between the fingers.

Mineral sub-soil

The mineral sub-soil will have an influence on the trees planted, particularly if the residual peat is shallow. Also, the size of the soil particles, also called texture, will have consequences on the fertilization if the depth of the peat deposit is thin enough for the trees' roots to have contact with the mineral sub-soil. A sub-soil sand layer does not have many nutrients and cannot supply the trees nutritional needs without fertilization. On the other hand, the presence of clay sub-soil will provide the trees with nutrients. In this case, only an initial fertilization is necessary as once the trees' roots come in contact with the sub-soil, the trees will get their nutrients from the clay. The chemical composition of the sub-soil material is therefore particularly interesting to know when the residual peat layer is less than 30 cm and could aid in adjusting the application of fertilizer.

For the sites where the depth of the residual peat is less than 2 m, it is also important to know if the sub-soil mineral is impermeable (clay or rock), which will slow the percolation of the water in the soil and increase flood risk. It is important to observe the signs of water saturation of the peat during flood periods (spring thaw or after a big rain event) which will have an impact of the survival of the trees (see following section on drainage).

The texture of the sub-soil is sometimes known during milling operations. If not, sampling is necessary. To determine the chemical composition, sub-soil material sample are handled the same way as peat (Appendix 1). It is particularly important to know the chemical composition mineral sub-soil for shallow peat deposits (less than 30 cm).

PROTOCOL FOR DETERMINING THE TEXTURE OF THE MINERAL SUB-SOIL

Sampling sub-soil is done with a shovel or a soil sampler when the peat depth is less than 1 m. The samples collected can be sent to a soil analysis laboratory to determine the exact texture (or textural class). It is also possible for an experienced manager to determine the soil texture manually. When the peat deposit is thin and when possible, we suggest verifying the sub-soil texture at a depth of 50 cm in order to determine possible changes in the structure which could influence the drainage.

When the depth of the residual peat is greater than 1 m, the textural class of the mineral sub-soil can be roughly determined using a threaded metal rod. When you extract the rod, it is possible to recuperate some particles of the mineral soil at the end of the rod and to manually evaluate the texture. If you feel small grains between your hands, it is sand. If the grains are very fine and have a texture similar to cake icing and stain your fingers brown, it is loam. Finally, if the particles are extremely fine, sticky and grey, the sub-soil is clay.

Drainage

Drainage directly influences the choice and success of reclamation. It is important to evaluate if the drainage network is suitable for the reclamation project and to make any necessary changes. If no information is available concerning the hydrology of the site, collect data during the year leading up to the reclamation in order to be able to make changes to the drainage system, if necessary. The following items should be noted:

- Signs of deficient drainage during snow melt and after big rain events: accumulation of water on the peat surface and overflowing of drainage canals.
- The sign of excessive drainage of the site: cracked surface due to the drying out of the peat during the summer.
- High water table (distance between the soil level and the groundwater level) measured using wells (PVC pipes with holes drilled throughout the length of the pipe) or by digging a hole with a shovel and waiting a day for the water to stabilize.

This data should be collected **at several spots on the site** and several times during the year without forgetting the spring and fall in order to have a precise portrait of the future plantation site.

MORE ADVICE

See the section *Monitoring* in the *Peatland Restoration Guide, 2nd Edition* for specifications concerning the installation of the wells and measuring water content in peat.

Proximity of extraction activities

The location of the plantation site in relation to the surrounding sectors or the peat still being milled will influence the site's reclamation plan. When you need to clean the ditches to make sure they are draining properly, as is the case for a forestry plantation, there will be little effect on milled areas adjacent to the plantation. On the other hand, during a restoration project blocking the drainage canals should take into consideration that areas still being milled will need drainage. For example, a main canal which is common to two sectors cannot be blocked and thus secondary canals must be very well blocked. One could also delay the restoration project until milling activities cease on neighboring fields which enable the restoration of the first abandoned section. Although restoration must be a priority, this situation may lead managers to consider a different reclamation option.

Another element to consider is the possible peat contamination of the fields being milled by seeds from plants on reclaimed peatlands. In order to reduce the contamination risk to the lowest possible, it is important to bury the fertilization during plantation to stop the spread of invasive species (see Chapter 5). If you leave the reclaimed site full of weedy species, you risk contamination and will need to invest lots of energy and resources to get the weeds under control.

Finally, the coexistence of the milled and reclaimed sites means that reclaimed sites run the risk of plants being buried by wind erosion from the milled site. High mortality due to burial has already been observed on old plantations on milled peatlands. The trees were most probably buried during the first years after plantation.

This phenomenon is inevitable, but certain measures can help minimize it:

- Do not plant in areas where much peat has accumulated from wind erosion.
- Use large seedlings (see Chapter 4) on the edges of the plantation for the sectors where wind erosion will likely deposit peat. Make a tree belt using larger plants which will have the capacity from the beginning on to surpass peat accumulation and will serve as a wind-break to protect the reclaimed sector by breaking the wind and capturing peat particles.
- Avoid as much as possible storing peat which has not been covered or protected directly adjacent to reclaimed sectors.

MORE ADVICE

We suggest to photocopy the data collection sheet *Plantations – Description of the Site shown* in Appendix 2 and to use this to gather all pertinent information. A sheet should be filled out for each plantation sector.

REFERENCES AND SUGGESTIONS FOR FURTHER READING

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PHOTO : L. Rochefort

CHAPTER 3
PREPARATION OF PLANTATION SITE

Simply abandoning a peatland after milling activities have ceased should never be considered. Natural regeneration for such sites is slow and even after several decades, abandoned fields are virtually void of vegetation, are not aesthetically pleasing, or a good habitat for fauna (Figure 11). Additionally, the peat is exposed to atmospheric oxygen and oxidizes which emits carbon into the atmosphere. Milled peatlands are good sites for forest plantations because the substrate is devoid of weeds or pathogens which can contaminate nearby fields being milled. Establishing plantations on these sites can, however, be a challenge as the water level can fluctuate greatly and substrate is acidic and not very fertile. Trials in Europe and North America have nevertheless shown that certain tree species have interesting growth potentials on milled peatlands, providing drainage and fertilization are carried out. Moreover, forest plantations improve the sites aesthetics while diversifying the landscape and increasing biodiversity.

THE SUBSTRATE (RESIDUAL PEAT)

In North America commercial extraction is generally geared towards peat that is very slightly decomposed. Thus, the depth of the residual peat is greater than in Europe, where peat is milled for the energy sector where highly decomposed peat can be used. This difference has an important influence on physical and chemical characteristics of the peat, which are not constant within the peat profile. The peat in the deeper layers is generally more decomposed, has a smaller water retention capacity, is less acidic and contains more nutrients (Figure 12). Thus, European trials allow indications as to which species and plantation methods should be used as well as expected results, but they must be adapted to the North American context.

PHOTO : GRET

Figure 11 Abandoned peatland after vacuum-milling in New Brunswick.

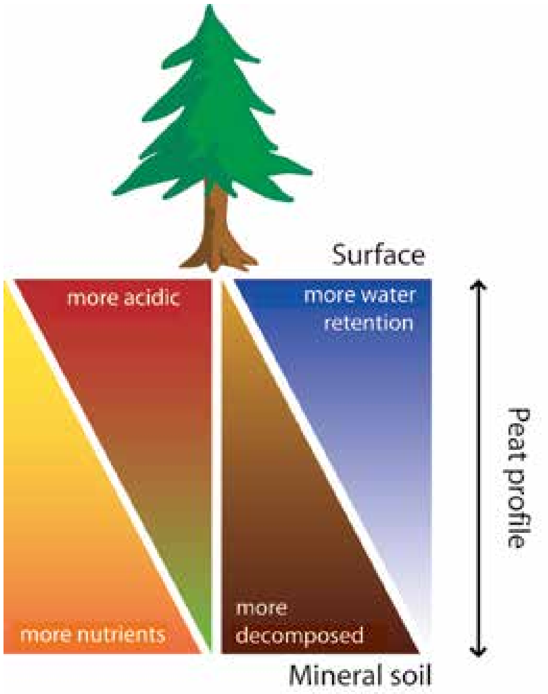

Figure 12 Physical characteristics of peat along a profile.

Physical point of view

When peat milling ceases the abandoned surfaces are characterized by a total absence of vegetation. The peat, when left uncovered, is subjected to wind or water erosion and oxidation. Peat has a good water retention capacity which gradually decreases as the degree of decomposition increases. It also acts as a good thermal insulation, which means that frost can persist for a long period into the spring. Finally, the surface temperature of the soil can be relatively high during the summer because the dark color absorbs the sun's rays.

During fall and spring, when the weather is clear and without clouds and the night temperature oscillates between freezing and thawing, certain sectors can experience frost heaving (Figure 13). During the night, crystal ice forms beneath the peat, lifting the peat some centimeters, and during the day when the temperature is warmer, the ice melts and the soil particles are moved from where they were originally. This phenomenon hinders the establishment of vegetation because young plants are uprooted.

PHOTO : V. Bérubé

Figure 13 Frost heaving creates a particular micro-topography by the creation of ice crystals under the peat particles.

Chemical point of view

Residual peat made up mainly of *Sphagnum* is generally acidic (pH less than 5.1) and has a low electrical conductivity. The strong acidity of the peat influences the availability of nutrients. Generally speaking, the nutrients in *Sphagnum* peat are low and not sufficient for tree growth (Table 1). The majority of nitrogen contained in the peat is immobilized in the organic material and is not available for plant growth. The nitrogen in organic matter is unavailable because microbial activity is generally low in the anaerobic conditions of natural peatlands. The quantity of phosphorus in residual peat is very low. Due to the acidity of the peat and the anaerobic conditions, a large part of the phosphorous contained in the peat is immobilized and cannot be assimilated by the plants. Moreover, the peat contains too much nitrogen compared to phosphorous; the N:P ratio ranges between 100:2 and 100:4, while the ideal ratio for tree growth ranges between 100:10 to 100:13. The nutrition of the trees is unequal, meaning they lack phosphorous compared to the amount of nitrogen assimilated. Finally, the residual peat is also deficient in potassium because is cannot be well retained by the soil particules and is easily washed off the site.

Table 1 Means and standard deviations of the concentrations of total chemical elements (mg/g) and available chemical elements (µg/g) as well as the pH and electrical conductivity (µS/cm) of peat for the Canadian mean after peat milling activities[1].

Nutrients	Total	Available[2]
Nitrogen (N)	9,79 (3,33)	$N\text{-}NH_4$: 511,03 (344,08) $N\text{-}NO_3$: 46,40 (44,83)
Phosphorous (P)	0,23 (0,13)	23,80
Potassium (K)	0,24 (0,08)	44,48
Calcium (Ca)	4,38 (2,93)	5361,52
Magnesium (Mg)	1,32 (0,38)	855,21
Sodium (Na)	0,76 (0,69)	475,69
Iron (Fe)	1,10 (0,57)	NA[3]
pH	4,4 (0,9)	
Electrical conductivity	64 (6)	

1 Data from: Andersen *et al.* (in preparation). A reference system for peat and water chemistry in peatlands of Canada and Alaska.
2 Data was collected only for Québec, New Brunswick and Alberta.
3 Not available

AVAILABLE NUTRIENTS *VERSUS* TOTAL NUTRIENTS

Only a fraction of the total quantity of an element contained in soil can be absorbed and assimilated by a plant. These elements are called **available nutrients** which are exchangeable or available. Actually, a large part of the nutrients contained in the soil is strongly related to the amount of soil particles which are in the form of organic matter. The gradual action of bacteria which decomposes organic material frees these element, thus they become available for plant growth. The **total nutrients** contained in the soil are the nutrients still bound to organic matter and those which can be assimilated.

The content of nutrients in peat varies along the peat profile (see Figure 12). The deep layers of peat where peat is more decomposed contain more nutrients than the *Sphagnum* peat located in the top layers. The nature of the mineral sub-soil can also have an influence on the quantity of nutrients present in bottom 10 to 30 cm of peat. Studies in Finland found that clay sub-soil generally contains more phosphorous, which favors the growth of trees (Aro and Kaunisto 1998). On the other hand, if sand is the sub-soil substrate, there will be no effect on tree growth, while a sub-soil that is morainic acid can have negative effects on tree growth (Kaunisto 1997).

HYDROLOGY

Generally speaking, drainage ditches lower the groundwater level during milling and are spaced every 30 to 40 m. These canals influence the water level 10 to 20 m on either side of the ditch. They can remain active several years after milling activities have been abandoned (Figure 14). The area between the ditches is generally shaped in a reverse 'u' shape with the highest part in the center and falling off in each direction towards the canals. The section between ditches is called a peat 'field.' Additionally, deep ditches are dug along the border to a natural peatland can have an influence on surface water (meaning the 10 to 25 cm from the surface) and its influence can reach up to 60 m from the drainage ditch.

The water table is generally low during the summer season, but can fluctuate greatly during the year. Despite the presence of ditches, the risk of flooding is real, particularly during snow melt and if the ditches collapse. Blocking drainage ditches is an extremely important step for the restoration of peatlands and for the survival of peat moss (*Sphagnum*). However, maintaining the drainage system is preferable for the establishment of forestry plantations. Thus, it is very important during the planning stage to define the goals of the plantation because the preparation of the site will depend on the type of reclamation chosen.

PHOTO : G. Caisse

Figure 14 Drainage ditch between two peat fields.

The advantages of drainage

Drainage is often used in forestry for increasing the success of plantations in humid areas. In a natural peatland, lowering the water level by draining generally improves the forestry potential (increasing in forest cover, tree survival and tree growth). The ideal water depth for forestry plantations is **more than 30 cm for *Sphagnum* peat** and **at least 50 cm under the surface for sedge peat**.

Maintaining a good drainage system on cutover or cutaway peatlands also favors the survival and growth of trees. The drainage improves the aeration of the peat, which favors microbial activity and the mineralization of organic materials. Higher decomposition and the resulting mineralization allow a greater amount of nutrients to be made available for plants. Drainage also increases soil temperature and, in turn, the length of growth season, because the substrate heats more quickly in the spring. Finally, the planted trees on well-drained soils generally develop a root system which is deeper than plants which grow in wet soils. Having a deeper root system gives trees more anchorage as well as access to nutrients and water from deep soil layers.

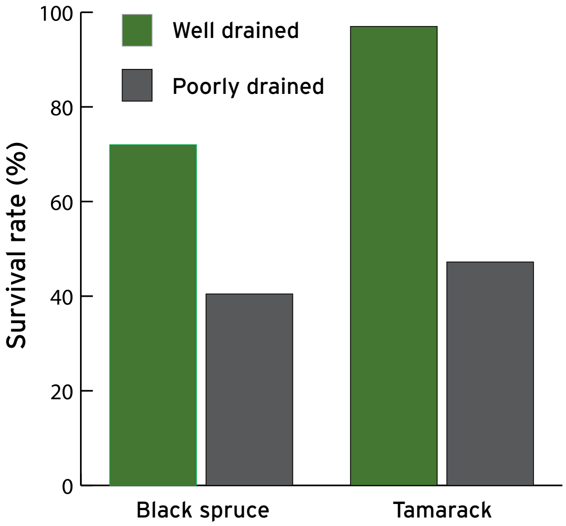

Figure 15 Figure illustrates the effect of drainage on the survival of two tree species planted on milled peatlands. Data adapted from Caisse (2007).

Insufficient drainage

Insufficient drainage impairs the development and root growth: when they are submerged for long periods they lack oxygen and can die from asphyxiation. The survival rate of plants planted on poorly-drained sites is also greatly inferior to those observed for well-drained sites (Figure 15).

Too much drainage

A drainage system which lowers the water level too much will create water stress for the plants, which means a low survival and growth rate. The oxidation of the peat is also accelerated, increasing thus the greenhouse gas emissions (CO_2), which is not considered responsible ecosystem management.

PREPARATION OPERATIONS

Site preparation is different according the objectives of the plantation (Figure 16). When a forest plantation is planned, the soil preparation operations aim to facilitate tree rooting and to optimize growing conditions for the trees. As for plantations which complement restoration, the preparations aim to rewet the site and create conditions which are optimal for *Sphagnum* and brown mosses. These conditions are not, however, ideal for tree growth.

MORE INFORMATION

Use the data sheets *Plantations – Preparation of operations* (Appendix 2) to note the date, duration and description of the preparation operations which were carried out before plantation started.

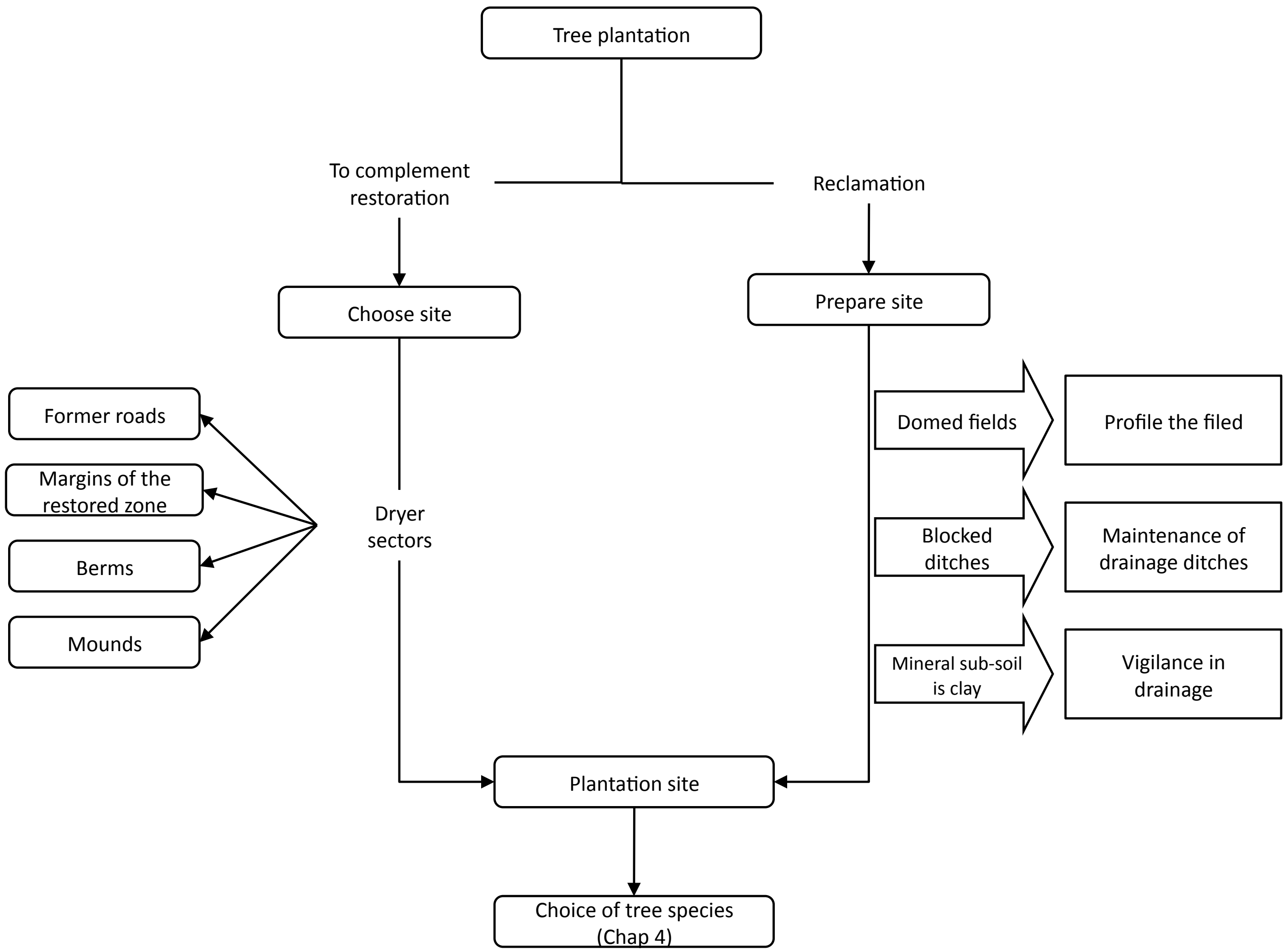

Figure 16 Diagram illustrating preparation operations of the site.

Plantation as a complement to restoration

If the planned reclamation is ecological restoration with forest plantations in the form of forested islands, the drainage ditches should be blocked to assure that the site is rewetted. This hydrology is generally bad for tree growth because the water table will be less than 40 cm below the soil surface. For such a case, it is important to plant trees in the mounds (microsites) or sectors which are higher (for example on the windrows) so that the water level will be low enough to allow for the trees survival and growth. The growth rates expected are lower than for trees that grow on mineral soil, but this situation is tolerable because the goal is the conditions found in natural peatlands where tree growth is very slow.

For plantations where the goal is to recreate a lagg, reforestation is made on the border of the restored zones. It is also possible to carry out the plantations similar to sylviculture and to block the ditches after two growing seasons, so that the trees are well established. You must, however, assure that you leave a space for machinery to circulate when you rewet the site.

Plantation forestry as a reclamation option

According to the local characteristics, certain preparation options should be carried out in order to improve the site before trees are planted (Figure 16). It is essential to clean out the drainage ditches when they have partially or completely collapsed. One must assure that all ditches situated near the plantation are functional to a depth of 70 to 90 cm. These drainage ditches can be cleaned out with a backhoe. For the case where the canal network is not enough to sufficiently drain certain sectors of the plantation, the existing ditches can be made deeper or a new ditch can be dug.

If the center of the peat fields is domed, meaning the middle of the fields is much higher than the area along the ditches, the fields should be profiled to create a flat topography for the fields. Convex field topography creates dry conditions in the middle of the field runoff toward the ditches. Flat fields will reduce runoff toward the ditches and favor a more uniform distribution of water. The fields are re-profiled by moving a variable amount of peat from the center of the field toward the ditch and can be carried out with a grader (worm drive). It is however important to make sure that the displaced peat does not go into the ditches as it would block the drainage.

The peat itself plays and important role in the hydrology of the site. Well aerated peat is always more efficient in absorbing and redistributing water than peat which has already been compacted. Thus, it is important to limit the repeated passage of machinery when the peat is saturated with water (in spring, after big rain events) in order to avoid reducing hydraulic conductivity. Limiting machine use on saturated peat should be done both before and after planting.

IN SHORT

One must remember that well aerated peat and a good amount of moisture during the growth season as well as a deep peat layer above water table favors the growth of trees. The degree to which the drainage system should be maintained depends on the goals of the reclamation project.

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PHOTO : A. Jacob

CHAPTER 4
CHOICE AND PLANTING OF VEGETATION

In North America the first planting trials for tree species on residual peat began in the beginning of the 1990s. Different tree species have been tested over the years (Figure 17). This chapter summarizes information on species choice and is based on studies carried out by PERG or plantations carried out by peatland managers from the horticultural peat industry.

SPECIES CHOICE

Not all tree species are suitable for all the types of reclamation. The pertinent information for choosing among the species currently recommended in North America is shown in Figure 18 and in the individual description for each species.

SUGGESTED READING

We recommend that you consult the book *Trees in Canada* (Farrar, 1995) to learn more about how to identify the tree species described below.

PHOTO : S. Hugron

Figure 17 Larch plantations at Pointe-au-Père (Lower St. Lawrence, Québec) seven years after planting.

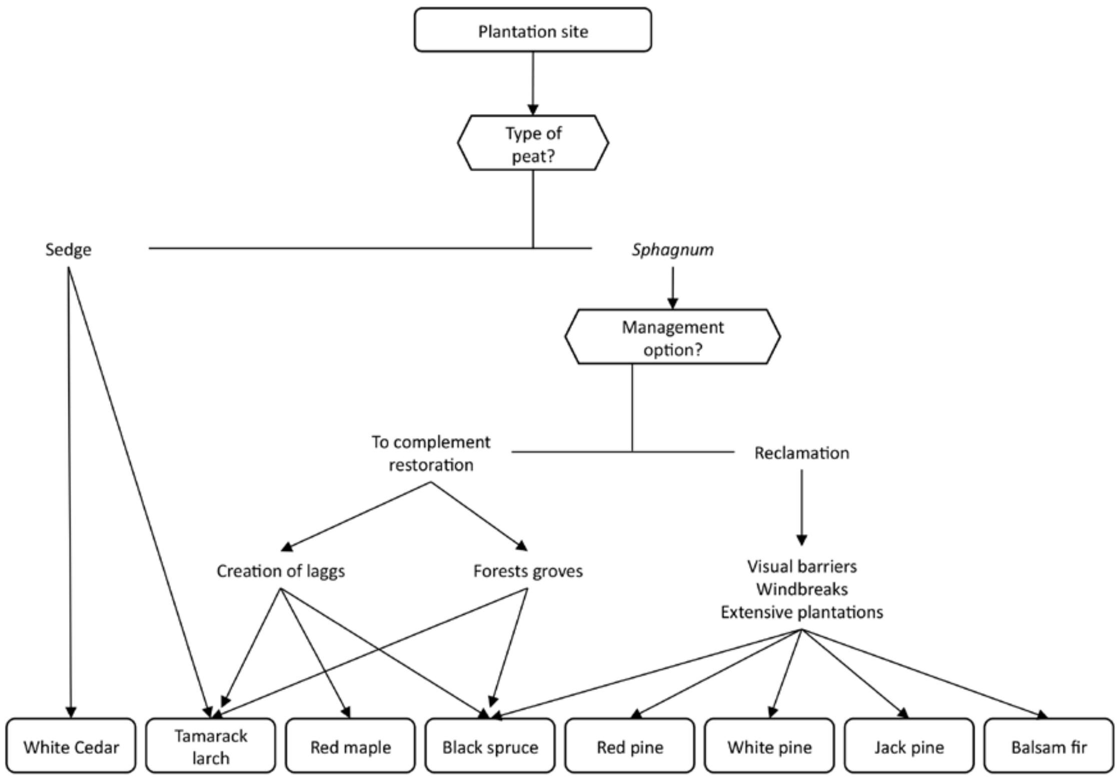

Figure 18 Diagram for choosing species according to the characteristics of the site.

Generally speaking, we suggest using species which are native to the region for plantations. For plantations which complement ecological restoration, trees found in undisturbed peatlands in the region should be used. It is also important to pay attention to the plant hardiness zone of the chosen species and to make sure you don't plant trees in a zone which is too cold for them (Figure 19). Thus, a species such as the red maple which belongs to the plant hardiness zone 3a will have lower survival and growth rates if planted in the plant hardiness zone 2b. Conversely, Nordic species planted in a more temperate climate often have acceptable or even higher survival and growth rates (for example: a black spruce whose plant hardiness zone is 1a would have good (even better) survival and growth rates when planted farther south).

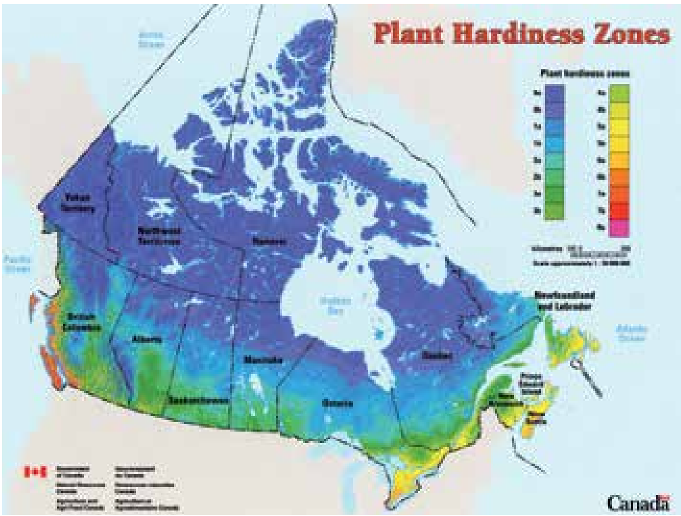

Figure 19 Winter hardiness zones for plants in Canada (Source: www.planthardiness.gc.ca).


PHOTO : G. Ayotte

Abies balsamea (Balsam fir)

French name: Sapin baumier | **Family**: Pinaceae

GENERAL DESCRIPTION

Mature height[1]
height: 18 to 25 m | Width: 7 m | DBH[2]: 70 cm

Growth rate: Slow

Average maximum age: 150 to 200 years

Rooting: Superficial

Susceptibility to disease: Not problematic

Susceptibility to pests: Average to high; principally to the balsam woolly adelgid and to spruce budworm

Tolerance to competition: High, can establish in the shade

HABITAT

Plant hardiness zone: 1a

Natural habitat: Diverse habitats, prefers cold and moist climate

Drainage: Average moisture (well drained to humid)

Soil texture: Gravely to sandy loam or organic soil

pH: Slightly to strongly acid

Exposure to sunlight: Sunlight or partial shade

REPRODUCTION

Fruits: cones

Age of sexual maturity: 20 to 30 years

POTENTIAL USE

Restoration: Species non-indigenous for bogs, so it use in restoration projects is not recommended

Reclamation: Effective as windbreaks because of its persistent foliage. Interesting ornamental value, the species is used as Christmas tree.

FERTILIZATION

No experiments were performed on this species by the PERG. However, there are plantations on peat by a Christmas tree producer that resulted in satisfying growth rates. No data on tree fertilization is available.

DID YOU KNOW THAT?

Despite its name, the spruce budworm prefers to feed on balsam fir and can cause significant damages in a balsam fir plantation. In addition, this species is particularly susceptible to damage by fire because its needles, bark and resin are highly flammable.


PHOTO : S. Hugron

[1] For all species, maturity height on moist organic soil will be inferior to the values presented in the tables, since those represent the height under optimal conditions, which generally correspond to well-drained mineral soil.

[2] Diameter at breast height.

PHOTO : G. Ayotte

Acer rubrum (Red maple)

French name: Érable rouge | **Family:** Aceraceae

GENERAL DESCRIPTION

Mature height
height: 18 to 20 m | Width: 15 m | DBH: 46 to 76 cm

Growth rate: medium, average height of 81 cm three years after planting on residual peat

Average maximum age: 150 years

Rooting: Superficial

Susceptibility to disease: Not problematic

Susceptibility to pests: Not problematic

Tolerance to competition: Medium to high, tolerates shading

HABITAT

Plant hardiness zone: 3a

Natural habitat: Wetlands like swamps and laggs

Drainage: Soil with high humidity

Soil texture: Clay or organic soils

pH: acid

Exposure to sunlight: Sunlight or partial shade

REPRODUCTION

Fruits: di-samara

Age of sexual maturity: About 4 years

POTENTIAL USES

Restoration: Interesting species for the creation of laggs (margins of forested peatlands).

Reclamation: As screens of windbreaks hedges in alternation with coniferous species. High ornamental value because its foliage turns entirely red in autumn.

FERTILIZATION

Recommended formulation by seedling	**Expected survival rate**	**Expected growth** height of tree (3 years)
400 g Of 3.4-19-29.2	About 70%	92 cm
If no fertilization	About 70 %	38 cm

PARTICULARITIES OF PLANTATION

It is best to plant red maple in the spring than any other time of year. Moreover, if the purpose of the plantation is to optimize the survival of trees rather than growth, no fertilization is required.

PHOTO : S. Hugron

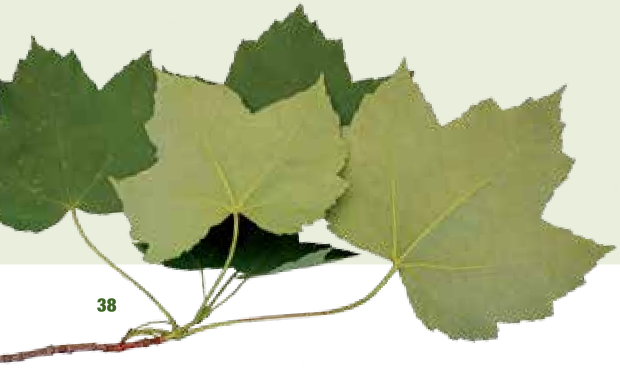

PHOTO : G. Ayotte

Larix laricina (Tamarack larch)

French name: Mélèze laricin | **Family:** Pinaceae

GENERAL DESCRIPTION

Mature height
height: 15 to 23 m | Width: 10 m | DBH: 36 to 51 cm

Growth rate: medium, average height of 4.6 m nine years after planting on residual peat

Average maximum age: 150 to 180 years

Rooting: Superficial

Susceptibility to disease: Not problematic

Susceptibility to pests: Not problematic

Tolerance to competition: Low, hence the importance of weeding during the first years after planting

HABITAT

Plant hardiness zone: 1a

Natural habitat: Wetlands (peatland, swamp, lagg) to well drained soils

Drainage: Medium to high humidity

Soil texture: Clay, loam, sand or organic soils

pH: Alkaline to acid

Exposure to sunlight: Full sunshine

REPRODUCTION

Fruits: Cones

Age of sexual maturity: From 4 years, but production is optimal at 75 years

POTENTIAL USES

Restoration: Creation of forested groves and laggs for ecological restoration projects in fens and bogs.

Reclamation: Can be planted in windbreaks in alternation with slower growing species. Its effectiveness in windbreaks is lower during winter because its foliage is deciduous. To consider for plantations along roads, because it is resistant to de-icing salt. Ornamental value is high its foliage changes color in autumn.

FERTILIZATION

Recommended formulation by seedling	**Expected survival rate**	**Expected growth** Terminal shoot (2 years)
10 g of 11-17-9 10 g of 20-10-15 10 g of 20-11-9	Over 90%	10 to 20 cm
10 g of 18-17-15	Over 90%	30 cm
If no fertilization	About 50%	1 cm

PARTICULARITIES OF PLANTATION

Species that exhibits the higher growth rate among those tested in cutover peatlands, which makes it particularly interesting for reclamation projects. The tamarack larch is a species with high evapotranspiration rates, which must be taken into consideration in ecological restoration projects since a large number of seedlings could cause a local drawdown of the water table in sites where rewetting is not optimal.

PHOTO : G. Ayotte

PHOTO : G. Ayotte

Picea mariana (Black spruce)

French name: Épinette noire | **Family:** Pinaceae

GENERAL DESCRIPTION

Mature height
height: 20 m | Width: 5 m | DBH: 30 cm

Growth rate: Slow, on residual peat the oldest plantations reach 1.5 to 4 m after 10 years.

Average maximum age: 200 years

Rooting: Superficial

Susceptibility to disease: Not problematic

Susceptibility to pests: Not problematic

Tolerance to competition: Low, hence the importance of weeding during the first years after planting

HABITAT

Plant hardiness zone: 1a

Natural habitat: Boreal forest and wet sites including Sphagnum-dominated peatlands

Drainage: Humid to well-drained

Soil texture: Organic soils

pH: acid

Exposure to sunlight: Sunlight or partial shade

REPRODUCTION

Fruits: cones

Age of sexual maturity: About 30 years

POTENTIAL USES

Restoration: Creation of forested groves and laggs for ecological restoration projects in bogs.

Reclamation: Effective as a windbreaks or screens thanks to its evergreen foliage. Since its growth is slow, spruce can be planted in alternation with fast growing species to get quick results. The spruce trees can then be favored during selective logging.

FERTILIZATION

Recommended formulation by seedling	**Expected survival rate**	**Expected growth** Terminal shoot (2 years)
10 g of 11-17-9 10 g of 20-10-15 10 g of 20-11-9	Over 80%	Over 6 cm
If no fertilization	About 50%	3 cm

DID YOU KNOW THAT?

The most abundant tree species in North American ombotrophic peatlands. Experimental plantations on residual peat gave very good results, it is therefore the main tree species that should be used for the restoration of bogs.

PHOTO : L. Rochefort

PHOTO : G. Ayotte

Pinus banksiana (Jack pine)

French name: Pin gris | **Family:** Pinaceae

GENERAL DESCRIPTION

Mature height
height: 13 to 20 m | Width: 7 m | DBH: 30 cm

Growth rate: slow

Average maximum age: About 150 years

Rooting: In depth

Susceptibility to disease: Not problematic

Susceptibility to pests: Not problematic

Tolerance to competition: Shade intolerant, hence the importance of weeding during the first years after planting

HABITAT

Plant hardiness zone: 1a

Natural habitat: Poor and dry soils of the boreal forest

Drainage: Low to medium humidity

Soil texture: Sand or organic soils

pH : acid

Exposure to sunlight: Full sunshine

REPRODUCTION

Fruits : cones

Age of sexual maturity: 5 to 10 years

POTENTIAL USES

Restoration: The jack pine is a not species recommended for restoration projects because it is not naturally found in peatlands; however it is indigenous to North America.

Reclamation: Effective as windbreaks or visual barriers.

FERTILIZATION

Recommended formulation by seedling	**Expected survival rate**	**Expected growth** Terminal shoot (2 years)
10 g of 20-10-15	Over 90%	9 cm
If no fertilization	No data available	

DID YOU KNOW THAT?

The Jack pine has serotinous cones that only open under the effect of heat, such as during forest fires.

PHOTO : G. Ayotte

Pinus resinosa (Red pine)

French name: Pin rouge | **Family:** Pinaceae

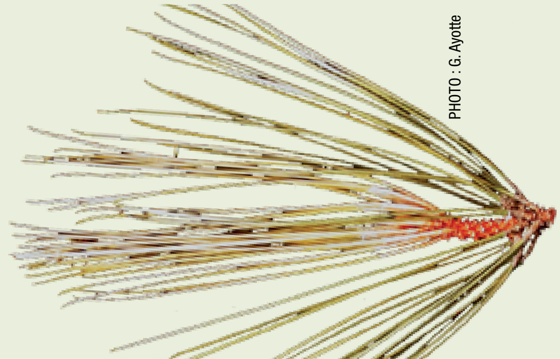

PHOTO : G. Ayotte

GENERAL DESCRIPTION

Mature height
height: 21 to 30 m | Width: 12 m | DBH: Up to 75 cm

Growth rate: medium

Average maximum age: About 200 years

Rooting: In depth

Susceptibility to disease: High (scleroderris canker)

Susceptibility to pests: Low (various insects)

Tolerance to competition: Low to medium, slower growth in the shade

HABITAT

Plant hardiness zone: 2b

Natural habitat: sandy plain and rocky outcrops, generally infertile soil

Drainage: Low humidity (well drained soil)

Soil texture: Sand or sandy-loam

pH: acid

Exposure to sunlight: Full sunshine

REPRODUCTION

Fruits: cones

Age of sexual maturity: 5 years

FERTILIZATION

Recommended formulation by seedling	**Expected survival rate**	**Expected growth** Terminal shoot (1 year)
The different formulation tested did not improve survival or growth rate after one growing season.		
If no fertilization	About 80%	4 cm

POTENTIAL USES

Restoration: The red pine is not a species recommended for restoration projects because it is not naturally found in peatlands

Reclamation: Effective as windbreaks or visual barriers.

DID YOU KNOW THAT?

The scleroderris canker is a fungus that causes mortality of the buds and reddening of the needles, from the base to the tip, in the spring. It is therefore important to inspect the seedlings before planting, preferably in spring, since it is the period at which the disease is easier to detect. In case of infestation, immediately consult a specialist.

PHOTO : S. Hugron

PHOTO : G. Ayotte

Pinus strobus (White pine)

French name: Pin blanc | **Family:** Pinaceae

GENERAL DESCRIPTION

Mature height
height: 20 m | Width: 7 m | DBH: Up to 1 m

Growth rate: Fast

Average maximum age: 200 to 450 years

Rooting: superficial

Susceptibility to disease: High (white pine blister rust)

Susceptibility to pests: Low (white pine weevils pest)

Tolerance to competition: Medium, tolerates shade, but not vegetative competition

HABITAT

Plant hardiness zone: 2b

Natural habitat: General, good growth on poor soils

Drainage: Well drained soils

Soil texture: sand

pH: acid

Exposure to sunlight: Sunlight or partial shade

REPRODUCTION

Fruits : cones

Age of sexual maturity: 20 to 30 years

POTENTIAL USES

Restoration: The white pine is not a species recommended for restoration projects because it is not naturally found in peatlands

Reclamation: Effective as windbreaks or visual barriers.

FERTILIZATION

Recommended formulation by seedling	**Expected survival rate**	**Expected growth** Terminal shoot (1 year)
The different formulation tested did not improve survival or growth rate after one growing season.		
If no fertilization	About 96%	4 cm

DID YOU KNOW THAT?

The white pine blister rust is caused by a fungus that firstly affects the needles (presence of yellow dots on the needles in the spring). When the fungus reaches the branches and trunk, the bark is distorted by bulges and takes an orange color. It is imperative to act quickly and remove the affected parts as soon as the disease is detected. Do not hesitate to call upon a specialist if you suspect a problem in your plantation.

PHOTO : G. Ayotte

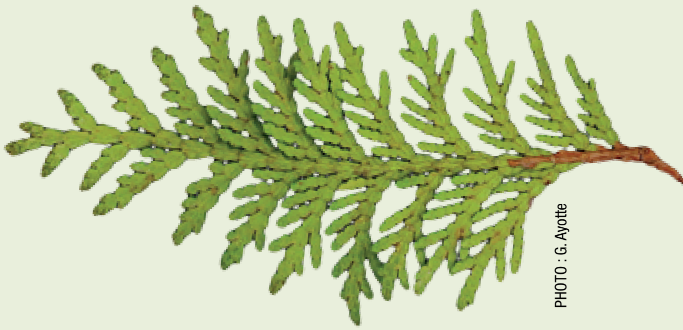

PHOTO : G. Ayotte

Thuja occidentalis (White cedar)

French name: Thuya occidental | **Family:** Cupressaceae

GENERAL DESCRIPTION

Mature height
height: 12 to 15 m | Width: 4 m | DBH: 30 to 60 cm

Growth rate: Slow to medium, in poor sites trees can reach 5 m height in 50 years.

Average maximum age: 400 years

Rooting: superficial

Susceptibility to disease: Not problematic

Susceptibility to pests: Not problematic

Tolerance to competition: Medium to high, tolerates shade

HABITAT

Plant hardiness zone: 3

Natural habitat: Nutrient rich wetlands like swamps or fens

Drainage: High humidity

Soil texture: Clay, loam, sand or organic soils

pH: Acid, neutral or alkaline

Exposure to sunlight: Sunlight or partial shade

REPRODUCTION

Fruits : cones

Age of sexual maturity: From 6 years, but production is optimal at 75 years

POTENTIAL USES

Restoration: Creation of forested groves and laggs for ecological restoration projects in fens.

Reclamation: Effective as windbreaks or visual barriers; forms dense hedges with evergreen foliage. Ornamental value is interesting.

FERTILIZATION

Recommended formulation by seedling	Expected survival rate	Expected growth
No fertilizers were tested		
If no fertilization	About 98% (on 25 cm of residual peat)	No data available

DID YOU KNOW THAT?

The white cedar is the species commonly used to form cedar hedges.

PHOTO : S. Hugron

Complement to restoration

Creation of forested islands

Among the species studied for planting on milled peatlands, the black spruce and larch have been studied the most and perform the best in terms of survival and growth. These species should be given priority for restoration projects on peatlands with *Sphagnum* peat because, aside from a good yield, they are the two species which are the most abundant in undisturbed bogs. In 2004, forested islands of black spruce were tested by François Quinty (Planirest Environnement Inc.) on a peatland near Lac-Saint-Jean, Québec. The trees were planted after restoration on the drier areas of the peatland (water level varied between -35 and -45 cm during the year). After 4 years, the survival rate of the black spruce was greater than 90% (Figure 20). For a restoration project on a peatland where the residual peat is sedge peat, the larch is a very good option because they are found in undisturbed fens. The results of trials carried out in New Brunswick indicate that white cedar (*Thuya occidental*), a species typical to undisturbed fens, would also be a good candidate for plantations on minerotrophic (sedge) peat.

PHOTO : F. Quinty

Figure 20 Spruce trees imitate a forested island on a restored peatland near Lac-Saint-Jean, Québec four years after plantation.

DID YOU KNOW THAT…

When the lower branches of a black spruce are covered with a carpet of *Sphagnum*, they can grow roots creating thus new 'daughter plants' around the original plants (Figure 21). This process called layering can be the origin of islands of spruce in undisturbed peatlands. On restored sites where *Sphagnum* grows well this phenomenon is expected to be observed.

PHOTO : S. Hugron

Figure 21 Daughter plants resulting from the layering process around a mature black spruce tree.

Creation of laggs

For projects where the goal is to create a forested border around the peatland, many tree species can be used in combination. Among those which have already been tested and which show a good survival rate, the larch and red maple are worthy of interest.

VEGETATION DIVERSITY OF LAGGS

Laggs are transitional ecosystems between peatlands and adjacent uplands. These areas are 'hot spots' for diversity containing many plant species (Figure 22). Here is a list of the principal tree species found in laggs:

Trees:

- Red Maple *(Acer rubrum)*
- Tamarack Larch *(Larix laricina)*
- Black Spruce *(Picea mariana)*
- White Cedar *(Thuja occidentalis)*
- Yellow birch *(Betula alleghaniensis)*
- Eastern White Pine (Southwest of Québec) *(Pinus strobus)*
- Red Pine (Southwest of Québec) *(Pinus resinosa)*

Shrubs:

- Withe-rod *(Viburnum nudum* var. *cassinoides)*
- Catberry *(Nemopanthus mucronatus)*
- Speckled Alder *(Alnus incana* ssp. *rugosa)*
- Sweetgale (fen lagg) *(Myrica gale)*

All of these species are potentially interesting for reclamation projects whose goal is the recreation of a lagg. An experimental project for the creation of forested zone along the border of a peatlands is currently being carried out by PERG. This experiment will also evaluate the establishment rate of Sweetgale using cuttings.

PHOTO : É. Paradis

Figure 22 Diverse vegetation of the peatland border (lagg).

Other reclamation projects

If the goal of the tree plantation project is a wind break or privacy screens (Figure 23), you should think about whether you prefer winter foliage or not? If winter foliage is desired, evergreen trees (i.e. black spruce, white cedar, balsam fir or pines) should be planted. If no foliage in winter is preferred, you should plant deciduous or larch trees. It should also be mentioned that the larch is the species that grows most quickly on a milled peatland and can thus create a wind break or a privacy screen relatively quickly.

PHOTO : S. Hugron

Figure 23 Larch planted to create a wind break.

Considering the effort and costs involved in planting trees on milled peatlands, it is important to carry out preliminary tests before planting a **new species**. Small-scale plantations with several dozen trees are enough to verify the survival and growth of new species.

Not-recommended species

The use of species which are not native to North America is not recommended for reclamation or restoration projects because these species could become invasive species and because it is better to protect the native diversity. Table 2 summarizes information on tree species already tested in field trials, but which are not recommended for plantations on milled peatlands.

Table 2 Species not recommended for plantations on residual peatlands

Species	Why shouldn't it be used?
Scots pine	Grows well on residual peatlands, but is not native.
Hybrid poplar	Survival rate on residual peatlands is low and is not native.
White and grey birch	Native to North America, but not typical for natural peatlands. Have a high potential to become invasive species because they produce large quantities of seeds and can establish easily on peat. Can invade restored sites and contaminate adjacent milled sites. It may be necessary to carry out active measures to control them (see chapter 6).

Use of companion species

The presence of certain tree and shrub species can be beneficial for the growth of other tree species. For example, the mountain alder (*Alnus viridis* (Chaix) DC. ssp. *crispa*) has already been tested as a companion or nursing plant for the black spruce. These trials showed that the presence of alder increased the growth of black spruce because alder is a nitrogen-fixing plant and provides adjacent spruce trees with a long-term supply of nitrogen. Alder trees can, for example, be integrated into a tree island or could add diversity to a windbreak.

In 2010, PERG (within the framework of a research project by Étienne Paradis) tested the effect of mosses carpets on the survival and growth of trees. The preliminary results showed that mosses and straw mulch increased survival and growth rates of black spruce (Figure 24), which is probably because these groundcovers stabilize the substrate.

Figure 24 The black spruce planted with moss fragments and covered with straw mulch (A) showed higher survival and growth rates than trees planted without moss (B).

SEEDLING CHOICE

The morphology of root system (seedlings type) as well as the initial dimensions of the seedling (size) will directly influence the success of the tree plantation. The choice among tree species and their size depend mainly on the goal of the plantation as well as the conditions of the plantation site. The site's susceptibility to frost heaving (Figure 13) and propensity to be invaded by competitive species are the principle factors which will influence the choices made during planting. The technical constraints related to transport, storage and handling are also factors to consider.

Seedling type

Among the two types of seedlings presented (Table 3), we suggest using those planted in pots rather than trees with bare roots (Figure 25).

PHOTO : F. Quinty

Figure 25 Black spruce seedlings in pots.

Table 3 Advantages and disadvantages of different seedling types

Potted seedlings
Short delay in nursery culture (2 years of less);
Simplified transportation to the plantation site and simplified storage (no refrigeration necessary);
Planting simpler than for bare root plants (thus a planters are more productive);
Excellent survival rate because the stress at planting is less than for the bare root plants;
To use for sites where frost heaving is not a problem.

Bare root seedlings
Robust (excellent height/diameter ratio);
Resists being crushed by competitive vegetation or by snow;
Plants are lighter, thus transportation is easier and less expensive (1.5 to 2 times lower);
Average survival rate is 80% (plants mainly die in the first growing season);
Possess a root system which is dense and spread out which allows for a better contact with the soil;
Should be used for sites which are subject to frost heaving;
Recommended for sites where many competitive species are present.

Seedling size

Two sizes of seedling are currently being recommended for residual peatlands in North America are (1) small seedlings (SS) whose root system is circa 110 cm^3 in pots and large seedlings (LS) whose root system is greater than 350 cm^3, Table 4. The small seedlings are young (1 ½ to 2 years) and their height is approximately 20 to 25 cm for the black spruce. The large seedlings are generally 2 years old at delivery for the seedling in pots and 3 to 4 years old for the bare root seedlings. In the case of the LS for the black spruce, the height is usually 35 to 45 cm for the seedlings in pots or 40 to 60 cm for the bare root seedlings. There are also medium sized seedlings (MS) whose root system are 200 cm^3 and should be used for sites where some competitive plants have established.

Table 4 Comparison of different seedling sizes.

Small seedlings (SS)
Root system 110 cm^3 (110 cc)
Less expensive to buy and plant (the larger the plants, the higher the plantation costs);
Take less space and are lighter, thus easier and less expensive to transport;
To use for the pure tree plantation where there is no risk of competition from invasive species or peat deposition from wind erosion.

Large seedlings (LS)
Root system more than 350 cm^3 (350 cc)
Resistant to being buried by peat transported by wind erosion :
Will outcompete other vegetation (weedy species or plants established during restoration) with minimum maintenance;
Reach a reasonable height more quickly;
Should be used for projects where fast growth is desired (wind breaks);
Desirable for restoration projects and sites at risk of invasion by other vegetation (the LS are larger than invading vegetation) or sites at risk of wind erosion burial.

Origin and ordering of seedlings from nurseries

Generally speaking, it is important to order your seedling far in advance as a late order could delay your plantation due to delays in production, preparation and delivery. You should allow 1 ½ to 2 years for small seedlings. The production time increases with seedling size; thus, orders should be placed 3 to 4 years before planting for large seedlings. It is recommended that you verify the availability of different tree species when planning the plantation because certain species could be difficult to obtain, notably the tamarack larch which is not frequently used for large-scale reforestation.

If your management plan was completed well in advance and your nursery offers this possibility, it is ideal to place a special order of trees whose seeds were collected from a peatland near the restoration site. The trees thus have a certain adaptive advantage, like a tolerance to acidic, poorly-drained soils. Notably, it may be difficult to obtain native tamarack larches from a nursery, thus it would be advantageous to supply the nursery with your own seeds.

THE PLANTATION

Quality of the seedlings

Before planting potted seedlings, it is essential to assure their quality. They should be in good health and have a good height/diameter ratio (H/D ratio). Do not use seedlings if they have stayed in the same pots for too long (i.e. 3 years instead of 2 for 110 cc pots) or which are too etiolated and have a H/D ratio which is too high. Note that it is possible to know the age of a young coniferous plant by counting the number of growth scars on the main stem. A good H/D ratio is important for plants growing on milled peatlands where there are strong winds because of the large areas void of vegetation make the sites very windy (Figure 26). Stocky plants will withstand the wind better.

PHOTO : A. Jacob

Figure 26 Tamarack larch from a nursery where it was left in the pot longer than recommended. The H/D ratio is too high to assure normal survival and growth rates.

In order to judge the health of seedlings at the moment of delivery, here are some things you should observe:

- The H/D ratio of seedlings raised in pots should be adequate;
- The stem should be straight with a terminal shoot that is intact and well-formed;
- The root system should be well-formed, contains a good proportion of rootlets (long-haired roots), should not be rolled up in the pots (sign that pots were too small) and the root system should not be damaged when the pot is removed;
- There should be no insects on the seedlings, wounds or necrosis on the stems and branches, nor should there be holes, spots or discoloration on the leaves or needles (possible fungal infection) or dry or partially-absent leaves or needles (tendency to fall when touched);
- If health problems are suspected, you should cut some roots using pruning shears. The inside of the cut sections should be completely white and healthy. If the interior is brown or spotted, the plant is wilting, dead or frozen.

SUGGESTED READING

If you have doubts concerning the quality of the seedlings you have been given, we suggest that you consult the field guide *Inventaire de qualification des plants résineux cultivé en récipients* from the MRNF (2011) which illustrates the different criteria presented in this guide. Additionally, you will find H/D ratios and the seedling size expected for each species. This guide is available of the PERG web site under the tab *About* (see other useful documents under the section *general documents on peatlands*)

Handling of seedlings

Here are some precautions which should be taken when seedling are being handled in order to maximize the chances of successful establishment after planting:

- Pay particular attention to not damage the seedlings during transportation. The buds are particularly fragile and can easily fall off;
- Transport the seedling in a covered vehicle in order to protect them from the wind;
- At all times protect the seedlings from direct sunlight, wind and frost if they will be stored outdoors for more than 12 hours;
- Keep the seedling's substrate humid at all times (the root system is considered to be wet enough if some water comes out when you squeeze it in your hands). If you are planting bare root trees, the root system should be kept wet at all times (it may be necessary to cover them with a wet jute);

• Carry out the plantation as quickly as possible (particularly for the bare root seedlings which are under more stress).

If the seedlings need to be stored several hours or a maximum of two days, place them in a cool place (circa 5 °C). It is not recommended to let the plants soak in water (Figure 27) because the roots may suffocate, rendering them incapable of transporting water. Seedlings which have roots that are no longer functional should not be planted.

PHOTO : J. Bussières

Figure 27 Seedlings in pots still in their flats and left in a drainage canal to keep them wet. This practice is not recommended because it can lead to root suffocation and eventually the death of plants.

PLANTING

Moment of planting

Planting trees in pots can be done at any time as long as the soil is not frozen and there has not been a long period of high temperatures or drought. That being said, planting trees when the buds are dormant reduces water stress during planting. Thus, the optimal period is in spring as soon as the soil has thawed and before the buds break or in the autumn after the leaves have fallen. Planting bare root trees must be carried out when they are in a dormant state, preferably in spring.

In the case of the formation of forested islands for ecological restoration, we recommend that the trees be planted one year after restoration. This delay allows site managers to evaluate the success of rewetting and to focus on the driest areas of the site where the *Sphagnum* regeneration is the lowest. It is suggested to wait until the site is relatively dry to reduce traces and any damage to the restored surface. If the site is relatively humid, it is preferable that workers use snow shoes without spikes to avoid trampling.

In the case where the trees are planted to recreate laggs or for reclamation goals other than restoration, the trees can be planted as soon as milling activities cease. You must make sure, however, that work which requires machinery (i.e. re-profiling and blocking the canals) has been completed.

DID YOU KNOW THAT…

During the plantation, note the information related to the choice of species, the quality of the seedlings and their planting on the data sheets *Plantations – Planting the trees* (Appendix 2).

Choice of sectors and microsites for plantations

On your restoration plans, trees should be planted on sites which most closely imitate the habitat where these tree grow in a peatland of your region. You could combine the trees in groups of 8 to 10 trees in order to imitate natural islands in peatlands. When recreating a forested lagg around a restored peatland, plant the trees so that they resemble a natural lagg (not in a single continuous line). If the restored section is part of a large area where other areas will be restored subsequently, be careful when creating a forested border that one section is not cut off from another which will be restored in the future. Figure 28 illustrates this situation:

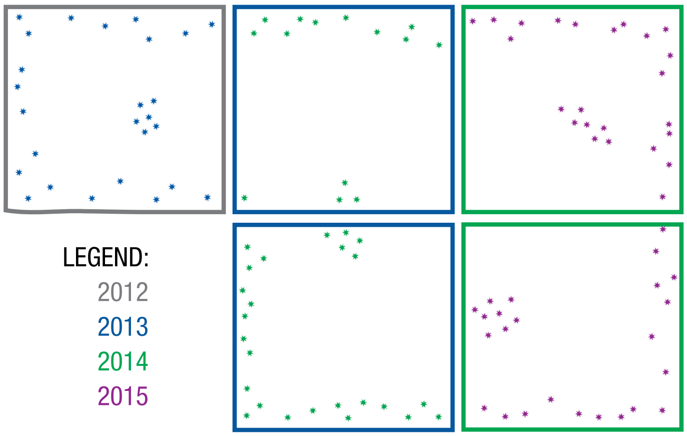

Figure 28 Hypothetical diagram of an abandonment sequence and the plantation on different sectors of a peatland with an illustration of the chosen locations. Note that each sector is not planted individually, but forms part of the final site reclamation.


PHOTO : L. Rochefort

Figure 29 Black spruce plantation on the border of a peatland in a sector where ecological restoration was not possible due to the presence of mineral soil and debris on the surface of the milled peatland.

Regardless of whether you are creating forested islands or forested laggs, you should always plant the trees in the driest sectors and microsites. Rewetting for restoring peatlands aims to maintain the water level within the top 40 cm (ideally between 10 and 30 cm below the surface) to provide optimal conditions for moss growth. For tree plantations, the ideal water level is lower than 30 cm for *Sphagnum* peat and at least 50 cm under the surface for sedge peat. Thus, the **sectors where the microsites are 10 to 30 cm higher than the average site surface are sufficient for planting trees**, as is the case for berms. In this respect, plantation located on berms can contribute to preventing or reducing wind erosion when the restored peatland is located where there is a steep drop. Additionally, the plantations can be an option to consider for the sectors where ecological restoration is not possible due to, for example, the presence of mineral soil close to the surface (Figure 29).

If the trees are planted randomly on the site, they might be planted in areas where the conditions are not ideal for trees. The sectors and situations to avoid are the following:

- Flat sectors with a high water table;
- Depressions;
- Mounds too high and too dry (water level more than 75 cm below the surface).

Besides recreating forested laggs or islands, you could plant trees on sites where you are not satisfied with the water table depth or the establishment success of the introduced vegetation after restoration measures have been carried out. Effectively, if the water level has a tendency to remain low in certain sectors, you are unable to rewet the site, and the conditions remain too dry for moss growth, it is better to plant trees than have bare peat. Trees play an integral part in natural peatland ecosystem and they can, if they are used in an intelligent and careful manner, contribute to the biodiversity and balance of your system.

Plantation techniques

The plantation should be carried out manually by an experienced person (Figure 30). In order to favor their complete development, it is recommended that 1m space be left between trees. A space of 1 m should also be left between trees within the same island. It should be noted that if you manage a milled peatland sector where the only goal is silviculture, the spacing normally recommended in forestry is at least 140 cm.

PHOTO : J. Bussières

Figure 30 Planting the trees on a milled peatland using an instrument called a planter.

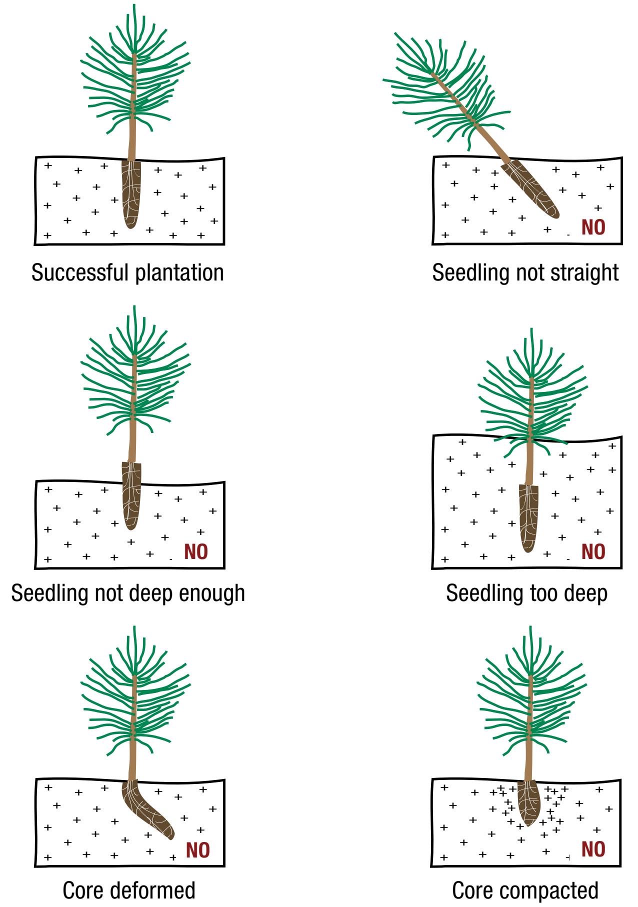

Figure 31 Diagram illustrating a tree planted correctly (upper left) and a trees planted incorrectly.

Here are some guidelines for planting (Figure 31):

- **Location:** in the driest areas (but no more than 75 cm above the water level) if the plantation is part of a restoration project. The plants should not be planted on stumps or debris;
- **Verticality:** the plants should be straight (at least within 30° of a vertical line from the surface);
- **Planting depth:** during planting, the soil core must be completely buried and covered with a maximum of 3 cm of peat. The enlargement (collar) which marks the transition from the roots to the tree stem should be at the same level as the soil. No part of the core (or root in the case of bare root trees) should be exposed and no branch should be covered with soil;
- **Compaction:** the planter should compact the soil with his feet to eliminate pockets of air and prevent the plant from moving if you pull on the bundle of needles. Be careful of excessive compaction because it could deform the soil core and destroy the seedling's root system;
- **Fertilization:** should be carried out during planting (see Chapter 5).

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Above: Fertilized black spruce seedlings (with straw mulch)
Below: Black spruce plants which were not fertilized (without straw mulch)

PHOTOS : L. Rochefort

CHAPTER 5

FERTILIZATION

TREE NUTRITION

There are 17 minerals which are essential to the survival and development of plants. The organic elements (carbon, oxygen, and hydrogen) come mainly from atmospheric CO_2 and water. The minerals are present in the soil and water. When plants grow in a nursery they usually receive a complete and optimal nutrition, which assures the balanced growth of different parts of the tree and allows the seedling to accumulate water and nutrient reserves.

As soon as a tree is planted it is submitted to hydraulic stress as a large quantity of water is lost by evapotranspiration of the needles and leaves while little water is acquired by the root system because the connectivity between the soil and roots had not yet been established. The water reserves the plant has accumulated in the nursery are limited and can respond to the evapotranspiration needs for only several minutes to hours. The initial survival of the plants depends principally on their ability to rapidly develop a functional root system in order to draw water and nutrients from the soil and assure a good anchorage in the soil.

The rapid development of a root system and fertilization are particularly important in milled peatland because the peat contains very little nutrients and it is usually too deep to allow plants access to the nutrients available in the sub soil mineral layer. The trees planted on milled peatlands without fertilizer quickly develop nutrient deficiencies and their survival as well as growth rates are generally low.

IMPORTANCE OF FERTILIZATION

In order to adequately reply to the nutritional needs of the trees three options are possible:

1) Plant trees in sectors where the residual peat deposit is shallow (20 to 30 cm) so that the roots can reach the mineral soil which is generally richer in nutrients than peat;
2) Work the soil so that the underlying mineral soil is mixed with the residual peat,
3) **Fertilize the trees when they are planted**.

The first two options above are not ideal in the North American context as the residual peat is usually deeper than 20 to 30 cm. Additionally, mixing the mineral soil with the peat could create problems with competitive species and pollute the surrounding water.

Adding a fertilizer containing nitrogen (N), phosphorous (P), and potassium (K) at planting increases the survival rate of the seedlings and improves the growth and development of the trees, especially their root system (Figure 32). Nitrogen is the element that has the greatest influence on the trees nutrition during the first growth season, because this element is used for the construction of a root system, leaves and branches. For its part, phosphate fertilization stimulates microbial activities in the soil, increasing the mineralization rate of nitrogen which then becomes available for trees. Without the addition of phosphate the mineralization process is slow, and in the peatlands where the residual peat layer is deep, the mineralization rate is not fast enough to supply young trees with their nutritional needs. Moreover, phosphorous reserves in the plants are generally used up within the first growing season. Fertilization becomes vital to assure good growth afterwards. Finally, potassium is essential for the root system and plays an important role in photosynthesis.

In summary, fertilizers used during planting should contain available nitrogen for the first growing season, phosphate which releases slowly and is available in the second growing season and potassium in a sufficient quantity to assure good growth of the seedling. A good survival rate of trees requires a smaller dose than the doses needed for optimal growth. On the other hand, fertilizing too much greatly diminishes the survival rates of the trees. The selected doses for trees planted in peatlands should offer a balance between survival and growth of seedlings.

PHOTOS : É. Paradis

Figure 32 Growth of larch trees planted four years before: (a) not fertilized and (b) fertilized.

How trees respond to fertilizer differs according to the species and depends in part on the depth of the roots which influences directly the acquisition of the resources. Although the root systems in milled peatlands stay mainly on the surface, the depth of the tree roots can vary considerably according to the species. For example, the majority of the roots for the black spruce are located in the first 20 cm of the peat (maximum 60 cm), while the grey pine's roots are mainly located in the upper 46 cm of the peat surface (maximum 270 cm). Additionally, the specific ecology of species influences its response to fertilizer. For example, the larch is generally found in the richest sections of the peatland and it uses the nutrients acquired from fertilization for its growth in biomass. While the black spruce, which is generally found in poor areas of undisturbed peatlands, uses the nutrients from fertilizer to increase diameter and there is little effect on its growth rate. This species is also very sensitive to toxicity when a fertilizer dose is too high. In conclusion, it is recommended to base the fertilizer type and dose on the species planted and the goals of the plantation.

INITIAL APPLICATION OF FERTILIZER

The initial fertilization should be applied during planting. It is recommended to bury the fertilizer in the soil to reduce the germination and proliferation of competitive species. Here is how to proceed with fertilization:

1) During planting dig a second hole some centimeters from the plantation hole and to the same depth;
2) Insert the fertilizer in the hole;
3) Cover the fertilizer with peat.

It is preferable to use this technique rather than to insert the fertilizer directly in the hole dug for the tree because the fertilizer may burn the roots. This method favors the spreading out of roots as they will grow towards the source of nutrients. Additionally, even when the fertilizer is buried in the soil it is important to assure **good drainage management** of the plantation site because the floods can cause the fertilizer to rise to the surface and increase the occurrence of competitive species (Figure 33).

Figure 33 Birch tree invasion of a larch plantation in Alberta where the water level was too close to the surface for plots fertilized with tea bags (left) and not fertilized (right).

If, for technical or logistical reasons, fertilization cannot be carried out at the same time as planting, localized (spot) fertilizing should be favored over fertilizing the entire site. Localized fertilizing requires three times less fertilization than fertilizing the entire site and achieves the same result. Generally speaking, fertilizing the entire site should be avoided for the initial and subsequent fertilizations because it favors the establishment of weeds. In the case where the plantations are invaded by weedy species, maintenance should be carried out to assure the survival and growth of the trees (see Chapter 6).

Fertilizer form (tea bag or tablets) and doses

It is important to select a **slow-release fertilizer**. This gradually releases nutrients ensuring that fertilizer is available for the plants and microorganisms over a long period of time before the fertilizer is leached away. Consequently, the fertilizer dose can be relatively weak which reduces the invasion of weedy species.

It is advisable to use premixed and packaged commercial products for each tree species rather than to try and mix several fertilizers together and package them yourself. Additionally commercial fertilizers often include a variety of secondary minerals (sulfur, iron, magnesium, manganese, and zinc) in their product which reduces the risk of deficiencies for these minerals. There are currently different products on the market and we tested two types: tablets and tea bags.

Tablets release the fertilizer gradually and generally over two years depending on the manufacturer (many companies make this type of tablets). In light of results from studies carried out by PERG, we recommend the use of 10 g of tablets made up of **20-10-15** (N-P_2O_5-K_2O).

FERTILIZER INGREDIENTS

In Canada, fertilizers are described using three numbers which represent the percentages of **N – P_2O_5 – K_2O** contained in the fertilizer in relation to the total weight. For example, for one tablet of 10 g, there is:

10 % of P_2O_5 = 1 g

20 % of N = 2 g → **20 – 10 – 15** ← 15 % of K_2O = 1,5 g

It should be noted that in Europe, and therefore in European literature, fertilizers are shown in the form **N – P – K** rather than **N – P_2O_5 – K_2O**. In order to convert a quantity of P_2O_5 to P, divide the value by 2.29 and for converting K_2O to K, divide the value by 1.21.

PHOTO : RTI inc.

Figure 34 Photograph of a tea bag.

The tea bags are produced by the Californian company *Reforestation Technologies International* (contact Alan D. Baum at 1-831-424-1494 for orders). These are small biodegradable bags (Figure 34) within which fertilizer is slowly and constantly released over 3 to 5 years, depending on the manufacturer. Studies carried out on milled peatlands have shown that the tea bag ***Forest Pak* (20-11-9) or *Restoration Pak* (11-17-9)** produced the best results.

Generally speaking, we recommend the use of the three fertilizer mixes mentioned above to optimize survival rates of trees planted on milled peatlands. They are easy to use and have a low fertilizer dose which reduces the risk of the site being invaded by weedy species if the water level rises close to the surface. If you want to maximize the trees' growth rate, other mixes than the ones mentioned above will give you better results (Table 5). In the case where the soil analysis was carried out before planting would reveal result that are very different than those presented in Table 1, the fertilizer dose should be adjusted by a professional.

Table 5 Fertilizers recommended according to the results of plantation experiments carried out in Québec and New Brunswick as well as the expected performance for the fertilizer mixes presented.

Species References[1]	Fertilizer in g of N – P_2O_5 – K_2O / plant	Expected performance			
		Survival	Terminal shoot 1 year	Terminal shoot 2 years	Tree height 3 years
Black Spruce a, b, c	1.1 – 0.7 – 0.7 or 2 – 0.5 – 1.2 (for optimal survival)	80 % and greater		6 to 7 cm	
	2 – 0.5 – 0,7 (for optimal growth)	80 % and greater		6 to 9 cm	
	No fertilizer	Circa 55 %		3 cm	
Red Maple a	4.2 – 23.3 – 35.7 (for optimal survival)	70 % and greater			92 cm
	No fertilizer	Circa 70 %			38 cm
Tamarack Larch a, b, c	2 – 0.5 – 0.7, 1.1 – 0.7 – 0,7 ou 2 – 0.5 – 1.2 (for optimal survival)	90 % and greater		10 to 20 cm	
	7 – 3 – 5 (for optimal growth)	90 % and greater		30 cm	
	No fertilizer	Circa 80 %		1 cm	
White Pine d	No fertilizer	90 % and greater		40 cm	
Grey Pine a	2 – 0.5 – 1.2 (for optimal survival and growth)	90 % and greater	9 cm		
Red pine d	No fertilizer[2]	80 % and greater	4 cm		
Eastern Cedar c	No fertilizer[3]	90 % and greater			

[1] References: a) Bussières 2005; b) Caisse 2007; c) Jean-François 2010; d) Demers 2007.
[2] The different experimental mixtures did not have a significant effect on the survival, nor the growth of the pines after one growing season.
[3] No fertilization experiment has been carried out for this species. The plantations we carried out on a site with a thin layer of residual peat (30 cm).

Lifetime of initial fertilizer

The positive effects associated with the initial fertilization are generally short-lived and span over less than five years. According to the goals of the plantation and the nutritional state of the trees, a second dose of fertilizer may be necessary, sometimes as early as three years after the initial fertilization.

OTHER AMENDMENTS AND SOIL WORKING TECHNIQUES

We recommend that you do not use other types of fertilizer or amendment because it will increase the risk of weed invasion. Adding manure, compost, mineral soil, lime, or ashes can only be done by mixing the residual surface peat using machinery. This practice releases fertilizer at the surface of the soil and may favor the germination and proliferation of undesirable species from the surrounding area.

Mixing the mineral sub-soil with the residual peat can be carried out to increase the amount of mineral in the residual peat. For the same reasons explained in the preceding paragraph, we do not recommend this option. Additionally, in Canada the residual peat layer is often too thick to be able to be mixed with the sub-soil layer. In the rare places where the residual peat is shallow enough for allow for this practice, the quantity of stumps and branches often present in deepest layers of the peat deposits also complicate the work and greatly increase the expense.

IN SHORT

Fertilization is generally necessary to assure the success of a tree plantation on *Sphagnum* peat deposit. Remember that it is preferable to analyse the peat before planting the plants. If the contents of chemical elements vary greatly from the values normally found on a peatland after milling for horticultural peat, consult a specialist in order to adjust the fertilization of the trees (Figure 35).

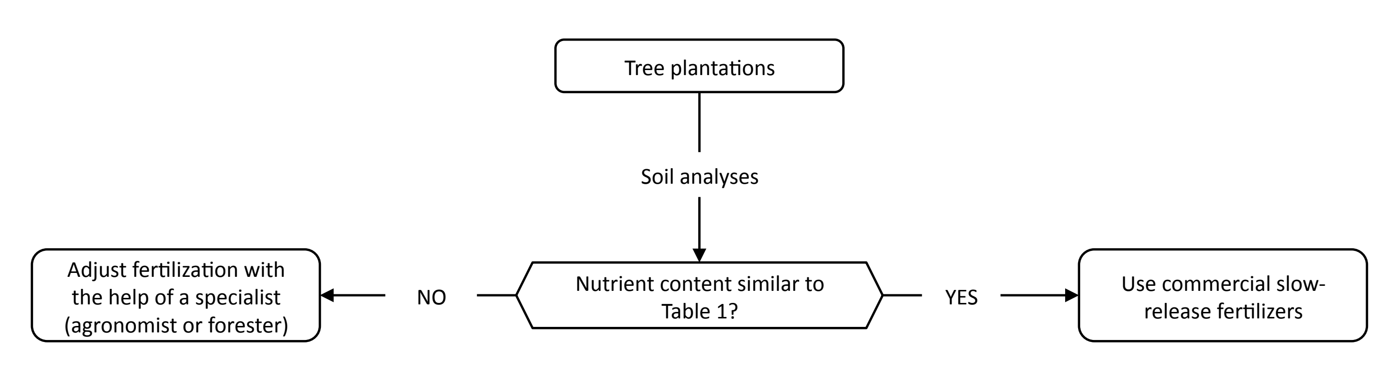

Figure 35 The choice of fertilizer

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PHOTO : V. Bérubé

CHAPTER 6
SURVIVAL, MAINTENANCE AND EVALUATION OF PLANTATION SUCCESS

Monitoring the plantations is an essential part of the reclamation project. This permits the evaluation of the plantation success and also the determination of whether the initial reclamation goals were reached. Monitoring also allows for an effective management of the plantations, permitting the rapid detection of problems and to carry out the necessary upkeep and changes.

MONITORING OF PLANTATIONS

Monitoring the plantation on mineral soils is generally carried out 1, 2, 5 and 8 years after planting the trees. We suggest following the same frequency, because this allow the comparison of the average yields for Québec. For the case of the plantations carried out on a restoration site, the monitoring could be done at the same time as the monitoring for the restoration. Here are some elements to compile for good monitoring:

Before plantation:

- The description of the site before plantation (see chapter 2):
  - State of the drainage system.
  - Degree of decomposition of residual peat using the von Post scale.
  - Depth of the residual peat.
  - Texture of the mineral sub-surface soil.
  - Results of chemical analyses of the residual peat (and the mineral sub-soil if the deposit is shallow).
- The description and nature of the preparation activities of the site and the date on which the jobs were carried out.

During plantation:

- A plantation plan.
- The species used (including their provenance, the type of plants and their size).
- The number of seedlings planted and the date they were planted.
- The average height of the seedlings when they were planted.
- The observations concerning the state of the seedlings before being planted (H/D ratio, sign of deficiencies, etc.).
- The fertilization plan (fertilizer type, formulation, dose per seedling, method and application date).

The years following the plantation (1, 2, 5 and 8 years after plantation):

- The survival rate (evaluated on 10% or more of the trees; can be determined for the whole plantation according to the area). A tree is considered 'alive' if it still has green leaves on one or several of its branches (Figure 36). The uprooted plants should be counted as plants which did not survive (Figure 37).
- Height of the trees and the length of the terminal shoot (measured according to random sampling within the plantation, for example 10 samples of 10 plants).
- Presence of injuries on the trees.
- Signs of nutritional deficiencies:
  - Symptoms.
  - Corrections made (details of the re-fertilization).
- Presence of weeds:
  - Degree of infestation and competition.
  - Methods of control used.
- Presence of illness and pest infestation:
  - Symptoms and estimation of its extent.
  - Methods of control used.

Figure 36 Spruce seedling where the terminal shoot is dead, but the tree survived.

PHOTOS : É. Paradis

Figure 37 Potted seedling which was uprooted by frost heaving and which is considered 'dead' for monitoring.

For each of the elements, it is important to note the date of observation and/or application (see the data sheet *Plantation – Monitoring* in the Appendix 2).

MEASURE TECHNIQUES

Monitoring: Walk through representative sectors of the plantation with a manual counter (Figure 38) to count the living plants with one hand and the dead plants with another. Adding the two numbers together will give you the total number of sampled trees.

PHOTO TIRÉE DE : www.groupemcneil-dendrotik.com

Figure 38 Manual counters for counting the trees. Photo from: www.groupemcneil-dendrotik.com.

Height: Using a meter stick or a measuring tape, measure the plant from the soil to the trees highest point (Figure 39). If the tree measures more than 3 or 4 m, use a clinometer according to the manufacturer's instructions.

PHOTO A. Jacob

Figure 39 Measuring the height of the tree while monitoring a young pine plantation.

Length of the terminal bud: Can be measured only for coniferous trees. Using a measuring tape, measure the main shoot of the plant from its extremity until the first growth scar is encountered (Figure 40).

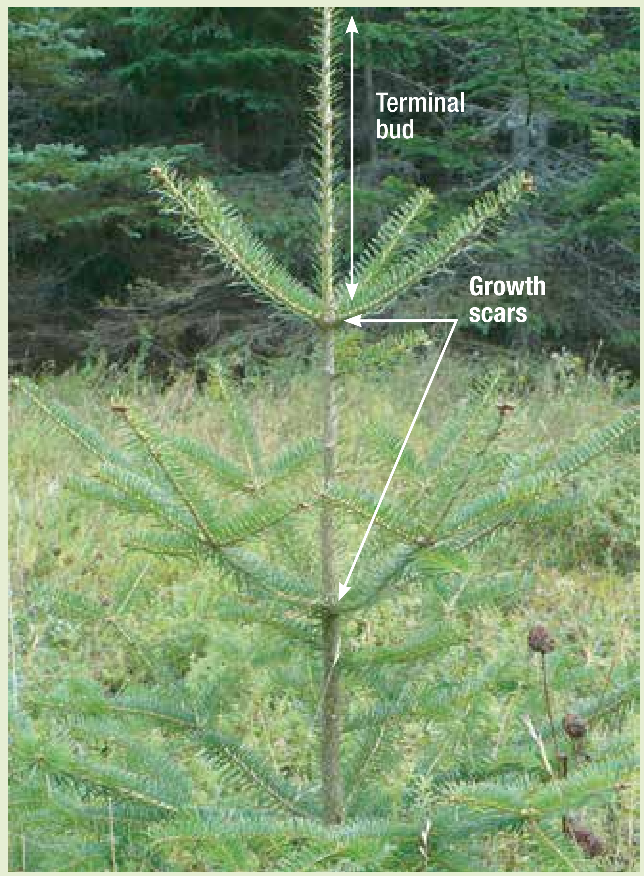

PHOTO S. Hugron

Figure 40 Terminal shoot of a balsam fir.

EVALUATION OF SUCCESS

Evaluating the success of a plantation should take performance indicators into account. These indicators should be established before monitoring begins and adapted to the type of reclamation. For the case of planting trees for ecological restoration, the success indicators should mainly take the survival rates of the trees, rather than their growth into consideration, because in natural peatlands the growth is generally slow due to the high water table (Figure 41). Lack of data makes it impossible to evaluate a precise threshold concerning the survival rate of plantations within this context. However, we suppose that a survival rate between 60 and 70% would be enough to fulfill the goals of ecological restoration taking the high water level into consideration.

PHOTO : L. Rochefort

Figure 41 Spruce trees where the growth rate is low in natural peatlands.

Currently, the majority of studies carried out on residual peat were done in drained, non-restored sectors where the survival rate was more than 80% for the conifers and 70% for the deciduous trees. A lower survival rate generally indicates inadequate fertilization or drainage and measures should be taken to improve the conditions for the trees.

MAINTENANCE

Periodic monitoring of the plantation success permits a peatland manager to determine if management is necessary. Generally speaking, these measures will be more efficient and less expensive if they are carried out as soon as the problems are diagnosed. Diagnosing problems will allow peatland managers to avoid possible failure of the plantation.

Weed control

Among the potential weeds, we include agricultural weeds, certain peatland species and tree species common to open areas, i.e. birch tree. Generally, the invasion of weeds on milled peatlands does not occur because the residual peat is acidic and not fertile. However, when weeds do succeed in invading a plantation, they will create competition with the trees for nutrients, water, light and space. A certain degree of invasion by weedy species can be tolerated (Figure 42). However, when competitive weedy species cover a large area of the soil surface, weed control measures should be carried out.

PHOTO : S. Hugron

Figure 42 The presence of a low cover of cottongrass in a plantation can be tolerated because it does not affect the trees' growth.

THE EFFECT OF WEEDS ON PLANTATIONS

Applying a dose of fertilizer which is too high to the surface of a milled peatland can lead to the invasion of weedy species. Weedy species can also invade sites which have been fertilized with tablets or tea bags if the site experiences flooding allowing the nutrients to rise to the surface (Figure 43). These weeds can intercept a good proportion of the light needed for tree growth. The invasion of plantations by small trees and shrubs diminishes mainly the growth in diameter of the trees which can lead to and increased instability of the seedlings. Mortality due to competition comes later. Furthermore, if the fields to be reclaimed are located directly adjacent to the fields that are still being milled, the presence of weeds can contaminate the peat being milled.

PHOTO : L. Rochefort

Figure 43 Establishment of birch within a spruce plantation due to flooding which allowed the nutrients buried under the soil (in tea bags) to rise to the surface.

Manual maintenance is possible for small surfaces. Due to the crumbly and loose nature of residual peat, it is relatively easy to manually pull out non-woody weeds. Trees and shrubs can be manually cut using pruners or a weed eater. Manual maintenance is generally an efficient way to control weeds, even if it must be carried out periodically.

DID YOU KNOW THAT?

If the plantation is invaded by large birches, it is better to cut them down when they have leaves and before the end of August. Birches should be cut at a height of 50 cm rather than at the soil surface (Figure 44) so they will not have the energy needed to develop new growth from the trunk (also called stump sprouts).

PHOTO : L. Rochefort

Figure 44 Cutting the Birch at 50 cm above the soil surface in order to limit the regeneration capacity.

Mechanical maintenance is recommended for large sites where the spacing between the plants is enough for machinery to circulate (mainly for projects which are not ecological restoration). Mowing down weeds using a lawn tractor should be carried out regularly and several time a year (Figure 45). The use of machinery should be restricted to the periods when the soil has an adequate carrying capacity, meaning you should avoid using machinery on soils which are too wet.


PHOTO : J. Bussières

Figure 45 Fields where weeds between trees and berry bushes were mowed. Note the peat pile and fields still being milled in the background.

Conifers are generally less affected by competition than the deciduous species. In both cases, when the height of the trees' leaves exceed the height of the weeds, weed control is no longer necessary.

For tree plantations carried out within the context of restoration, the risk of invasion by weedy species is low because the saturated conditions are not ideal for weeds. If they do invade a restored site, we recommend manual weeding because the circulation of machinery will be difficult in the saturated conditions and could damage the species introduced during restoration.

Pest control (insects, fungus, browsing)

Insects, fungus and browsing by animals can cause extensive damage to plantations. When monitoring, the relevant indicators that pests are present should be noted and action should be taken quickly to avoid an epidemic.

Deciduous trees are much more likely to be affected by deer browsing and damage caused by rodents. One method to protect the trees from deer browsing is to fence off the plantation so that it is inaccessible to the deer. Another interesting method is to insert a metal rod next to the tree which surpasses the tree and is attached to the trunk. This rod bothers animals when they browse the trees. Damage from rodents can be limited by inserting individual protectors at the base of the trees.

When the damage is caused by insects of fungi, it is recommended to call a specialist to identify exactly what has invaded your trees and to get advice for treating the illness. It is important to know that trees suffering from nutritional deficiencies are more susceptible to pests.

Re-fertilization

The beneficial effect of the initial fertilization will last between three and five years, after which tree growth will stagnate. Within the context of ecological restoration the slowing down of the growth rate is tolerable because the growth of trees in undisturbed peatlands is generally very low. Thus, in these conditions it is not recommended to apply a second fertilization unless you observe symptoms of deficiencies and a high mortality rate which can only be explained nutritional deficiencies.

Principal deficiencies

For acidic soils like peat, the macronutrients (N, P, K, Ca, Mg and S) are generally scarce and one can therefore expect deficiencies for these elements. On the other hand, certain micronutrients (Fe, Mn, Zn, Cu and Co) become more available as the acidity of the soil increases therefore deficiencies of these nutrients is low. For all milled peatlands, studies have shown that the element which limits growth the most is phosphorous. Deficiencies in nitrogen, potassium, copper and boron have also been observed on milled peatlands (Figure 46).

PHOTO : S. Hugron

Figure 46 A larch whose needles have turned yellow (front plant), probably due to nutrient deficiencies.

Certain symptoms of deficiencies can also be associated with drainage problems or damage caused by frost or pests. If a nutrient deficiency is suspected, we recommend having a soil and leaf analysis carried out in order to confirm the deficiency and to determine the exact cause of the deficiency. If in doubt, it is strongly recommended to consult a specialist (forester or agronomist, for example) in order to determine the exact cause of the observed symptoms and obtain advice on which steps should be followed to alleviate the problem.

For information purposes only, table 6 presents the symptoms of deficiencies for the macronutrients as well as for the two micronutrients for which deficiencies have already been observed on milled peatlands.

Table 6: Summary of the symptoms of deficiencies for each of the elements.

Element		Symptoms of deficiencies: Conifers	Symptoms of deficiencies: Deciduous
Macronutrients	Nitrogen (N)	Foliage turns yellow, starting with the oldest foliage. Growth is generally slowed (reduced number of branches and fruits).	
Macronutrients	Phosphorous (P)	Presence of a red/violet coloration on the foliage, starting with the oldest foliage. Slower growth and reduced fructification.	
Macronutrients	Potassium (K)	Yellowing of the old needles starting with the end. Needles short.	The edge of the leaves yellows, exhibits necrosis and finally dries completely.
		Growth slows; Branches dry out.	
Macronutrients	Calcium (Ca)	Rare deficiency. The tree tops turn brown and can curl up.	Chlorosis (discoloration) and necrosis of the leaves.
		Drying out of the terminal shoot.	
Macronutrients	Magnesium (Mg)	Yellowing or even reddening of the needles. Yellow-orange coloration can spread over the entire needle during the second year.	Yellowing between the nerves of the older leaves could result in leaves drying and rolling up.
Macronutrients	Sulfur (S)	Rapid decline of the young trees: the points of the old needles turn red, show necrosis, and fall off. Remaining needles can become pale green to bluish white	Color of young leaves is pale yellowish green; older leaves are not affected.
		Symptoms are similar to those exhibited when there is a deficiency of Nitrogen.	
Micronutrients	Copper (Cu)	Branches are soft and droop slightly. The tips of the leaves and needles discolor or turn brown. They might fall off prematurely.	
Micronutrients	Boron (B)	Terminal shoot is bent over. Premature death of the apical buds, the trees appearance is similar to a bush.	Young leaves are red to brown, smaller and thinner. New branches can be discolored and grow in a zigzag form.

In the case of plantations which are to be used as windbreaks or privacy screens, fertilization can have the beneficial effect of stimulating growth. When applying a second dose of fertilizer, adding phosphorous generally produces good results by increasing the growth rate of the trees. In North America, the application of 159 g per plant of rock phosphate (an elemental dose of 9 g of phosphorous per plant) increased the growth rate of black spruce and larch trees.

Re-planting

When a high mortality rate has been observed for a plantation (more than 20% for conifers and more than 30% for deciduous trees) the reason for the high mortality should be investigated. If the possible explanations for the high mortality rate are related to poor site preparation (i.e. drainage canals blocked), a poor initial quality of the seedlings, inadequate manipulation of the seedlings, or physical problems caused by machinery, we recommend improving the conditions which led to an increased mortality rate and replacing the dead seedlings.

IN SHORT

It is important to carry out monitoring of the plantations. Monitoring should be carried out over several years after planting. The presence of several problems or symptoms should be verified and if they are observed on the plantation, corrective measures should be carried out to improve the plantation site (Figure 47).

Don't hesitate to call a specialist to help carry out diagnostic tests to identify and resolve eventual problems.

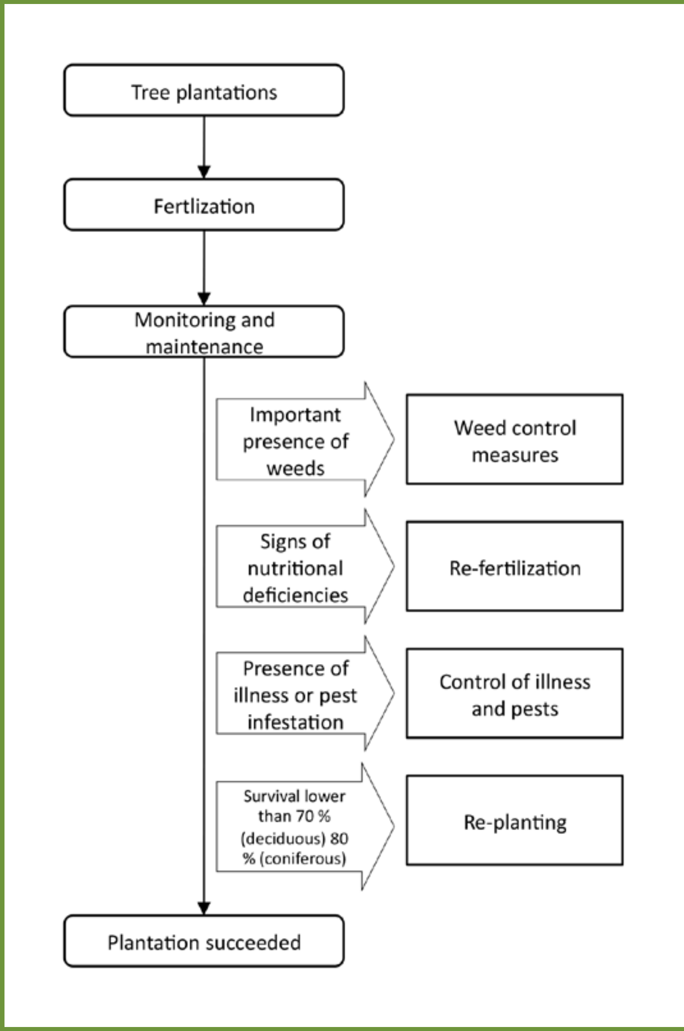

Figure 47 Monitoring and maintenance of the plantations.

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CHAPTER 7
CONCLUSIONS

Planting trees on milled peatlands presents an interesting complement to ecological restoration because it allows the increase of the habitat diversity and the vegetation associated with the restored sites. The plantations can be used alone as a reclamation option in the sectors where ecological restoration is not possible due to the site conditions or logistical problems. In the context of peat milling for horticultural peat, the environmental and economic concerns of Canadians point towards the importance of always prioritizing ecological restoration when this option is possible.

The plantation of trees is a project which entails several steps (see Figure 8) and which will be carried out over several years. The plantations should be planed long in advance, at the same time as the peat extraction is planned. It is extremely important to define before work begins whether the trees will be used to complement restoration or as reclamation option (Figure 9). This choice will greatly influence the subsequent stages and the criteria for evaluating the success of the plantations. The plantation jobs, which should be planned two years before execution, are: characterizing the future plantation site, choosing the species to be planted (Figure 22), ordering the trees from the nurseries and ordering any other material necessary, and determining the amount of manual labor needed for planting. Site preparation should be carried out at least several months before planting (Figure 20). The planting of the trees should be a very short stage to guarantee a good survival of the plants. The fertilization of the plants is essential to guarantee a good survival and growth rate (Figure 38). After plantation, the work is not done. Monitoring should be carried out regularly in order to evaluate the success and to be able to quickly determine potential problems and carry out the corresponding corrective measures (Figure 40). It is important to not delay in fixing problems because they could become worse and eventually cause the death of the plants.

Some large restoration sites may be difficult to access if the abandonment of milling activities or the beginning of divers re-wetting activities has made the soil too instable (soft) for the circulation of machinery. In this case it may be interesting to explore the option of carrying out the planting in winter. The government of Alberta (T. Vinge, Ministry of Sustainable Resource Development, personal communication) has developed a method for planting black spruce where the trees are already wintering into frozen organic soils. This approach allows for the creation of forested islands on sites relatively wet and deserves further exploration.

Each restoration and plantation project is unique and requires serious reflection at each stage, from conception to monitoring. We hope that this guide will be a complete tool to guide your plantation and will inspire you to carry out a project that will respond to your expectations.

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GLOSSARY

Anaerobic Environmental conditions characterized by a lack of oxygen. This is the opposite of the term 'aerobic.'

Berm An installation made of peat which should equally distribute the water over a restored and rewetted peatland.

Biodiversity Diversity of living organisms in a given region.

Bog A term with Irish origins which designates a peatland where the water supply comes completely from precipitation (rain and snow). In North America, bogs are dominated by peat moss (*Sphagnum*), ericaceous shrubs, and black spruce. Synonym for ombrotrophic peatland.

Broadcast fertilization Fertilization of the entire plantation surface.

Bud Break Period of the year, generally in the spring, when the buds open.

Chlorosis A condition in which leaves do not adequately produce chlorophyll. Such leaves are typically pale, yellow or yellow-white.

Deficiency Nutritional difficulties in plants resulting from a lack of an essential element.

Etiolated Plant State of a plant which is weakened by a lack of sunlight which can be noticed by paler than normal coloration, a weak development of the leaves and lengthening of the stem.

Fen A term which originates from English and is used to describe peatlands receiving an inflow of water and nutrients from adjacent mineral soil on top of precipitation. In North America, fens are dominated by brown mosses and sedges. Synonym for minerotrophic peatland.

Fine Roots Small, hairy roots which absorb water and nutrients.

Greenhouse Gases or GHG Gasses which are present in the atmosphere and contribute to global warming by their capacity to absorb and return infrared rays reflected from the earth.

Hardiness Zone The most northern zone where a species can survive. The hardiness zone depends on the average climatic conditions in each region, including the minimal winter temperatures, the duration of the frost-free period, summer precipitation, the maximal temperatures, snowfall, etc.

Hydrophytic vegetation Plant which grows in water and in soils saturated with water.

Lagg Term originating from Swedish which is used to describe humid zones at the margins of ombrotrophic peatlands (bogs).

Leaching Refers to the loss of water-soluble plant nutrients from the soil due to rain.

Localized fertilization Surface fertilization within circa 10 cm diameter of the tree, also called spot fertilization.

Milled Peatland Peatland where milling activities have ceased. Restoration or reclamation has not been carried out and the sites are left to spontaneous regeneration.

Nitrogen fixation Nitrogen is transformed through microbial action from its mineral form to a form which is available for plants.

Nutrients Organic and inorganic nutrients are available to the plants and which are vital for the plants survival and growth.

Nurse plant A plant species which contributes to the development of another plant species, notably by providing nutrients necessary for growth or improving the environmental conditions.

Oxidation Chemical reaction which occurs when the peat is in contact with atmospheric oxygen and which triggers the production of carbon dioxide (CO_2).

Peat fields Surface between two drainage canals where peat is milled.

Peatland Wetland which is characterized by the accumulation of organic matter because biomass production is greater than decomposition which leads to the formation of a peat layer on the surface.

Peatland Reclamation Reclamation option where the goal is not the return of the original ecosystem. Synonym of rehabilitation.

Peatland Restoration Reclamation option where the goal is to restore the vegetation communities which will permit the return of the peat accumulating function and biodiversity specific to peatlands (for example, carnivous plants).

Privacy Screen Trees planted where the goal is to completely or totally hide a structure or a building for aesthetic reasons.

Propagule Part of a plant having the capacity to produce a new individual by asexual reproduction (for example, *Sphagnum* or moss fragment, section of a rhizome of certain vascular plants, branch section of certain woody species…).

Residual Peat Deposit of organic matter (peat) remaining after peatland milling.

Root asphyxia Death of a plants roots' due to a lack of oxygen. This occurs when the roots are submerged in the water for too long. The roots are no longer capable of drawing the water which the plant needs.

Weed A plants whose presence is not desired and which interferes with the growth and survival of plants targeted for plantations.

Windbreak Row of trees generally perpendicular to the direction of the dominant winds, where the goal is to slow down the wind speed and reduce wind erosion, and/or improve the local climatic conditions (temperature, humidity and snow accumulation). Windbreak hedges contribute to soil conservation.

APPENDIX 1: PROTOCOL

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PROTOCOL: COLLECTING SAMPLES FOR CHEMICAL ANALYSIS OF RESIDUAL PEAT

Description:
The following protocol describes how to collect and store peat samples before sending them to a specialized laboratory for chemical analysis.

Material:
- Clean containers for collection (for example, new 'Ziploc' bags);
- Knife or trowel for digging and collecting the samples;
- Gloves (so that you do not directly touch the peat);
- Marker to identify the sample bags;
- Cooler and ice packs to keep the samples cold before the analysis or before being put in the refrigerator or freezer.

Sample:
The peat is generally collected (circa 10 to 20 cm of the upper peat surface) using a trowel or a knife making sure to remove all vegetation or oxidized crust of the surface. Make sure that you identify the sample bag well so you know where the sample came from. You must collect at least one cup (250 ml) of peat to analyse the pH and the electrical conductivity and at least 2 cups (500 ml) if other analyses are planned. Keep the samples **cool** (cooler or refrigerator) as soon as they are collected. Keep samples that cannot be dried quickly in a freezer.

The samples must be dried at **a maximum of 40 °C as quickly as possible** after being collected or after thawing. Line the bottom of clean aluminum plates with plastic wrap (for example, 'Saran Wrap') and place the samples on top of the plastic wrap. Let the samples dry for 2 to 3 days or until they are dry. Remember to identify the aluminum plates with the sample number, date and collection site. Do not touch the samples with your hands.

Once the samples are dry, they can be placed in new, dry Ziploc bags or in clean plastic containers. The samples should be well identified. Once dried, the samples can be stored for several months before the analysis is carried out.

General chemical analysis for dried peat:
- P BrayII (ppm)
- Available Nutrients (in $NH_4Cl/BaCl_2$):
  Ca, Mg, Fe, Mn, K, Na (ppm)
- N/NO_3 (ppm)
- N/NH_4^+ (ppm)
- pH
- conductivity (uS)
- Cl^- (ppm)
- Total concentrations:
  N (%), P, K, Ca, Mg, Fe, Mn, Na (ppm)

APPENDIX 2: DATA SHEETS

* Document .pdf des fiches disponible pour impression à partir du site du GRET : www.gret-perg.ulaval.ca sous l'onglet publications.

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PLANNING – SITE DESCRIPTION

SITE:	
LOCATION (town, prov., lat. and long.):	
CONTACT NAME:	

GENERAL DESCRIPTION	**Available surface**	
	Date milling activities ceased	
	Site characteristics prior to peat extraction - Type of peatland - Dominant species - Presence of pools and/or tree islands	
	Existing Vegetation Vegetation that colonized the peat fields spontaneously: - Species - Cover (%)	
	Proximity of milling activities	
	Type of adjacent natural environment - Type of environment - Dominant species - Presence of pools and/or tree islands	

PLANNING – SITE DESCRIPTION

PEAT	**Depth of residual peat** Including the location of samples	
	Type of peat *Sphagnum* or sedge	
	Degree of decomposition	
	pH	
	Chemical analyses - Collection date and location of sample - Principal results	

MINERAL SUB-SOIL	**Texture** (if the peat depth is less than 150 cm)	
	Presence of mineral soil at the surface	
	Chemical analyses (if the peat depth is less than 30 cm)	

DRAINAGE	**State of canals** - Active - To be maintained	
	Possibility of rewetting - Is rewetting possible? - Are there any constraints?	
	Signs of deficient drainage	
	Signs of excessive drainage	

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PLANNING – PREPARATION MEASURES

SITE:	
LOCATION (town, prov., lat. and long.):	
CONTACT PERSON:	

DATE AND DURATION OF WORK	DESCRIPTION OF OPERATIONS	WORK CARRIED OUT BY

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PLANNING – PLANTING

SITE:	
LOCATION (town, prov., lat. and long.):	
CONTACT PERSON:	

Goal of the plantation Tree island, lagg, windbreak, etc.	
Origin of plants	
Reception date of plants	
Planting date	
Total number of trees planted - Including the spacing between plants	
Species planted - Including the number of plants/species - Average height of plants	
Condition of plants - H/D ratio adequate - Average height of the trees planted - Absence of signs of diseases or deficiencies	
Fertilization - Application date - Doses used for each species	

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PLANTATIONS – MONITORING

SITE:
LOCATION (city, prov., lat. and long.):
CONTACT PERSON:
DATE OF SURVEY:

TREE #[1]	SPECIES	TERMINAL SHOOT (CM)	HEIGHT (CM)	TREE #	SPECIES	TERMINAL SHOOT (CM)	HEIGHT (CM)

[1] Assign a number to each tree sampled. This will allow you to determine the total number of trees sampled.

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PLANTATIONS – MONITORING

SITE:
LOCATION (town, prov., lat. and long.):
CONTACT PERSON:
DATE OF SURVEY:

SURVIVAL RATE			
Species	**No. of plants living**	**No. of plants dead**	**No. of plants total**

NUTRITIONAL DEFICIENCIES

Description of symptoms	
Corrective measures carried out (including the application date)	

WEED INVASION

Description of invasion	
Corrective measures carried out (including the application date)	

DISEASES OR PESTS OBSERVED

Description of symptoms	
Corrective measures carried out (including the application date)