VEGETATION RESPONSES TO ECOLOGICAL RESTORATION (REWETTING) OF ABANDONED BLOCK-CUT PEATLANDS IN EASTERN QUÉBEC

by

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Abstract

Abandoned block-cut peatlands are typified by an alternating topography of mined trenches and raised baulks. Although these sites re-vegetate densely with native bog species, *Sphagnum* species characteristic of undisturbed bogs are conspicuously absent and peat accumulation has not recommenced. Ecological restoration of abandoned block-cut peatlands involves blocking remnant drainage ditches, “rewetting” the residual peat body to: 1) re-establish vegetation assemblages dominated by *Sphagnum*, and 2) re-establish the upper, hydrologically active layer (acrotelm) that characterizes intact peatlands. This study evaluates the progress towards achieving these goals in three rewetted block-cut sites in eastern Québec.

Plant species composition, above-ground biomass, and accumulated organic matter data were collected from mined trenches within rewetted and non-rewetted sectors of the study sites and used for comparison with nearby undisturbed reference bogs. Comparisons of current patterns of community vegetation structure in rewetted and non-rewetted sectors of the study sites indicated that vegetation assemblages are strongly influenced by water table position. In areas where rewetting resulted in a water table position at or just above the peat surface, rapid community scale vegetation change occurred, with widespread mortality of vascular vegetation followed by recolonization by hydrophytic ericaceous and herbaceous species, and hollow/lawn *Sphagnum* species (<4 years following rewetting). Despite this positive change, vegetation assemblages within rewetted sectors still differ significantly from those found in natural reference sites up to 17 years following rewetting.

Changes in above-ground biomass indicated a significant reduction in tree biomass, a significant portion of which is present as dead-standing tree biomass 4 years following rewetting. Shrub biomass initially decreased, but then increased 10 years following rewetting as species compositions shifted.

Accumulated organic matter shifted from a predominance of ericaceous litter to fibric peat in rewetted sectors, the depth of which is increasing as a function of time. These findings provide initial evidence of re-establishment of the acrotelm; however, additional research is required to determine whether the newly accumulated peat will provide the hydrological functions perceived of the acrotelm in undisturbed bogs. Continued detailed observation of the biotic recovery of these ecosystems will provide valuable information for future restoration endeavors.

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List of Abbreviations

ANOVA – Analysis of Variance

AOM – Accumulated Organic Matter

NMS – Non-Metric Multidimensional Scaling

MRPP – Multi-Response Permutation Procedure

PERG – Peatland Ecology Research Group

UPGMA – Un-weighted Pair Group Method of Averaging

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Chapter 1: Introduction

Peatlands are terrestrial wetland ecosystems sustained by a humid and cool climate and a high water level, where vegetation decomposition is slow and incomplete, leading to an accumulation of organic matter commonly referred to as peat (Moore and Bellamy 1974). Peatlands are extensive in Canada, covering approximately 1.7 x 10^6 km^2, or roughly 17% of Canada's landmass. Although the majority of this extent occurs in the northern boreal region (Gorham 1991), peatlands located in the more densely populated southern regions of Canada face intensive encroachment and degradation from several industries, including oil sands exploitation, urban expansion, forestry, agriculture, and peat extraction for fuel and horticultural use (Rochefort 2000; Poulin et al. 2004).

Peat extraction is particularly prominent in eastern Québec, and is restricted to a relatively small area of the St. Lawrence Lowlands, resulting in extensive localized degradation of peatland habitats (Pellerin and Lavoie 2000). Due to increasing concern about this degradation, as well as international attention on the effects of peat extraction in the early 1990s, the Canadian horticultural peat industry became increasingly interested in efforts to ecologically restore degraded peatlands to ensure continued ecosystem function particularly with respect to peat accumulation (Rochefort 2000). As such, a North American approach to restoring *Sphagnum* dominated (bog and poor fen) peatlands has been developed since that time (Rochefort et al. 2003). While the majority of this work has been geared towards the restoration of vacuum-milled sites (the current mechanized method of peat extraction), efforts have also been made to restore peatlands that were exploited using the block-cut (manual labour) method (Roul 2004; Ketcheson and Price 2011). Monitoring and assessment are key components to ensure that restoration goals are being achieved (Hobbs and Norton 1996); this study seeks to evaluate the success of restoration activities (rewetting) in several abandoned block-cut peatlands in eastern Québec, Canada.

1.1 Disturbance and abandonment of block-cut peatlands

The evaluation of restoration success requires an understanding of the disturbance history of a site, as well as information on how the biotic/abiotic conditions have changed as a result of the disturbance. The characterization of these conditions also serves as a baseline from which to measure changes in manipulated abiotic conditions and the extent of biotic recovery resulting from restoration activities (Hobbs and Norton 1996).

The block-cut method of peat extraction results in fairly extensive alteration of abiotic conditions (although less in scale than mechanized methods), which in turn affect patterns of biotic recovery upon site abandonment. Block-cut peat extraction was undertaken manually by hundreds of workers with shovels. First, a network of primary drainage ditches was cut into the surface of the peatland, creating rectangular sectors and lowering the water table (Figure 1.1a). Peat was extracted from these individual sectors by cutting an initial trench perpendicular to the primary drainage ditches (Figure 1.1b). Blocks of peat were cut from the face of the initial trench and were stacked to dry on racks located on the undisturbed surfaces. Living vegetation (often referred to as skag) was often removed from the row being cut and discarded into the centre of trenches, resulting in a highly variable trench surface topography, often with a convex cross-sectional profile (Lavoie and Rochefort 1996; Price and Whitehead 2001).

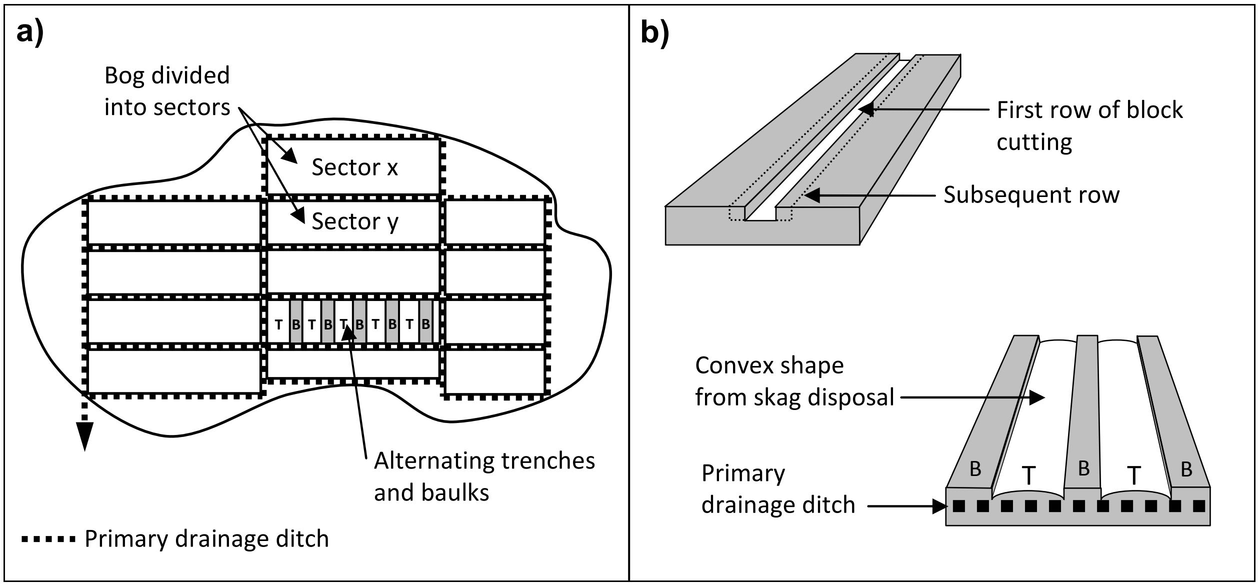


Figure 1.1 Schematic of Block-Cut Peat Extraction

a) A linear network of drainage ditches was cut into the peatland, dividing it into sectors of varying size. b) As peat blocks are cut, trenches widen outwards, resulting in an alternating topography of trenches (T) and baulks (B) in each sector. Trenches are often convex due to disposal of skag in the centre of trenches. Adapted from Robert et al. (1999).

As extraction progressed, trenches would be widened until a 3-4 m strip of undisturbed surface remained (a baulk) between adjacent trenches (Figure 1.1b). Trenches may end up as long as 200 m, by 10-15 m wide. At abandonment, the resultant topography was a series of alternating baulks and trenches, ranging in depth from 0.75 - 1.5 m (Robert et al. 1999); however, the final baulk/trench arrangement varies by sector. Generally, a considerable amount of the peat body was left intact after extraction, with the thickness of the remaining peat in extracted sectors ranging from 0.4 to > 4 m in depth (Girard et al. 2002). In the late 1960s, the block-cut technique was rapidly abandoned as the extraction process became mechanized, and several peatlands exploited using this method were also subsequently abandoned (Warner and Buteau 2000).

Peat extraction using vacuum machines became dominant in the mid-1970s and is presently used (Price et al. 2003). A network of drainage ditches is cut into the peatland; these ditches must be deeper than those used in the block-cut method to permit more intense drainage of the peat body to allow for the use of heavy machinery (Robert et al. 1999). All living vegetation is scraped from a large area of the peat surface and pushed to one side, exposing the peat body. The peat surface is then contoured to a convex shape within each sector to promote runoff to drainage ditches, and is milled to loosen the peat and promote desiccation (Robert et al. 1999). Dried peat particles are then collected using tractor-drawn vacuum machines; this cycle is continued over decades until the majority of the peat body has been removed.

1.1.1 Post-extraction biotic/abiotic conditions

The changes to biotic/abiotic conditions resulting from the disturbance of peat extraction are extensive. Undisturbed bogs are characterized by a “diplotelmic” (two-layered) structure. The *acrotelm* is the ‘skin’ or surface layer (<0.5 m deep) composed of living newly dead plants (principally *Sphagnum* mosses), that overlies the *catotelm*, which represents the majority of the peat body (Ingram 1978). The acrotelm is located above the lowest point of seasonal water table fluctuation and encompasses its seasonal oscillations (Ingram 1978; Ingram and Bragg 1984). The hydrophysical properties of the acrotelm are thought to play an important role in water regulation during periods of precipitation deficit (Ingram and Bragg 1984), maintaining sufficiently wet conditions at the bog surface to support non-vascular *Sphagnum* species (Van Breemen 1995). The most fundamental impact of peat extraction (common to both methods of extraction) is the complete removal of the acrotelm and the subsequent exposure of the more humified and compacted catotelmic peat as the new bog surface. The lower hydraulic conductivity and reduced storage capacity of the catotelmic peat results in increased seasonal water table fluctuations (Price 1996; Whittington and Price 2006). After abandonment, remnant drainage networks are often left intact, keeping the water table below the surface of the peat, and further affecting the physical structure of the peat through consolidation, shrinkage, and oxidation (Price and Schlotzhauer 1999).

The complete removal of the seed bank and any living plant propagules, in addition to hydrological disruptions, make vacuum-milled sites much less favorable for self-regeneration than those subjected to block-cut extraction (Wheeler and Shaw 1995; Lavoie and Rochefort 1996; Price et al. 2003). In block-cut sites, the localized disposal of skag is thought to aid in vegetation recovery. Girard et al. (2002) reported that the abiotic variables most strongly influencing patterns of vegetation regeneration are water table level, and thickness and pH of the residual peat deposit. Vegetation communities found to regenerate in abandoned block-cut sites are dominated by vascular vegetation, typified by a dense cover of ericaceous shrubs (70 - >90%), with sparse *Sphagnum* cover (<10%) that is restricted to the shallow ditches and low-lying areas within trenches (Lavoie and Rochefort 1996; Price and Whitehead 2001; Girard et al. 2002). Leatherleaf (*Chamaedaphne calyculata*)*,* Labrador tea (*Ledum groenlandicum*)*,* sheep laurel (*Kalmia angustifolia*)*,* rhodora (*Rhododendron canadense*), and blueberry (*Vaccinium angustifolium*) are the dominant ericaceous shrub species (Lavoie and Rochefort 1996). Tree cover remains variable (0 – 78%), and is comprised mainly of black spruce (*Picea mariana*), and tamarack (*Larix laricina*), with an increased presence of non-peatland tree species including jack pine (*Pinus banksiana*) and birch (*Betula* sp.) (Girard 2000;

Girard et al. 2002). The hydrophysical properties of the catotelmic peat limit water availability to plants, making these abandoned sites inhospitable to recolonization by non-vascular *Sphagnum* mosses (Price and Whitehead 2001, 2004). Areas where *Sphagnum* was found to successfully recolonize exhibit distinct hydrological characteristics, including a high water table (generally <40 cm from the peat surface), soil moisture >50%, and soil water pressure > -100 mb (Price and Whitehead 2001). These characteristics were found to be spatially correlated with the topography of the abandoned site, where consistently dry conditions exist on baulks, and more variable conditions exist within trenches. The convex cross-sectional profile resulting from skag disposal (Figure 1.1b) creates drier conditions near the centre of trenches, while lower sections of the skag and shallow ditches along the edges of trenches exhibit more favorable conditions (Price and Whitehead 2001). The water table beneath these features is relatively flat, resulting in large differences in water table position between them (Price and Whitehead 2001; Ketcheson and Price 2011). The dominance of vascular plants in abandoned sites increases evapotranspiration by up to 25%, further decreasing water availability for *Sphagnum* mosses (Van Seters and Price 2001). Lavoie and Rochefort (1996) concluded that the scarcity of *Sphagnum* suggests that abandoned block-cut bogs do not readily return to a functional peatland ecosystem, because there is no development of a new acrotelm and subsequent reinitiation of peat formation. Similarly, Van Seters and Price (2001) concluded that without suitable management, these sites will be unable to support *Sphagnum* regeneration for a very long time. These conclusions highlight the need for ecological restoration in abandoned block-cut peatlands.

1.2 Ecological restoration of abandoned block-cut peatlands

The Society for Ecological Restoration International defines *ecological restoration* as "the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed" (SER-I Science and Policy Working Group 2004). While restoration can follow different paths based on intended land use, the most common approach is the "biodiversity strategy" (Joosten 2000) of returning the degraded ecosystem back to a reasonable approximation of a peatland's original condition (Gorham and Rochefort 2003). Ecosystem structure and function are inherently linked; therefore a blend of structural and functional restoration goals must be identified from the perspective of community ecology (Palmer 1997). These goals are often sequential, with structural restoration leading to restoration of ecosystem function. (Palmer et al. 1997). For this reason Rochefort (2000) defines two key structural goals of *Sphagnum*-dominated peatland (bog and poor fen) restoration as:

- The re-establishment of vegetation assemblages dominated by *Sphagnum* species; and,
- The re-establishment of the diplotelmic hydrological layers that characterize intact 'active' peatlands (e.g. growth of a new acrotelm).

These two goals are considered essential initial steps to reinitiate self-regulation and restore ecosystem function in terms of carbon sequestration, nutrient cycling, and the formation of microhabitats which support biological diversity as found in undisturbed peatlands (Rochefort 2000).

While the restoration of vacuum-milled sites involves intensive site-level management and reintroduction of plant propagules along with rewetting (Price et al. 1998; Rochefort et al. 2003; Price and Whitehead 2004), block-cut sites are hypothesized to require a lower level of management (e.g. rewetting only) due to the extensive vegetation recovery observed following abandonment. Restoration of block-cut sites follows a traditional approach by re-establishing historical abiotic conditions and relying on successional processes to guide the recovery of biotic communities (Suding et al. 2004). From a vegetation standpoint, the intention of rewetting is to create a disturbance leading to vascular plant (e.g. tree and shrub) mortality and an immediate decrease in diversity (Tuittila et al. 2000; Lanta et al. 2006; Ketcheson and Price 2011). The increased (and stabilized) water table level results in a regime shift that alters the path of ecological succession (Folke et al. 2004), promoting proliferation of localized *Sphagnum* populations and the development of hydrophytic vegetation assemblages following the disturbance (Jeglum 1975; Mitchell and Niering 1993; Tuittila et al. 2000; Roul 2004; Asada et al. 2005; Lanta et al. 2006).

Rewetting of abandoned block-cut peatlands is most commonly accomplished by blockage of residual drainage ditches using various materials (i.e. humified peat, hay bales, plywood, etc). These materials provide a range of effectiveness and each have advantages and disadvantages; the type of material utilized in a restoration project depends on resource availability and local site conditions, including accessibility for machinery (Armstrong et al. 2009). The most common method of ditch blocking is to construct dams using humified peat taken from a nearby excavation, which is usually upstream of the proposed dam location. Previous rewetting efforts have shown that ditch blocking in primary drainage ditches of a whole peat extracted sector (Figure 1.1a) is effective at raising the water table and rewetting the peat body (LaRose et al. 1997;

Tuittila et al. 2000; Shantz and Price 2006; Lanta et al. 2006; Ketcheson and Price 2011), as well as reducing fluctuation of the water table (Ketcheson and Price 2011). However, the water table is relatively flat underneath the trench/baulk morphology (Price and Whitehead 2001; Ketcheson and Price 2011), resulting in large differences in surface moisture conditions. Similarly, site-level slope (e.g. site-wide topographical variation in addition to trench/baulk differences) and the location of dams greatly influence the magnitude of water table rise at any given location in response to rewetting (Roul 2004; Ketcheson 2011). While there have been preliminary reports of vegetation change in rewetted block-cut peatlands (Roul 2004; Ketcheson 2011), few studies have addressed the extent to which the structural goals of peatland restoration have been achieved in these sites.

1.3 Thesis overview

Monitoring and evaluation are essential steps in the ecological restoration process to determine whether restoration goals are being met, and to improve future restoration efforts (Hobbs and Norton 1996; SER-I Science and Policy Working Group 2004). This study uses monitoring and evaluation to determine whether the structural goals of peatland restoration are being achieved in three rewetted block-cut bogs in eastern Québec. Two evaluation techniques are used: first, *direct comparison* is a technique utilizing selected parameters that are measured in the rewetted sites and compared to those in both the un-restored (non-rewetted) and reference ecosystems (SER-I Science and Policy Working Group 2004). Second, *trajectory analysis* is a technique utilizing monitoring data collected periodically at rewetted sites, which is plotted in relation to a reference ecosystem to determine whether the rewetting is causing the intended vegetation changes (SER-I Science and Policy Working Group 2004).

The following specific research questions were asked to determine whether rewetting is effective at achieving the structural goals of peatland restoration:

1) To what extent has rewetting changed vegetation community composition in rewetted areas of the study sites compared to non-rewetted areas, and are there trends between the study sites?
2) To what extent does rewetting facilitate a shift in vegetation communities towards those present in natural undisturbed bogs?
3) How are above-ground biomass and organic matter accumulation affected by rewetting, and how do these values compare with natural undisturbed bogs?
4) Is there evidence indicating the possible formation of a new acrotelm in rewetted sectors of the study sites?

Chapter 2: Methodology

2.1 Field methods

2.1.1 Study sites

The three sites chosen for this study are ombrotrophic (nutrient poor) bogs located in the Rivière-du-Loup Region of Québec, Canada, in close proximity to the St. Lawrence River, and are underlain by marine clays of the historic Champlain Sea (Lee 1962). Mean annual precipitation (1971-2000) was 963 mm, 29% of which fell as snow (Environment Canada 2003). The mean annual temperature (1971-2000) was 3^{o}C, with a minimum monthly average of -11^{o}C in February and a maximum monthly average of 17^{o}C in August (Environment Canada 2003). Meteorological data were recorded at the St. Arsène weather station, located in close proximity to the three study sites.

Post abandonment, mined trenches typically represent 70-90% of the total peatland area, as well as the new overall surface elevation that rewetting will affect. For this reason, field work was confined to trenches, which serve as discrete sample units. Survey trench selection was based on trenches that had been previously surveyed by members of the Peatland Ecology Research Group (PERG).

Cacouna peatland (N 47^{o} 53.55', W 69^{o} 27.24') (Figure 2.1) is located approximately 10 km northeast of Rivière-du-Loup, Québec. Patterns of post-abandonment hydrological conditions and natural revegetation in Cacouna peatland have been studied extensively (Lavoie and Rochefort 1996; Girard 2000; Price and Whitehead 2001; Van Seters and Price 2001; Girard et al. 2002; Price and Whitehead 2004).

The bog was originally 211 ha, but due to agricultural encroachment and road/rail construction, it has been reduced to approximately 148 ha (Girard et al. 2002). A major disturbance to the bog's hydrology occurred when the inter-colonial railway was constructed through the bog in 1876, which effectively divided the bog into two hydrologically isolated parts due to peat compression (Price and Whitehead 2001). Peat extraction within the bog began in approximately 1942, and by 1961, >90% had been exploited (Lavoie and Rochefort 1996). Peat extraction within each sector ceased as drainage due to ditching became ineffective, resulting in abandonment of sectors at different times, ranging from 1955-1975 (Girard et al. 2002). Between 1983 and 1989, a 16 ha portion of the site north of the railway was leveled in anticipation of vacuum peat extraction; however, the site was never used and was completely abandoned in 1989. Girard et al. (2002) estimated that although 34% of the peat body was lost due to harvesting, peat oxidation/subsidence, and agricultural activities, the remaining deposit ranges in thickness from 0.6 – 3.9 m.

Several small sectors in the northern section of the site exhibited high regeneration of *Sphagnum* species, but the majority of the site lacked the hydrological conditions appropriate for *Sphagnum* recolonization and subsequent development of a new acrotelm (Lavoie and Rochefort 1996; Price and Whitehead 2001). Consequently, the PERG became interested in rewetting the site. Rewetting of Sectors 13 and 14b of the site commenced in 2006 as part of a Master's project under the supervision of Dr. Jonathan Price at the University of Waterloo (Ketcheson 2011). A total of 29 dams were installed in the primary ditch network, with an approximate elevation change of 0.25 m between dams (Ketcheson 2011).

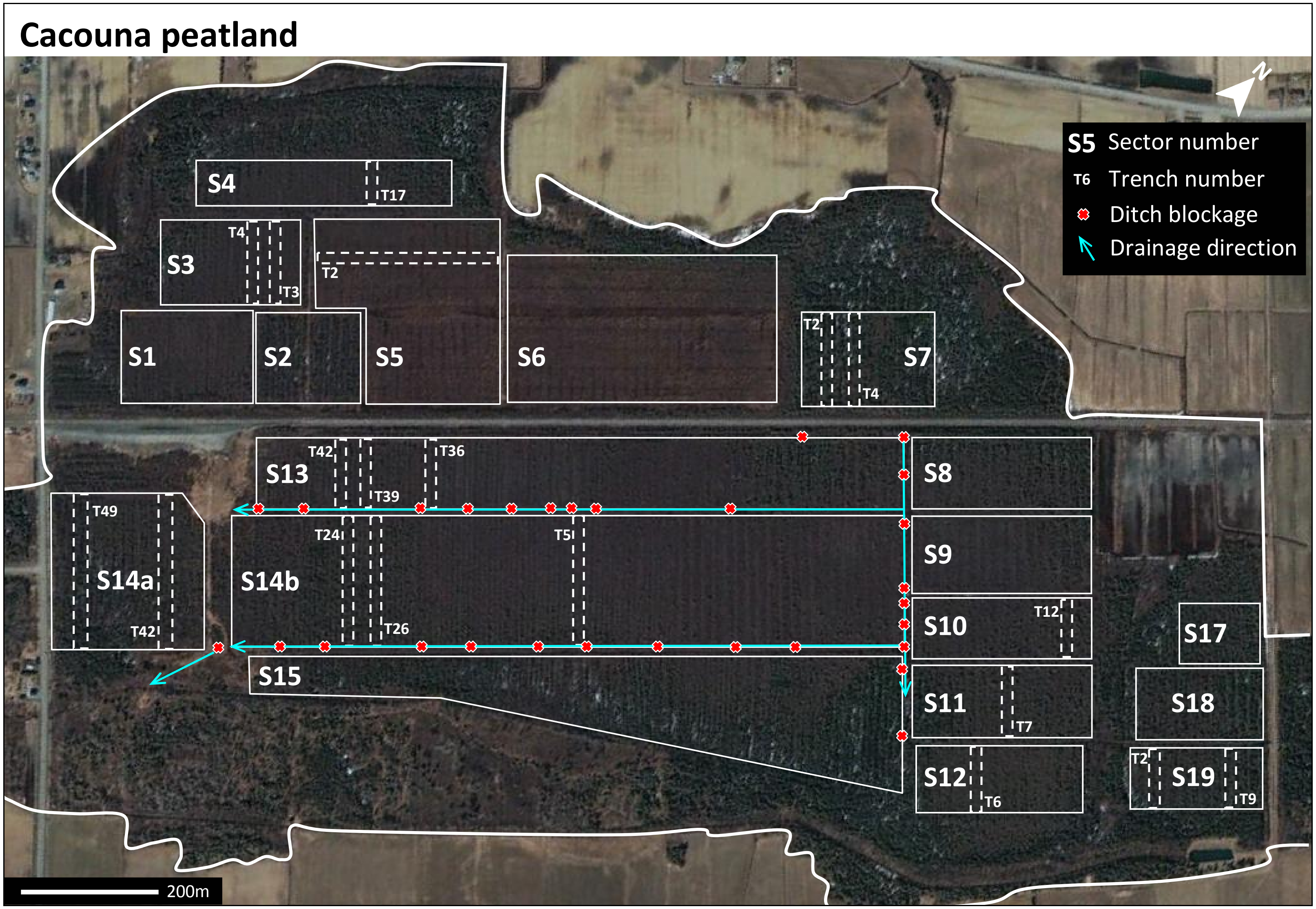


Figure 2.1 Layout and Sampling Locations in Cacouna Peatland

Survey trenches were located in rewetted and non-rewetted sectors of the study site. The sector and trench numbers are combined to make a unique identifier for each survey trench e.g. Sector 7, Trench 2 is denoted as S7T2. Imagery © Google 2011 by permission.

Île Verte peatland (N48° 01.89’, W69° 18.39’) (Figure 2.2) is located approximately 28 km northeast of Rivière-du-Loup, Québec. The site is approximately 157 ha. Peat extraction is thought to have begun in the mid-1940s, although the exact date is unknown. Exploitation in the majority of sectors completely removed the top ~0.5 - 0.75 m of peat, and a second subsequent layer of removal was started, resulting in variable trench/baulk topography at time of abandonment. This is evidenced in the surface elevation of pathways and roads between sectors, which are 1.0 - 1.5 m above that in the trenches, representing the original surface elevation. The whole site was abandoned in 1976; however, all sectors sampled as a part of this study were abandoned in the mid-1960s to ensure comparability. The remaining peat deposit ranges from 1.6 – 4.0 m deep (Argus Inc. 1993; Poulin et al. 2005).

In 1993, Argus Inc. Environmental Consultants conducted a habitat enhancement pilot project for Ducks Unlimited within Sector 15a of the site, which is approximately 1.5 ha. The project aimed to create three 150 m² ponds, and reduce their acidity to a pH of ~ 5 to increase nesting vegetation cover and invertebrate forage for American Black Duck (*Anas rubripes*) broods. An excavator was used to complete various works, including:

- Excavation of the three ponds;
- Cleaning and reactivation of upstream drainage ditches to improve water movement to the ponds;
- Installation of an anaerobic alkaline filter containing $CaCO_3$ directly upstream from the ponds; and,
- Infilling of drainage ditches and installation of a plywood weir downstream of the ponds to retain water onsite (Argus Inc. 1993).

Subsequent pH surveys have determined that these efforts were largely unsuccessful (Poulin, unpublished data); however, the backup of water resulting from the plywood weir inadvertently caused flooding in the drainage ditches on the upstream side of the alkaline filter, rewetting a large portion of Sector 11 and Sector 15b. Rewetted survey trenches selected for this study were located upstream of the works to ensure the alkaline filter had minimal influence on chemical and vegetational characteristics present.

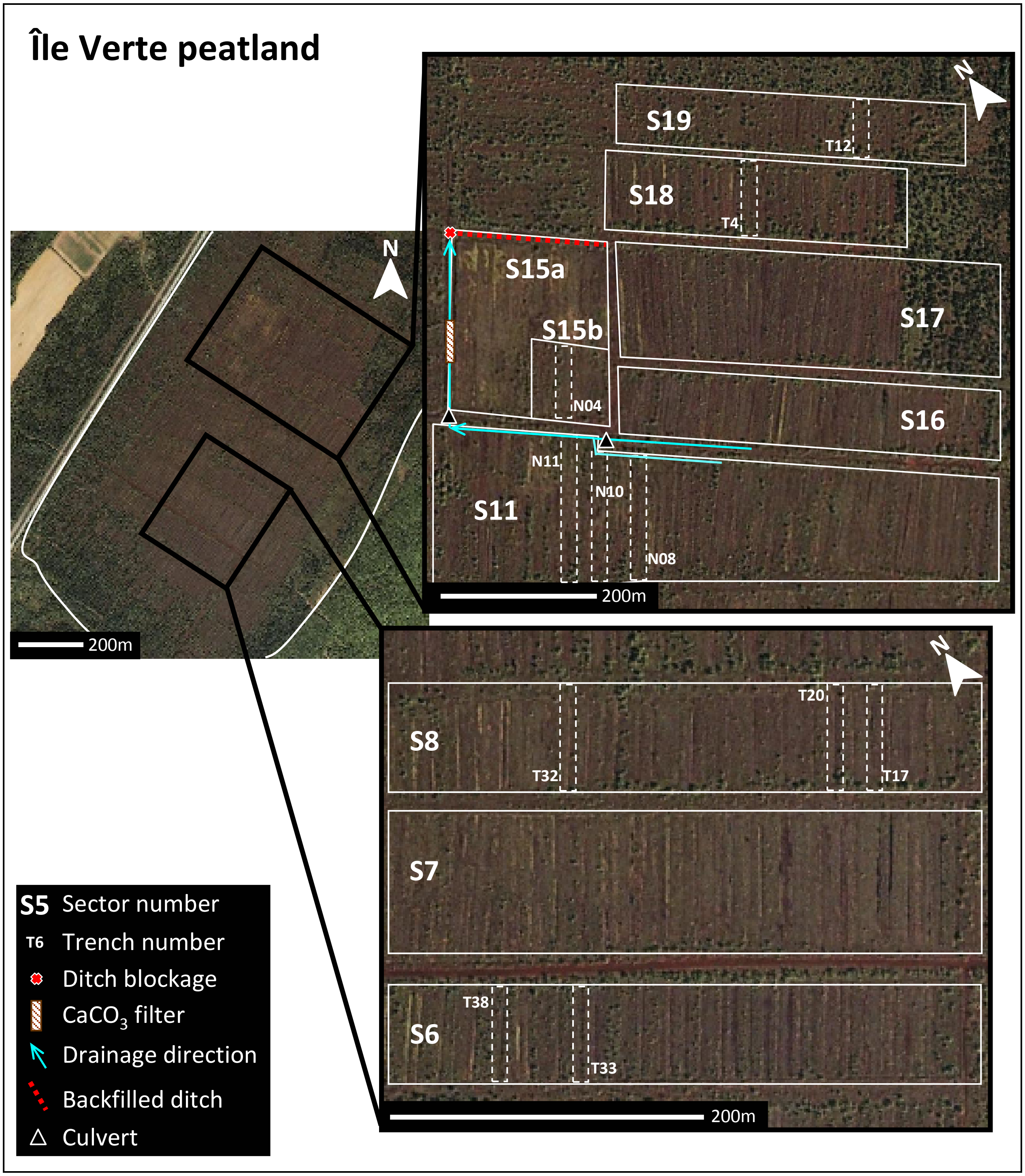


Figure 2.2 Layout and Sampling Locations in Île Verte Peatland

The Argus Inc. pilot project is located in Sector 15a. Back-up of water in drainage ditches resulted in flooding of a large portion of S11and S15b. The sector and trench numbers are combined to make a unique identifier for each survey trench e.g. Sector 7, Trench 2 is denoted as S7T2. Imagery © Google 2011 by permission.

Rivière-du-Loup peatland (N47° 48.73, W69° 29.23’) (Figure 2.3) is located approximately 3 km east of Rivière-du-Loup, Québec. The site is approximately 3375 ha, but has become highly fragmented due to road construction, agricultural infringement, industrial development, and peat harvesting (Desaulniers 2000). In 1995, approximately 57% of the peatland was still being actively exploited using the vacuum method of extraction (Desaulniers 2000). This study utilizes two areas of the peatland that were historically exploited using the block-cut method. Peat extraction is thought to have begun in the 1940s, although the exact date is unknown; both areas were abandoned by the mid-1960s. The remaining peat body is approximately 3 m deep on average (Robert et al. 1999). Peat dams were used to block ditches in various locations in 2000 by Premier Tech, however, very little information exists as to the total number of blockages installed or the rationale for their location and spacing. Blockages shown in Figure 2.3 are based solely on field reconnaissance during the 2010 field season; a total of 20 dams were observed. A portion of Area F, Sector 2 is currently used by Premier Tech as a demonstration garden to showcase their efforts at peatland restoration.

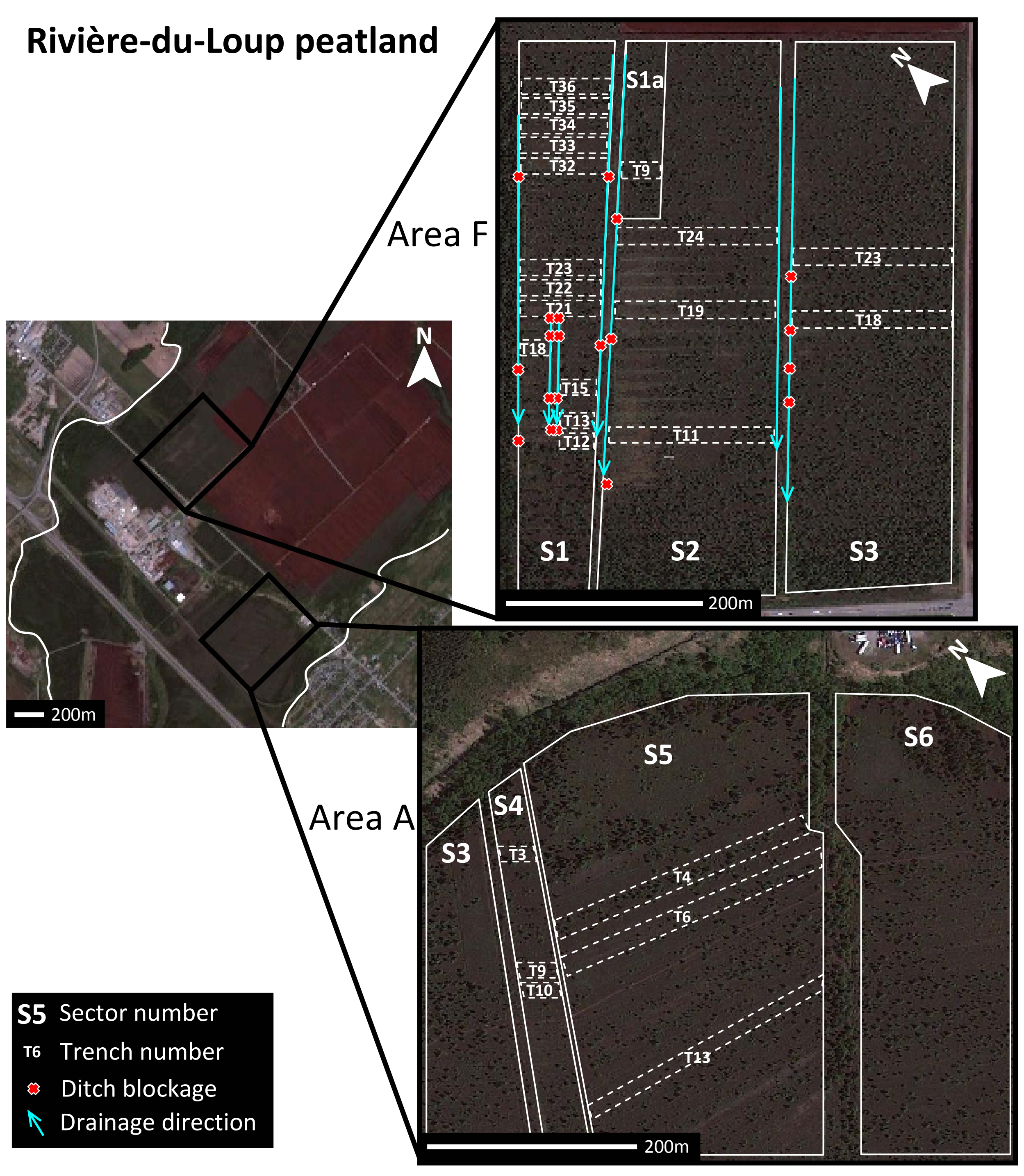


Figure 2.3 Layout and Sampling Locations in Rivière-du-Loup Peatland

Survey trenches were located in rewetted (Area F) and non-rewetted (Area A) sectors of the study site. The sector and trench numbers are combined to make a unique identifier for each survey trench e.g. Sector 1, Trench 12 is denoted as S1T12. Imagery © Google 2011 by permission.

2.1.2 Reference sites

Vegetation data collected in 2007 from seven references sites were provided by Rémy Pouliot of the PERG (Pouliot, unpublished data). These sites are all undisturbed ombrotrophic bogs located in the St. Lawrence lowlands, in relatively close proximity to the study sites. All reference data are implicitly time- and space-based, meaning they are of somewhat limited applicability in providing an appropriate end-point upon which to evaluate the success of ecological restoration (White and Walker 1997). The use of seven undisturbed bogs as a reference for this study represents a suitable end-point against which to gauge the trajectory of restoration, as they incorporate spatial variation not only throughout each site, but regional geographic variation as well (White and Walker 1997).

2.1.3 Vegetation sampling

During the 2010 growing season, a total of 28 rewetted and 26 non-rewetted trenches were surveyed amongst the three study sites (Table 2.1).

Table 2.1 Distribution of Survey Trenches among Study Sites

Study Site	# Survey Trenches		TOTAL
	Non-Rewetted	Rewetted	
Cacouna	13	6	**19**
Île Verte	7	4	**11**
Rivière-du-Loup	6	18	**24**
TOTAL	**26**	**28**	**54**

Vegetation surveying followed the methods outlined in Poulin et al. (2005) to ensure comparability with historical data. Occurrence frequency of plant species was assessed using the point-encounter method, where a wooden rod approximately 1 cm in diameter was placed vertically on the ground, and all plant species touching the rod were recorded extending upwards through the canopy (Goodall 1952). Point-encounter sampling locations were arranged in a systematic sampling design (Bonham 1989). Ten equidistant transects were established width-wise across the survey trench, and ten equidistant points were distributed across each transect's length (N = 100 total; Figure 2.4). The proportion of points intercepted is the occurrence frequency of a species (Floyd and Anderson 1987). Unknown plant species were collected for subsequent identification; confirmation of *Sphagnum* species identification was conducted using stem-leaf diagnostic keys and a microscopy dissection station. Nomenclature followed Marie-Victorin (1964), Anderson et al. (1990), and Anderson (1990).

Trench-level vegetation structure was also classified using six vegetated and two un-vegetated strata types. The strata were:

- Trees;
- Ericaceous shrubs;
- Herbaceous plants;
- *Sphagnum* moss;
- Other mosses;
- Lichens;
- Open water; and,
- Bare peat.

The percent cover of each vegetation stratum was estimated visually while walking across the entire trench, after conducting the plant species surveys to get a more complete and continuous impression of the vegetation structure. Percentage cover of each stratum was estimated using five classes (Table 2.2).

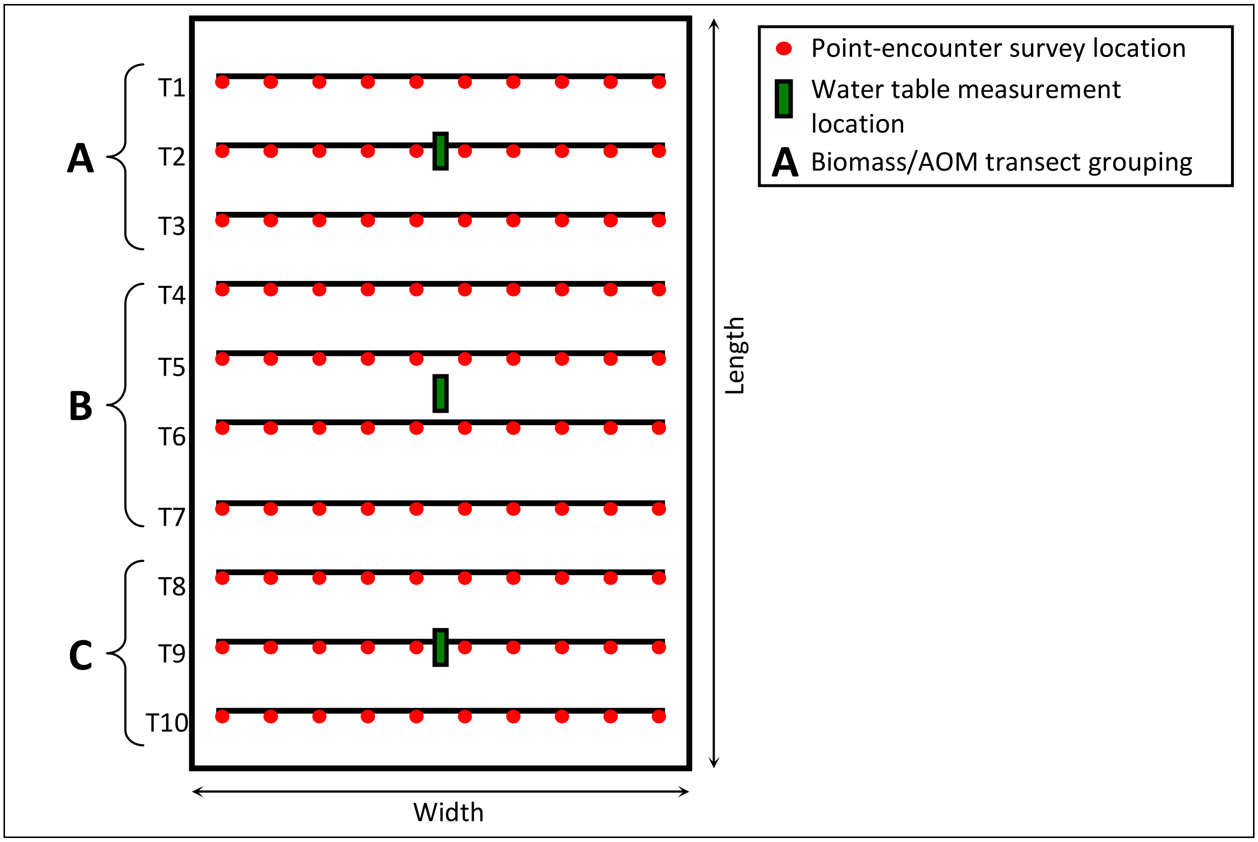


Figure 2.4 Schematic of Sampling Layout in Surveyed Trenches

Vegetation was sampled using 100 point-encounter surveys arranged along 10 transects. Water table measurements were taken in the centre of the survey trench at T2, between T5 and T6, and at T9. Above-ground biomass and accumulated organic matter (AOM) samples were taken at one randomly selected point-encounter location per transect grouping.

Table 2.2 Classes used to Estimate Percent Cover of Vegetation Strata in Surveyed Trenches

Class	Percent Cover
0	0
1	1-10
2	11-25
3	26-50
4	> 50

2.1.4 Water table measurements

Depth to water table was measured from soil pits at three locations per trench; 3 rounds of measurements were collected over the period of July 15 – Aug 30, 2011 to capture some of the dry seasonal variation due to evapotranspiration. Figure 2.4 displays the location of soil pits in relation to vegetation transect placement within surveyed trenches.

2.1.5 Above-ground biomass and accumulated organic matter sampling

Above-ground biomass and accumulated organic matter (AOM) were quantified in a sub-set of rewetted and non-rewetted survey trenches in the Cacouna (4 years rewetted) and Rivière-du-Loup (10 years rewetted) study sites (Table 2.3).

Table 2.3 Distribution of Characterized Trenches among Study Sites

Study Site	# Survey Trenches		Total
	Non-Rewetted	Rewetted	
Cacouna (4 Years Rewetted)	5	4	**9**
Rivière-du-Loup (10 Years Rewetted)	2	8	**10**
TOTAL	**7**	**12**	**19**

Three samples were taken per survey trench in a stratified-random sampling design based on vegetation sampling transect/point locations. The vegetation transects were grouped (Figure 2.4), and each point location was given a sequential number. A random number generator was used to select one of the vegetation survey points within each grouping as the location for above-ground biomass/AOM sampling.

Above-ground biomass sampling methods followed those used by Dyck and Shay (1999), Asada et al. (2005), and Benscoter et al. (2005). A 0.5 x 0.5 m plot was delineated, and living vascular vegetation within the plot, including tree seedlings, shrubs, and herbs, were cut to the level of the moss/litter layer. All material was collected and placed in a sealed bag for laboratory processing. All living and dead-standing trees >2m tall within a 4 m radius of the biomass plot were identified and their diameter at 0.25 m off the ground was measured. Above-ground tree biomass was estimated using regional, species-specific allometric equations as in MacLean and Wein (1976), Ker (1980), and Ker (1984); examples are provided in Appendix A.

In the laboratory, plant material was sorted into six vegetation strata:

- Tree seedlings;
- Ericaceous shrubs;
- Herbaceous plants;
- *Sphagnum* moss;
- Other true mosses; and,
- Lichens.

Sphagnum, other mosses, and lichens were separated from dead organic matter, e.g. where the *Sphagnum* transitions to fibric peat of a uniform brown color (Sjors 1991).

Sorted material was oven-dried at 70^{o}C to a constant mass and weighed. Above-ground biomass was estimated as the mean of the three samples taken per trench, expressed as dry mass per unit area (g·m^{-2}).

AOM samples were taken by collecting cores at the location of biomass plots after the vascular vegetation had been removed from the surface. Cores were taken using a serrated cylindrical metal corer with an inner diameter of 30 cm. Care was taken to extend the depth of the core to reach 15-20 cm into the residual peat left at time of abandonment; this level could easily be discerned in the field based on the change in colour and humification of the peat.

The cores were placed in a laboratory freezer until frozen. Rectangular sample blocks 20 cm x 20 cm x (variable depth) were cut from the frozen cores using a band saw. The newly cut faces of the block provided an undisturbed view of the AOM profile. AOM depth throughout each survey trench was estimated as the mean of measurements taken from the sample blocks.

The blocks were carefully examined to identify any distinct “succession profiles” where vegetation shifted due to rewetting; this shift was typified by a layer of tree or ericaceous shrub litter directly adjacent to the residual peat, subsequently overlain by a newly formed moss layer.

AOM samples were sorted into five categories:

- Woody roots;
- Herbaceous plants;
- Litter;
- Fibric peat; and,
- Mesic peat.

Sorted material was oven-dried at 70^{o}C to a constant mass and weighed. AOM was estimated as the mean of the three samples taken per trench, expressed as dry mass per unit area (g·m^{-2}).

2.2 Data analysis

2.2.1 Community scale vegetation change

Two approaches were used to assess the effects of rewetting on peatland vegetation community structure:

1. Direct comparison was used to contrast current patterns of vegetation community structure in rewetted and non-rewetted sectors of the study sites,

as well as between the study sites. This portion of the analysis used the data collected as a part of this study (2010) and also the data from the undisturbed reference sites (2007).

2. Trajectory analysis was used to assess changes in community-scale vegetation composition over time by comparing historical vegetation survey data to those data collected for this study. Community-scale vegetation change was evidenced by divergent change between rewetted and non-rewetted sectors of the study sites, as well as by the extent of convergence between rewetted sectors and reference data collected from natural undisturbed bogs.

Details regarding statistical analyses used in both methods are provided below.

2.2.1.1 Comparison of current patterns of community vegetation structure in rewetted and non-rewetted sectors

An Un-weighted Pair Group Method of Averaging (UPGMA) cluster analysis was used to identify vegetational similarities between survey trenches as represented in a Bray-Curtis distance matrix. Infrequent species were removed from the matrix to reduce noise in the dataset. Species were removed if they occurred in <5% of the trenches *and* had a maximum occurrence frequency of <5% throughout all trenches. A final UPGMA clustering dendrogram was created to display similarities and dissimilarities in vegetation assemblages among all survey trenches, and to see if trenches separated out by treatment (rewetting). In this analysis, the dendrogram was reordered by swiveling its branches at fusion nodes such that the order of the survey trenches best reflects their relationships in the original Bray-Curtis distance matrix (Borcard et al. 2011). Mantel correlation comparisons were used to determine the optimal number of “cuts” to delineate clusters within the dendrogram (Borcard et al. 2011). Cluster analysis was performed using the R statistical computing software, version 2.9.1 (R Core Development Team 2006).

Non-Metric Multidimensional Scaling (NMS) was used in conjunction with the cluster analysis to further explore and characterize vegetation assemblages occurring in rewetted and non-rewetted survey trenches. NMS utilized Bray-Curtis distance measures, a maximum of 6 axes, and 500 iterations (250 of which were run with randomized data). Abiotic variables back-correlated with resultant NMS axes were: time since abandonment in years, average depth to water table, and time since rewetting in years. NMS was performed using PC-ORD Version 6 (McCune and Meford 2011) on untransformed species frequency data.

Multi-Response Permutation Procedure (MRPP) was used to determine whether vegetation community structure was significantly different as a result of rewetting. MRPP was performed using PC-ORD Version 6 (McCune and Meford 2011), utilizing Bray-Curtis distance measures, and a natural weighting method to calculate group weights.

A vegetation heat mapping matrix was also created based on the UPGMA cluster analysis dendrogram and the relative abundance of species within each trench. The matrix is said to be “doubly ordered”, meaning the survey trenches are re-ordered according to their dendrogram clustering, and the plant species are re-ordered based on their weighted averages for all survey trenches (Borcard et al. 2011). Species frequencies were transformed using the Braun-Blanquet scale, which was color coded to show successively darker shading for increasing frequency values. The resultant heat map provides a comprehensive picture of vegetation assemblages across all surveyed trenches, as well as the dominant species of each of the UPGMA clusters. Vegetation heat mapping and Braun-Blanquet data transformation were performed using the R statistical computing software version 2.9.1 (R Core Development Team 2006).

Frequencies of major tree, ericaceous shrub and *Sphagnum* species were compared for rewetted and non-rewetted sectors of the study sites, as well as with the natural reference sites. Boxplots were used to visually examine frequency differences between groups. Non-parametric Kruskal-Wallis one-way analyses of variance (ANOVA) were used to test the hypothesis of no significant difference between groups. Games-Howell post hoc tests were used to make pair-wise multiple comparisons between groups when significant differences were indicated (Welch 1947; Kruskal and Wallis 1952). These methods were chosen as the data were not normally distributed. Several *Sphagnum* species encountered in the study sites were infrequent or absent in the natural reference sites; in these cases non-parametric Mann-Whitney U tests were used to test the hypothesis of no significant difference between rewetted and non-rewetted trench groupings. Statistical tests were performed using SPSS Base 17.0 (SPSS Inc. 2008).

2.2.1.2 Changes in community vegetation structure over time

Historical monitoring data from Poulin et al. (2005) were used in conjunction with the 2010 survey data collected in this study to track changes in vegetation assemblages. Collectively these data represent repeated measurements on the same survey trenches; trends in vegetation change in both rewetted and non-rewetted sectors were examined to determine the extent to which divergent vegetation change due to rewetting had occurred. Similarly, the natural reference data represent an endpoint by which to gauge the trajectory of vegetation change over time. Historical and natural reference data were standardized to species occurrence frequencies (%) and integrated with the 2010 survey data collected in this study. The 2010 survey data were reduced to only those trenches with replicate historical data. Infrequent species (occurring in <5% of trenches and max. frequency <5%) were removed from the resultant matrix.

NMS was used to examine similarities and dissimilarities in vegetation assemblages over time within rewetted and non-rewetted sectors of the study sites, as well as with the natural reference sites. Succession vectors were added between repeated measurements of survey trenches to indicate the movement of survey trenches in the ordination space over time. The nature of this movement, as indicated by the length and direction of the succession vectors, represents the extent and nature of community scale vegetation change over time: short vectors linking repeated measurements of a survey trench indicate that vegetation assemblages are relatively stable; conversely, long succession vectors indicate that significant changes have occurred. The direction of succession vectors for rewetted and non-rewetted survey trenches indicates whether divergent vegetation change has occurred, or if vegetation assemblages in rewetted trenches are becoming more similar to those found in undisturbed bogs. NMS and succession vector work were performed using Bray-Curtis distance measures in PC-ORD Version 6 (McCune and Meford 2011) on untransformed species frequency data.

Cover class data for the different vegetation strata collected as a part of this study (2010) were also compared to values from 1994 as second method gauge vegetation change over time in rewetted and non-rewetted sectors of the study sites. Median cover class values for each vegetation strata were calculated from values of all survey trenches common to one sector, and were compared to determine whether cover of each stratum had increased or decreased.

2.2.2 Above-ground biomass and accumulated organic matter

Above-ground biomass and AOM were compared based on time elapsed since rewetting in years (non-rewetted, 4 years, and 10 years rewetted). Boxplots were used to visually examine data distributions, and non-parametric Kruskal-Wallis one-way ANOVAs were used to determine whether biomass and AOM were significantly different (Welch 1947; Kruskal and Wallis 1952). Games-Howell post-hoc multiple comparisons were used to determine significant differences in inter-group samples. All statistical tests were performed using SPSS Base 17.0 (SPSS Inc. 2008).

The rate of fibric peat AOM accumulation was estimated for rewetted and non-rewetted areas by grouping survey trenches by UPGMA cluster and time elapsed time since abandonment/rewetting (depending on treatment). Grouping the survey trenches in this manner allowed a more accurate depiction of the variability in fibric peat AOM accumulation rates resulting from the non-uniformity of rewetting. Fibric peat was singled out from the other AOM sort categories in this portion of the analysis because it is the principal component comprising the acrotelm in an undisturbed bog, and therefore provided the best measure to evaluate whether a ‘neo-acrotelm’ is forming as a result of rewetting. For non-rewetted trenches, the fibric peat accumulation rate was calculated by dividing the fibric peat AOM by the time elapsed since abandonment, expressed in $g \cdot m^{-2} \cdot year^{-1}$. For rewetted trenches, the accumulation rate was calculated by dividing the fibric peat AOM by time elapsed since rewetting, expressed in $g \cdot m^{-2} \cdot year^{-1}$. However, accumulation rates in rewetted areas were interpreted with caution, as a clear succession profile was not always observed in the AOM sample blocks to serve as a marker from which to measure accumulation since rewetting.

Chapter 3: Results

3.1 Community scale vegetation change

A total of 89 plant species (Appendix B) were surveyed amongst the three study sites. Removal of infrequent species resulted in a total of 65 species for inclusion in subsequent analyses.

3.1.1 Comparison of current patterns of community vegetation structure in rewetted and non-rewetted sectors

Mantel correlation comparisons within the UPGMA cluster analysis dendrogram indicated an optimal solution of 7 survey trench clusters (Figure 3.1). Vegetation assemblages tend to be more similar among survey trenches that co-occur within the same sector, as indicated by their ordering within the dendrogram. The number of clusters and the interspersion of rewetted and non-rewetted survey trenches throughout the dendrogram indicate variability in vegetation assemblages regardless of treatment. The variation of vegetation assemblages in rewetted and non-rewetted survey trenches is also shown in the NMS ordination of all 2010 vegetation data (Figure 3.2), based on their interspersion throughout the ordination space. The NMS resulted in a two dimensional solution with a cumulative r^2 of 0.925 and a final stress of 12.27.

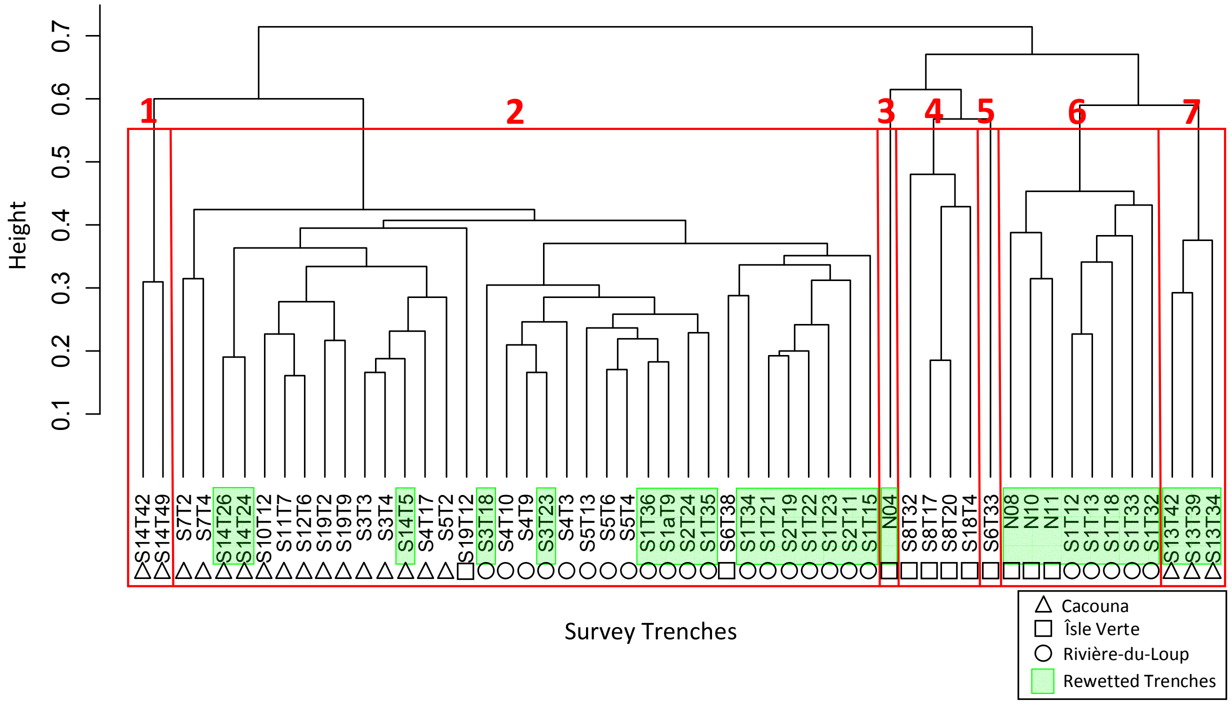


Figure 3.1 UPGMA Cluster Analysis Dendrogram of 2010 Survey Trenches

The seven resultant clusters from UPGMA cluster analysis are overlaid in red. Rewetted trenches (green shading) The “height” between fusion nodes indicates the relative dissimilarity of vegetation within survey trenches.

There are differences in vegetation assemblages found in the three study sites, as indicated by their separation along Axis 2. There is more overall variation in vegetation assemblages in the Cacouna and Îsle Verte sites than in Rivière-du-Loup, as indicated by the larger polygons encompassing survey trenches from the former two sites. MRPP results (Table 3.1) show that although there are significant differences in vegetation assemblages when survey trenches are grouped by treatment or study site, UPGMA clusters provide more accurate grouping based on vegetational similarities (as shown by the higher A value Table 3.1).

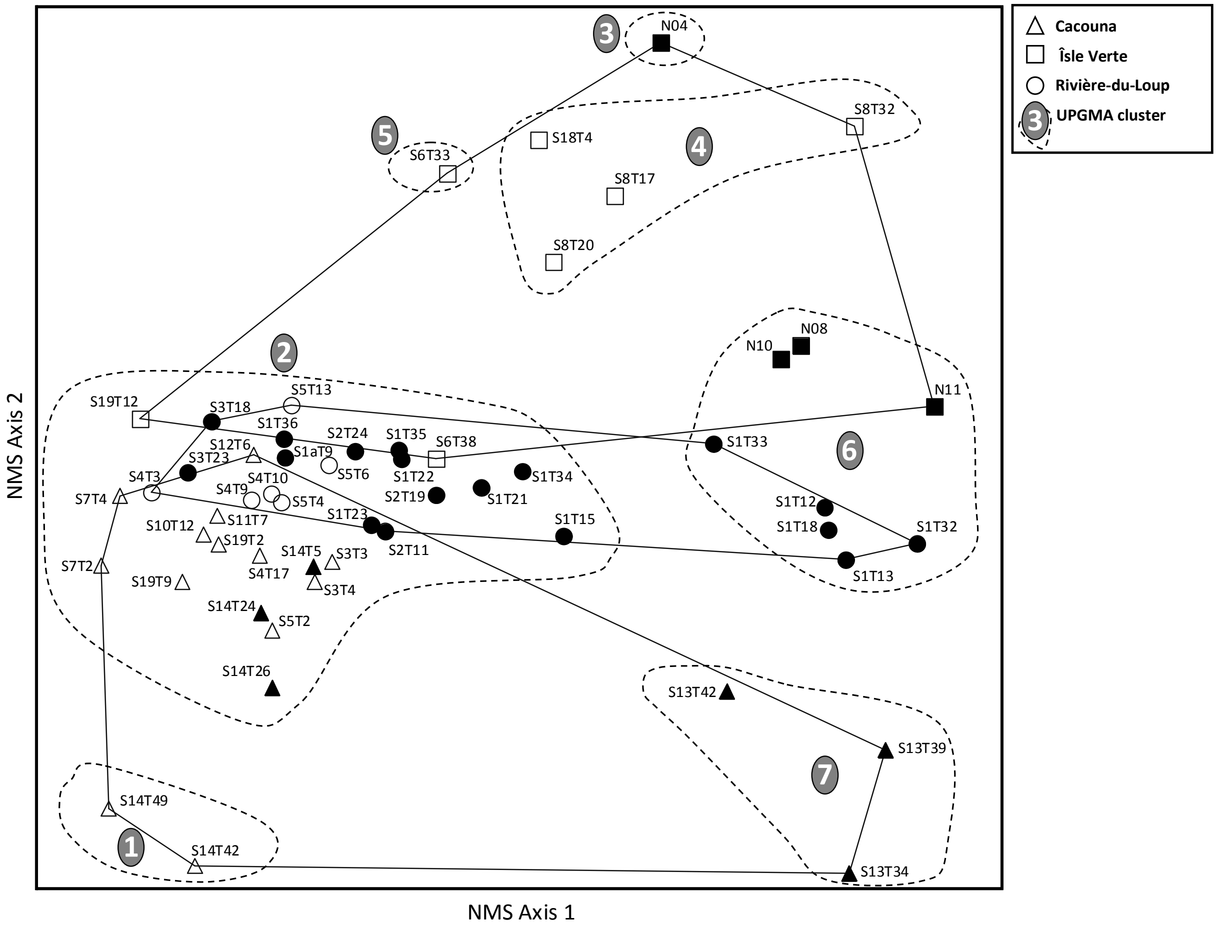


Figure 3.2 NMS of 2010 Vegetation Data – Survey Trench Distribution

Rewetted (closed symbols) and non-rewetted (open symbols) survey trenches are interspersed throughout the ordination space indicating variability in vegetation assemblages among treatments. Study sites (closed polygons) appear to separate along Axis 2. UPGMA clusters (dashed envelopes) appear to group survey trenches more accurately based on vegetational similarities. NMS results have been rotated by the second matrix variable ‘depth to water table’ to facilitate interpretation.

Table 3.1 MRPP Results for 2010 Survey Trench Groupings

MRPP Grouping	A	p
Study site	0.114	<0.01
Time since rewetting (years)	0.124	<0.01
UPGMA Clusters[a]	0.284	<0.01

a. UPGMA Clusters 3 and 5 excluded as MRPP requires each group to have ≥2 members.

Differences in community vegetation structure can be visualized by plotting the location of all plant species in the NMS ordination space and overlaying trench grouping centroids (Figure 3.3). Centroids represent the average position within the ordination space of all survey trenches within a particular grouping; they are located in proximity to species that contribute more heavily to their respective species assemblages.

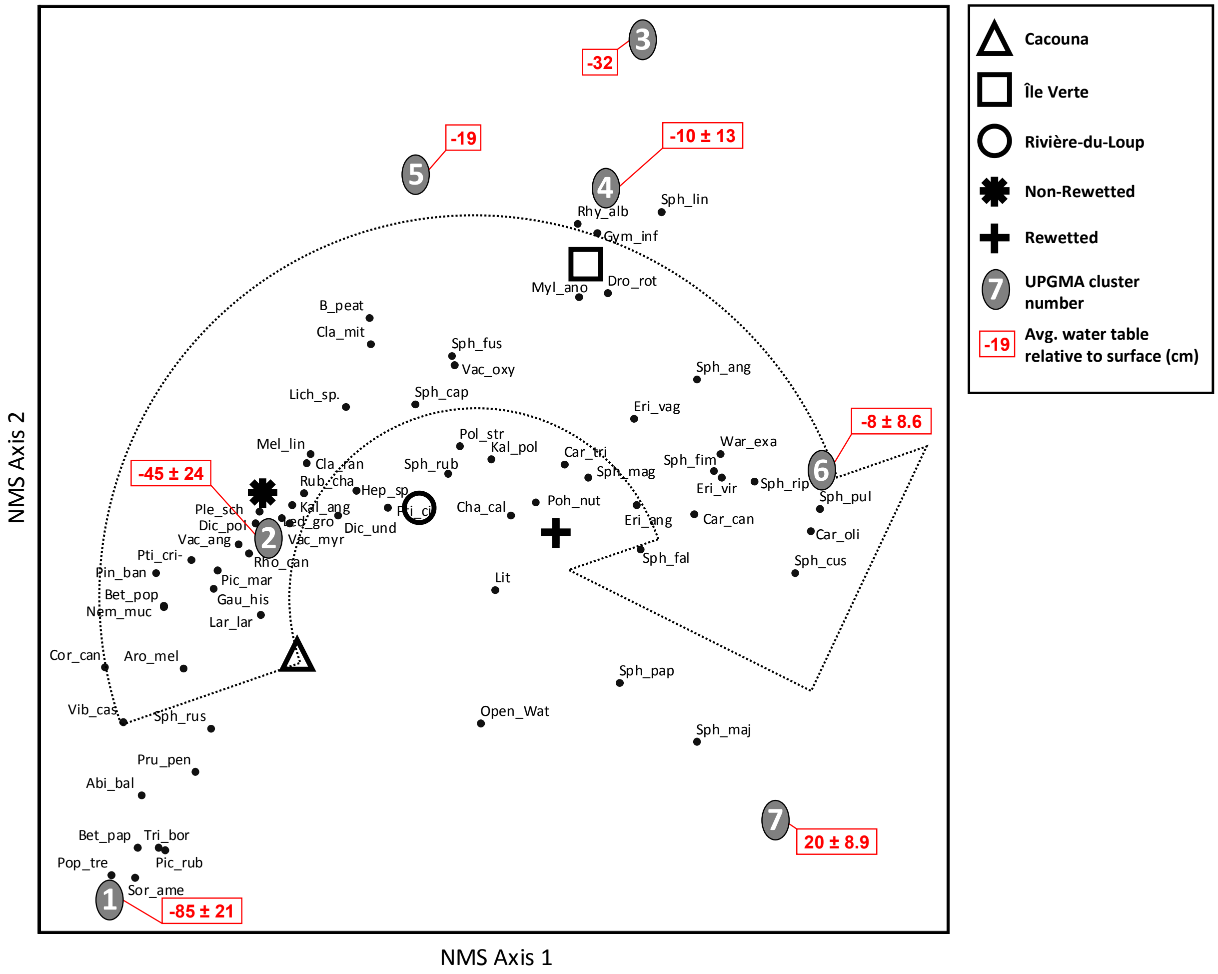


Figure 3.3 NMS of 2010 Vegetation Data – Plant Species Distribution

Group centroids for study sites, treatment, and UPGMA clusters are indicated in relation to plant species that contribute most heavily to their vegetation assemblages. Average water table positions (cm ± s.d.) for UPGMA clusters are displayed in red. Direction of overlaid arrow indicates rising average water table position. Refer to Appendix B for interpretations of species codes.

Time since abandonment in years was weakly negatively correlated with both NMS axes (Axis 1 Pearson r = -0.132, Axis 2 Pearson r = -0.38) indicating that this variable does not have a strong influence on vegetation assemblages. Average water table position (Pearson r = 0.775) and time since rewetting in years (Pearson r = 0.529) were more strongly correlated with NMS Axis 1; a horseshoe shape is evident in the depiction of the rising water table gradient corresponding to the UPGMA clusters (Figure 3.3; overlaid arrow). Vegetation assemblages can therefore be viewed as a continuum along a water table gradient, ranging from tree/ericaceous shrub dominated communities at one extreme, to open *Sphagnum* and hydrophytic herbaceous dominated communities at the other. Plant species that are highly correlated with NMS Axis 1 (Table 3.2) align with group centroids for rewetted and non-rewetted survey trenches, as well as the general sequence of UPGMA clusters.

Table 3.2 Plant Species Pearson Correlations with NMS Axis 1

Species	Species Code	Vegetation Stratum	r
Picea mariana	Pic_mar	Tree	-0.615
Ledum groenlandicum	Led_gro	Ericaceous	-0.796
Kalmia angustifolia	Kal_ang	Ericaceous	-0.726
Rhododendron canadense	Rho_can	Ericaceous	-0.723
Vaccinium angustifolium	Vac_ang	Ericaceous	-0.756
Pleurozium schreberi	Ple_sch	Other Moss	-0.559
Chamaedaphne calyculata	Cha_cal	Ericaceous	0.654
Eriophorum vaginatum	Eri_vag	Herbaceous	0.752
Sphagnum cuspidatum	Sph_cus	Sphagnum	0.619
Sphagnum fallax	Sph_fal	Sphagnum	0.719
Sphagnum riparium	Sph_rip	Sphagnum	0.518
Warnstorfia exannulata	War_exa	Other Moss	0.608

Table 3.3 Plant Species Pearson Correlations with NMS Axis 2

Species	Species Code	Vegetation Stratum	r
Abies balsamifera	Abi_bal	Tree	-0.449
Aronia melanocarpa	Aro_mel	Shrub	-0.408
Betula papyrifera	Bet_pap	Tree	-0.428
Larix laricina	Lar_lar	Tree	-0.491
Populus tremuloides	Pop_tre	Tree	-0.423
Sphagnum rusowii	Sph_rus	Sphagnum	-0.429
Drosera rotundifolia	Dro_rot	Herbaceous	0.651
Eriophorum vaginatum	Eri_vag	Herbaceous	0.474
Gymnocolea inflata	Gym_inf	Other Moss	0.454
Lichen sp.	Lich_sp.	Lichen	0.405
Mylia anomala	Myl_ano	Other Moss	0.75
Sphagnum capillifolium	Sph_cap	Sphagnum	0.513
Sphagnum lindbergii	Sph_lin	Sphagnum	0.483
Vaccinium oxycoccus	Vac_oxy	Ericaceous	0.442

The arrangement of vegetation assemblages along a water table gradient is further highlighted in the vegetation heat map (Figure 3.4), which quantitatively displays the frequency of plant species occurring in survey trenches belonging to each UPGMA cluster. Cluster 1 is made up of survey trenches common to Sector 14a of the Cacouna study site. The water table is very low (-85 ± 21 cm) in this sector, and vegetation assemblages are dominated by mature deciduous and coniferous trees which shade the understorey, resulting in low to moderate ericaceous cover. Several of these tree species are negatively correlated with NMS Axis 2 (Table 3.3), and are unique to the Cacouna study site. Cluster 2 is the largest of all the UPGMA clusters, and is comprised of survey trenches from each of the study sites. Towards the left side of the cluster are survey trenches in which the water table is low (generally >-50 cm), and vegetation assemblages are dominated by the tree and ericaceous shrub species negatively correlated with NMS Axis 1 (Table 3.2). These survey trenches represent the typical community vegetation structure previously found to spontaneously regenerate in abandoned block-cut bogs. Eleven of the 28 rewetted survey trenches are located on the right side of Cluster 2. In these trenches, the water table position is higher (-30 to -20 cm), resulting in slightly lower cover of dry ericaceous shrub species. *Sphagnum* and herbaceous species positively correlated with NMS Axis 1 (Table 3.2) were generally found to be occurring sporadically in low-lying areas of survey trenches.

Different assemblages of hydrophytic herbaceous and moss species that are positively correlated with NMS Axis 1 (Table 3.2) are dominant in Clusters 3-6, with the ericaceous shrub *Chamaedaphne calyculata* greatly increasing in frequency. Clusters 3 and 5 each contain a single survey trench due to localized and unique conditions that stand apart from other trenches surveyed. Cluster 3 is a survey trench located in Sector 15b of Île Verte, and was the only trench surveyed in this sector. Vegetation is typified by a high cover of the liverwort *Mylia anomala* (50 - 75%) and a significant component of lichens. Cluster 5 is a survey trench located in Sector 6 of Île Verte that has not re-colonized well with vegetation. The surface of the residual peat is bare in ~50% of the trench, with *Sphagnum* and ericaceous shrubs colonizing the trench along its edges. Cluster 4 is typified by low to moderate shrub cover and high cover of moss and hepatic species, with unique occurrences of several species that are positively correlated with NMS Axis 2 (Table 3.3). Although survey trenches within this cluster are non-rewetted, they have a water table at or just below the surface (-10 ± 13 cm), indicating that hydrological conditions have sufficiently recovered to allow conditions favorable for the proliferation of *Sphagnum*. Cluster 6 has a water table close to the surface (-8 ± 8.6 cm), with high cover of *Chamaedaphne calyculata* (50 - >75%), moderate cover of herbaceous species, including *Eriophorum vaginatum*, *Carex* sp. (25 - 50%), as well as the highest diversity of *Sphagnum* species. Cluster 7 is made up of 3 trenches in Sector 13 of the Cacouna study site. This sector had the highest water table (20 ±

8.9 cm); it is the only area surveyed that had standing water present throughout the survey trenches. Cluster 7 is typified areas of open water in absence of vegetation, dead-standing trees, and high cover of *C. calyculata* and several *Sphagnum* species, most notably *S. fallax* and *S. cuspidatum*.

Frequencies of major tree and ericaceous shrub species are reduced in rewetted sectors of the study sites (Figure 3.5). With the exception of *Chamaedaphne calyculata*, frequencies of ericaceous species in rewetted trenches represent an intermediate value between non-rewetted trenches and the natural reference sites (Figure 3.5b). There is a significant increase in occurrence frequency of *Sphagnum* species from the Section Cuspidata (most notably *S. fallax*) in rewetted survey trenches, however, these hollow and lawn species are present in much higher densities than in natural reference sites (Figure 3.5b). Occurrence frequencies of *Sphagnum* from the Section Acutifolia were not significantly different in rewetted and non-rewetted trenches; in fact, *S. capillifolium* is slightly more frequent in non-rewetted trenches (Figure 3.5c). Natural reference sites exhibit very high cover of *S. rubellum*, and to a lesser extent *S. fuscum*, in sharp contrast to the study sites regardless of treatment.

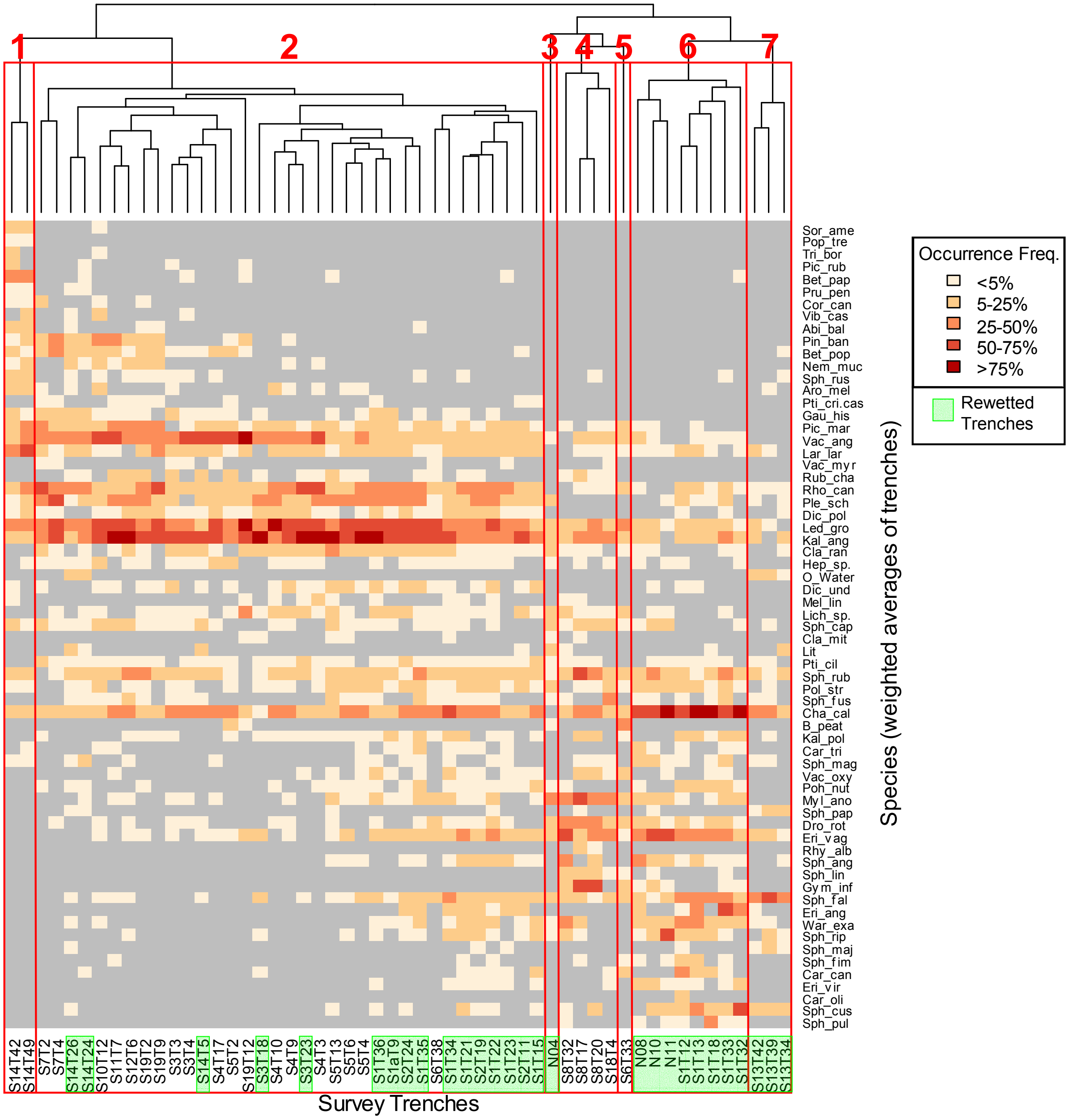


Figure 3.4 Vegetation Heat Mapping of 2010 Survey Trenches

Vegetation assemblages range from drier species on the top left to hydrophytic species on the bottom right. UPGMA clusters are overlaid in red. Plant species are re-ordered based on their weighted averages for all survey trenches. Refer to Appendix B for interpretations of species codes.

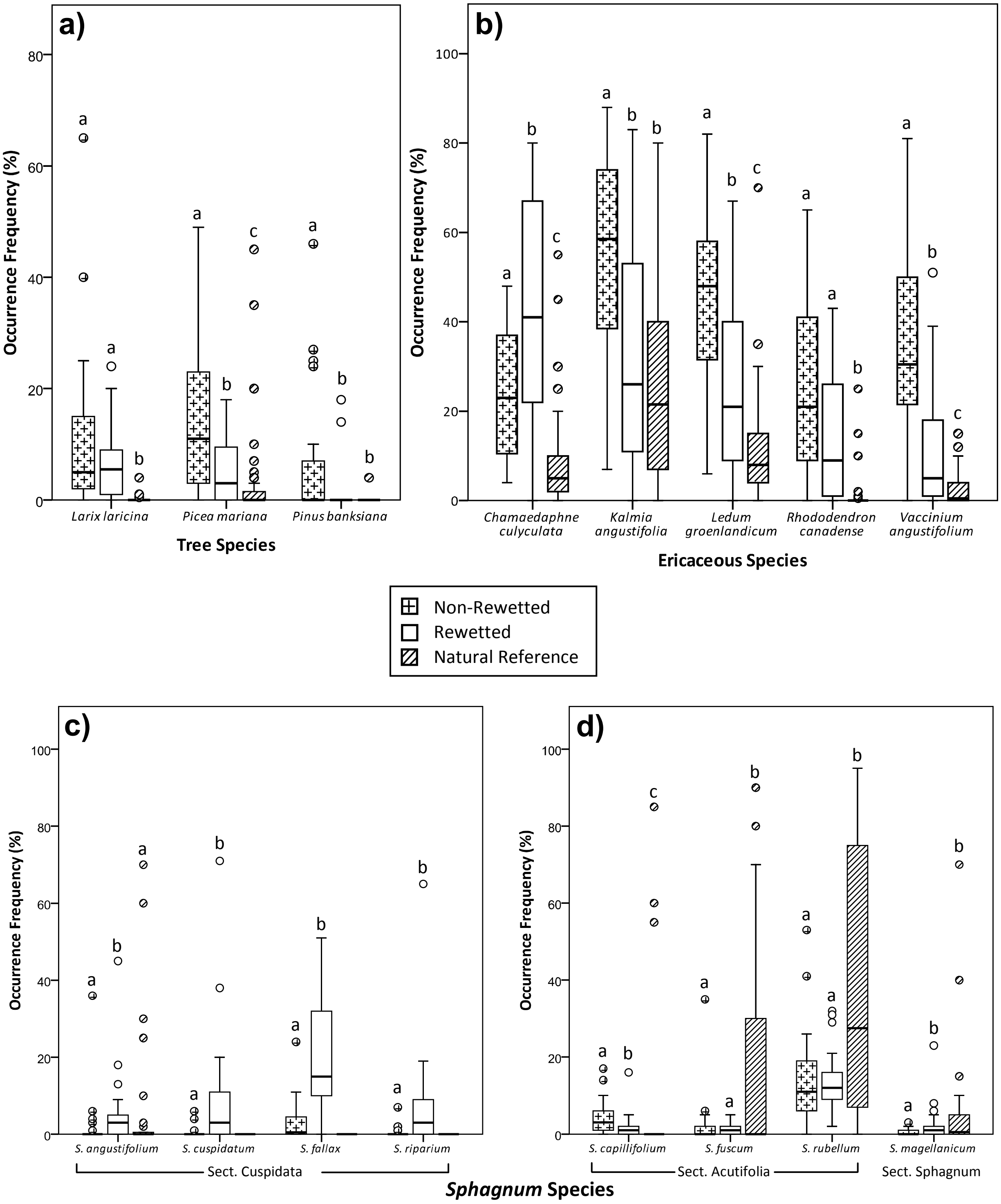


Figure 3.5 Occurrence Frequency of a) Tree Species, b) Ericaceous Shrub Species and c) and d) *Sphagnum* Species by Treatment as Compared to Natural Reference Sites

Boxplots display the median and quantiles. Circles denote outliers. Different letters indicate significant differences between groups using Games-Howell post hoc tests (p<0.05).

3.1.2 Assessing vegetation change over time

The NMS ordination of all combined temporal vegetation datasets (1994 - 2010) resulted in a 3 dimensional solution with a cumulative r^2 of 0.832 and a final stress of 14.95. Only NMS Axes 1 and 2 are displayed for interpretive purposes, as their cumulative r^2 was the highest of all 2D axis combinations.

Survey trenches that co-occur within the same sector exhibit a very similar type and amount of vegetation change over time, as evidenced by the similarity of their succession vectors. This is evident in both rewetted (Figure 3.6a) and non-rewetted sectors (Figure 3.7 a_1, b_1).

Rewetting caused different amounts of vegetation change in rewetted sectors of the Cacouna study site (Figure 3.6a, b). In 2005, one year prior to rewetting, all of the trenches exhibit similar vegetation structure, as indicated by the relatively small size of the 2005 polygon (Figure 3.6b). Following rewetting, vegetation assemblages were shifted in both Sectors 13 and 14b (Figure 3.6a), but to a larger extent in Sector 13.

The frequency of open water, litter and dead wood increased, indicating extensive vegetation mortality within survey trenches two years following rewetting. Vegetation recovered quickly, but differently, in each sector. In Sector 13, there was a large shift in vegetation assemblages, as evidenced by the length of succession vectors (Figure 3.6a); vegetation assemblages in this sector rapidly became dominated by lawn and hollow *Sphagnum* species from the section Cuspidata. The 2010 endpoint for these survey trenches now overlap a natural reference survey point, indicating that vegetation assemblages are becoming more similar to those found in undisturbed bogs. For Sector 14b, succession vectors indicate that vegetation assemblages bounced back to resemble those observed prior to rewetting. Overall, vegetation assemblages in rewetted sectors of the Cacouna study site are still distinctly different than those occurring in the natural reference sites 4 years following rewetting, as evidenced by separation of the 2010 and natural reference polygons (Figure 3.6b).

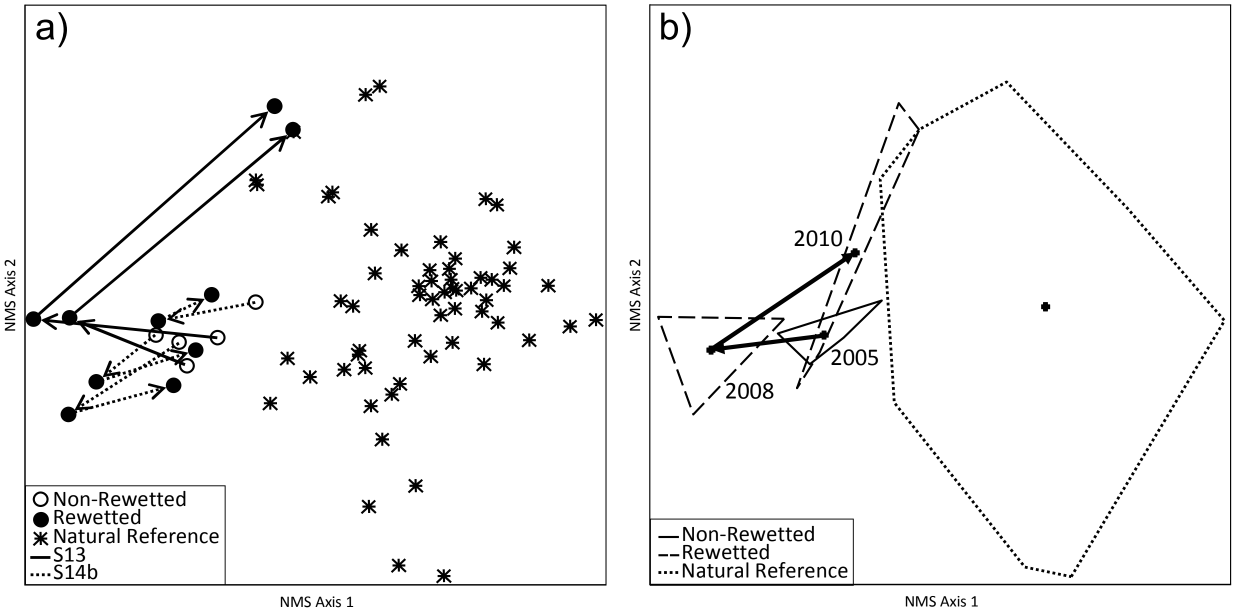
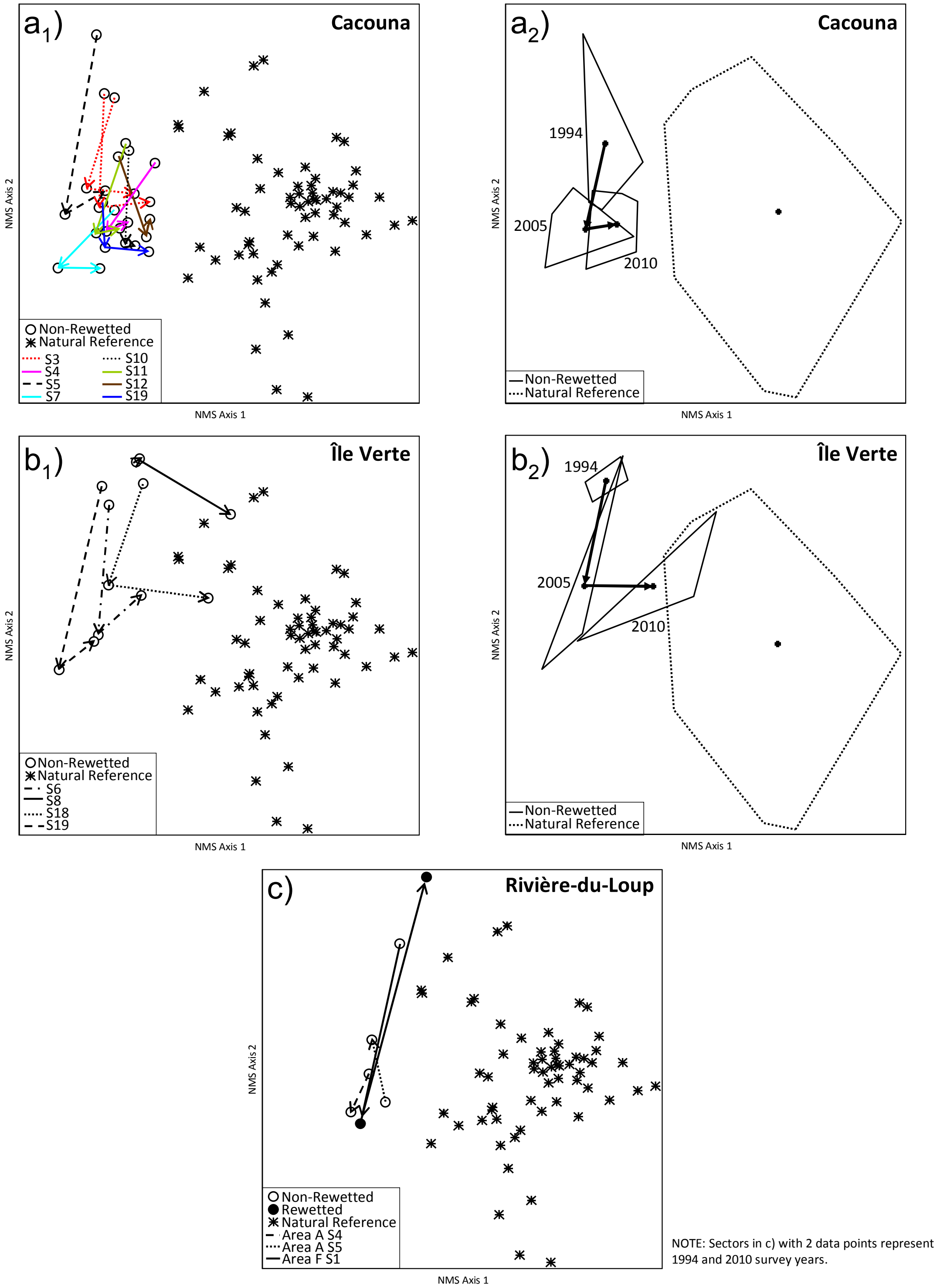


Figure 3.6 Vegetation Change over Time in Rewetted Trenches – Cacouna Study Site

a) Succession vectors indicate the amount and type of vegetation change in survey trenches resulting from rewetting, as measured over three survey intervals (2005-2008-2010). b) The overall direction/ extent of vegetation change between survey years, as depicted by polygons and group centroids. Both are compared to a static snap shot of the natural reference data (2007).

Vegetation assemblages in non-rewetted sectors of the Cacouna study site are changing significantly over time (Figure 3.7a$_1$). The direction of overall successional movement from 2005 to 2010 suggests that vegetation assemblages may be becoming more similar to those found in the natural reference sites (Figure 3.7a$_2$). A similar trend is apparent in non-rewetted sectors of the Île Verte study site (Figure 3.7 b$_1$, b$_2$). No historical data were available for rewetted sectors of the Île Verte study site, therefore no successional trend can be inferred. There were few data available for the Rivière-du-

Loup study site, but it appears that the non-rewetted sectors in Area A do not follow the same trend as the other two sites (Figure 3.7c). Vegetation change due to rewetting in Area F, Sector 1 was similar to that observed in Sector 13 of the Cacouna study site.



NOTE: Sectors in c) with 2 data points represent 1994 and 2010 survey years.

Figure 3.7 Vegetation Change over Time – (1994 – 2005 – 2010)

a_1) b_1) and c) Succession vectors indicate the amount and type of vegetation change in survey trenches as measured over three survey intervals (1994-2005-2010). b) The overall movement of non-rewetted sectors between survey years, as depicted by polygons and group centroids. All are compared to a static snap shot of the natural reference data (2007).

Trends in vegetation change over time are further confirmed by vegetation cover class data collected in 1994 and 2010 (Table 3.4). In rewetted sectors of the study sites, tree cover was generally found to decrease, and although ericaceous shrub cover stayed at >50%, it is likely the species composition shifted to being dominated by *Chamaedaphne calyculata* as shown in Section 3.1.1. *Sphagnum* cover increased in all rewetted sectors, with three of four increasing from <10% to >50% cover. In non-rewetted sectors, cover for different vegetation strata fluctuate independently. Tree cover increased or stayed the same in 6 of 8 non-rewetted sectors, while ericaceous cover remained high. *Sphagnum* cover in non-rewetted sectors generally remained low (<10 - 25%), except for Sectors 6 and 8 of the Île Verte study site, in which *Sphagnum* cover was moderate (26 - >50%).

Table 3.4 Vegetation Cover Class Changes 1994 - 2010 in Rewetted and Non-Rewetted Sectors within Study Sites

Study Site	Sector	No. Trenches Surveyed	Rewetted	Survey Year	Median Cover Class of Vegetation Strata[a]					
					Tree	Ericaceous	Herbaceous	*Sphagnum*	Other moss	Lichen
Cacouna	CS-S3	2	No	1994	3	4	1	1	1	1
			No	2010	2	4	2	2	1	2
	CS-S7	2	No	1994	3	4	1	1	1	1
			No	2010	4	4	1	1	4	1
	CS-S19	2	No	1994	3	4	1	1	1	1
			No	2010	4	4	1	2	1	1
	CS-S14a	2	No	1994	4	4	2	3	1	1
			No	2010	4	4	1	1	1	0
Île Verte	IV-S6	2	No	1994	1	3	1	3	2	1
			No	2010	1	4	1	3	3	1
	IV-S8	2	No	1994	1	3	2	3	1	1
			No	2010	0	3	3	4	4	1
Rivière-du-Loup	Area A S4	3	No	1994	1	4	1	1	1	1
			No	2010	3	4	0	1	1	1
	Area A S5	3	No	1994	1	4	1	2	1	1
			No	2010	2	4	0	2	3	2
Cacouna	CS-S13	3	No	1994	2	4	1	1	1	1
			Yes	2010	0	4	1	4	0	0
	CS-S14b	2	No	1994	3	4	1	1	1	1
			Yes	2010	3	4	1	2	1	1
Rivière-du-Loup	Area F S1	12	No	1994	3	4	1	1	1	1
			Yes	2010	1	4	3	4	2	1

a. Cover values are as follows: 1 = 1-10%, 2 = 11-25%, 3 = 26-50%, 4 = >50%

3.2 Above-ground biomass and accumulated organic matter

3.2.1 Above-ground biomass

Above-ground biomass was extremely variable in rewetted and non-rewetted survey trenches. This variability can largely be attributed to the size and density of trees, which highly influence the total above-ground biomass of the survey trenches due to their size. The rise in water table position due to rewetting caused large-scale tree mortality and a reduction in living tree biomass (Figure 3.8a). A significant portion of above-ground tree biomass is still present as dead-standing trees 4 years following rewetting, representing 38% of total biomass for these survey trenches; dead-standing trees were not observed in survey trenches that had been rewetted for 10 years. Ericaceous shrub biomass significantly decreased 4 years following rewetting, yet it appears to bounce back over time (Figure 3.8b). Herbaceous above-ground biomass was significantly higher in trenches that have been rewetted for 10 years, however it remains a minor contributor to total above-ground biomass, representing <1% of the total in both rewetted and non-rewetted trenches. Median *Sphagnum* above-ground biomass is roughly equal in all rewetted trenches regardless of time since rewetting. One non-rewetted survey trench displayed unusually high biomass of *Sphagnum* from the section Acutifolia (also shown in frequency data in Figure 3.5d), resulting in no significant difference between treatments. Other true mosses represented a small portion of above-ground biomass in both rewetted and non-rewetted survey trenches, the species of which varied according to the prevailing moisture conditions, resulting in no significant difference.

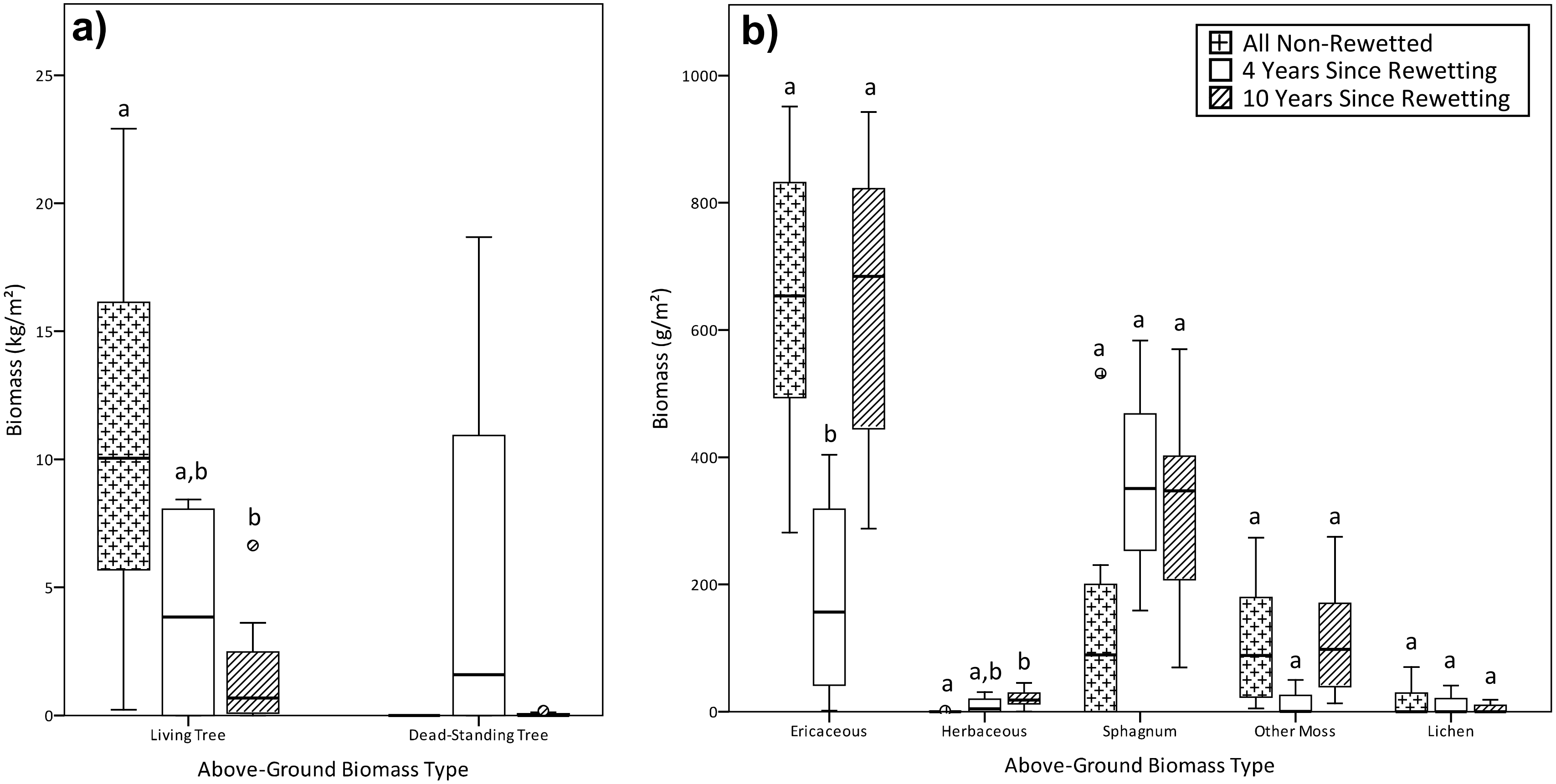


Figure 3.8 Above-Ground Biomass of a) Living and Dead Standing Trees and b) Vegetation Strata in Rewetted and Non-Rewetted Trenches

Boxplots show the median and quantiles, while outliers are shown as circles. Different letters indicate significant differences between groups using Games-Howell post hoc tests ($p < 0.05$). No statistical comparison was possible for dead-standing tree biomass as 2 of 3 groups did not have a variance. Note unit change between a) and b).

Lichen species were sporadically located throughout the survey trenches along centre skag areas of both rewetted and non-rewetted trenches, also resulting in no significant difference.

Above-ground biomass estimates for each of the vegetation strata are highly variable in undisturbed bogs (Table 3.5), yet they provide reference values for comparison with estimates from rewetted and non-rewetted sectors of the study sites. In as little as four years, rewetting reduced tree above-ground biomass to levels more similar to those found in undisturbed bogs, while they remain much higher in non-rewetted sectors of the study sites. Shrub biomass is slightly reduced, with values more equitable to those found in undisturbed bogs. Herbaceous biomass has increased in rewetted trenches, yet it is still generally lower than estimates from undisturbed sites; however, the values are higher 10 years following rewetting, which may indicate that herbaceous biomass is increasing as a function of time. Mean *Sphagnum* biomass in rewetted trenches of the study sites is higher than estimates from undisturbed bogs, yet the variance is also much higher, indicating less uniform conditions throughout the rewetted sectors of the study sites.

Table 3.5 Comparison of Above-ground Biomass Data with Estimates from Other Studies of Undisturbed Bogs

Study	Site Location (No. of Sites)	Pooled Mean ± S.D. ($g \cdot m^{-2}$)
	Tree	
Grigal et al. (1985)[a]	Raised bog, Minnesota (3) Perched bog, Minnesota (3)	33 ± 36
Swanson and Grigal (1991)[a]	Treed bog, Minnesota (26) Mod. Treed bog, Minnesota (35) Open bog, Minnesota (11)	3,293 ± 3,652
Dyck and Shay (1999)	Treed bog, Northwestern Ontario (1) Medium density treed bog Northwestern Ontario (2)	3,578 ± 2,807

Study	Site Location (No. of Sites)	Pooled Mean ± S.D. ($g\cdot m^{-2}$)
	Low tree density/open bog, Northwestern Ontario (5)	
This study	Non-rewetted trenches (7)	10,054 ± 7,858
	4 years since rewetting (excl. dead-standing trees) (4)	4,026 ± 4,658
	10 years since rewetting (8)	1,360 ± 2,377
	Ericaceous Shrub	
Grigal et al. (1985) [a]	Raised bog, Minnesota (3)	361 ± 327
	Perched bog, Minnesota (3)	
Swanson and Grigal (1991) [a]	Treed bog, Minnesota (26)	33 ± 40
	Mod. Treed bog, Minnesota (35)	
	Open bog, Minnesota (11)	
Dyck and Shay (1999)	Treed bog, Northwestern Ontario (1)	547 ± 262
	Medium density treed bog Northwestern Ontario (2)	
	Low tree density/open bog, Northwestern Ontario (5)	
Moore et al. (2002)	Mer Bleue (bog portion), Ottawa, Ontario (16)	478 ± 294
This study	Non-rewetted trenches (7)	685 ± 247
	4 years since rewetting (4)	180 ± 177
	10 years since rewetting (8)	599 ± 216
	Herbaceous	
Swanson and Grigal (1991) [a]	Treed bog, Minnesota (26)	80 ± 50
	Mod. Treed bog, Minnesota (35)	
	Open bog, Minnesota (11)	
Dyck and Shay (1999)	Treed bog, Northwestern Ontario (1)	22 ± 21
	Medium density treed bog Northwestern Ontario (2)	
	Low tree density/Open bog, Northwestern Ontario (5)	
Moore et al. (2002)	Mer Bleue (bog portion), Ottawa, Ontario (14)	40 ± 40
This study	Non-rewetted trenches (7)	2 ± 8
	4 years since rewetting (4)	10 ± 14
	10 years since rewetting (8)	21 ± 15
	Sphagnum	
Dyck and Shay (1999)	Treed bog, Northwestern Ontario (1)	260 ± 35
	Medium density treed bog Northwestern Ontario (2)	
	Low tree density/Open bog, Northwestern Ontario (5)	
Moore et al. (2002)	Mer Bleue (bog portion), Ottawa, Ontario (8)	144 ± 39
This study	Non-rewetted trenches (7)	146 ± 179
	4 years since rewetting (4)	361 ± 174
	10 years since rewetting (8)	344 ± 154

a. As reported in Campbell et al. (2000)

3.2.2 Accumulated organic matter

The average depth of AOM appears to be increasing as a function of time since rewetting (Figure 3.9).

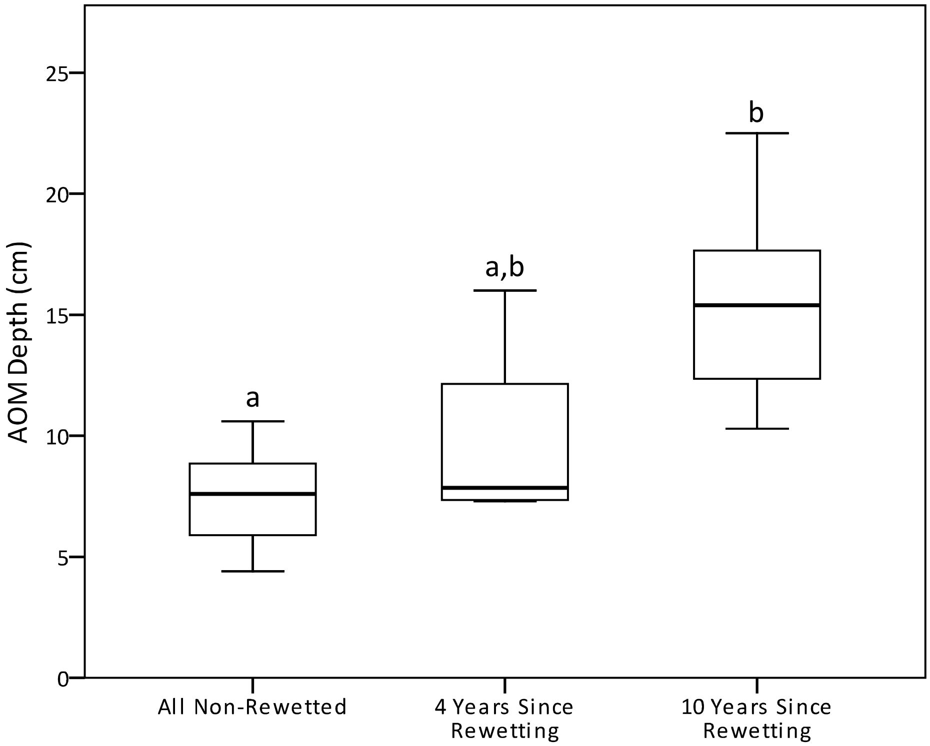


Figure 3.9 Accumulated Organic Matter Depth in Rewetted and Non-Rewetted Trenches

Boxplots show the median and quantiles. Different letters indicate significant differences between groups ($p < 0.05$).

Woody root AOM was significantly higher in survey trenches that have been rewetted 10 years (Figure 3.10). Herbaceous AOM comprised a small component of total AOM in both rewetted and non-rewetted trenches, and was found not to be significantly different between sample groupings, likely due to the presence of ubiquitous peatland species that are tolerant of both wet and dry conditions, such as *Eriophorum vaginatum* ssp. *spissum*.

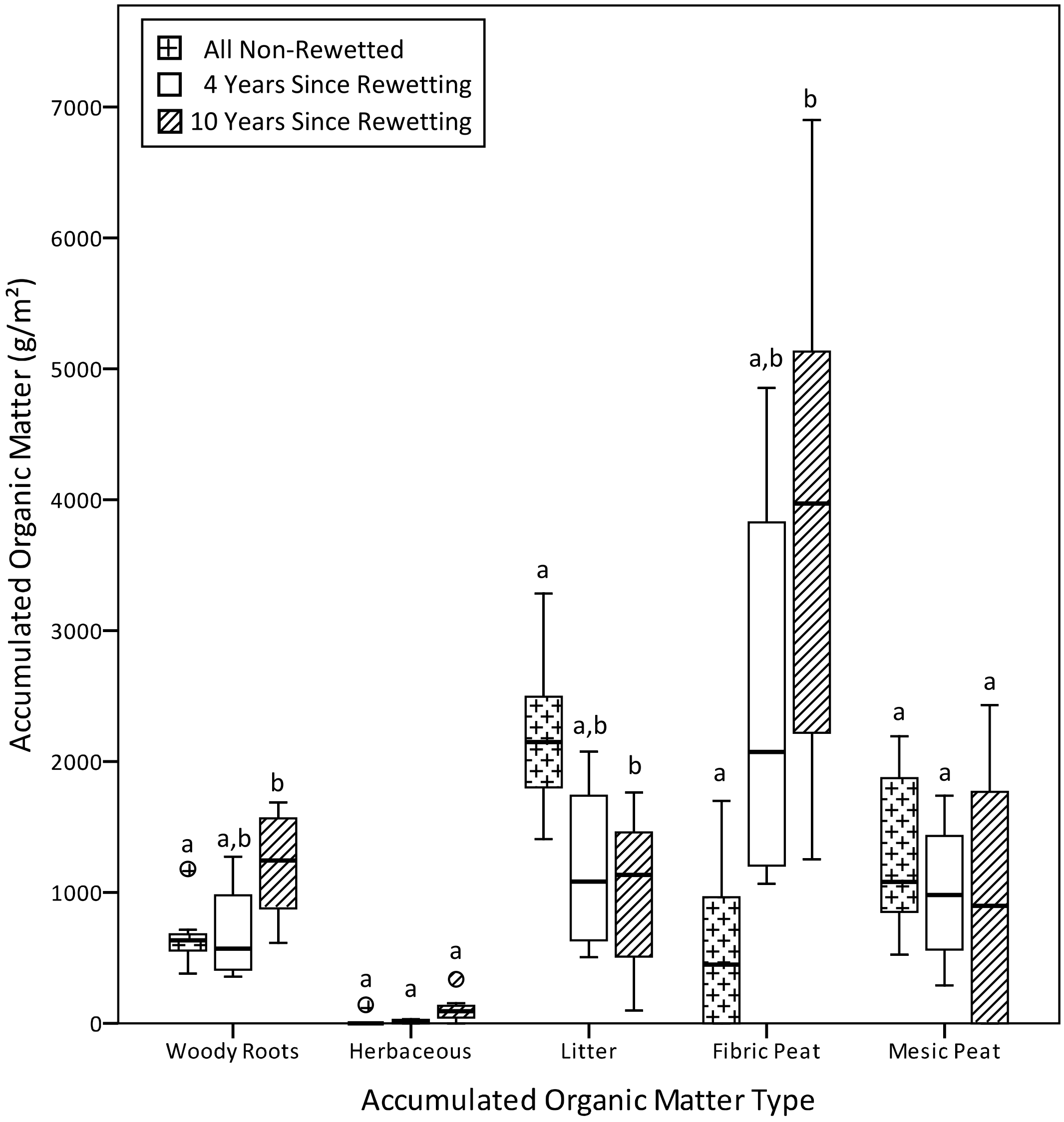


Figure 3.10 Accumulated Organic Matter By Type in Rewetted and Non-Rewetted Trenches Boxplots show the median and quantiles, while outliers are shown as circles. Different letters indicate significant differences between samples using Games-Howell post hoc tests ($p < 0.05$).

The most notable difference in AOM composition for rewetted and non-rewetted trenches is a shift from a predominance of litter in non-rewetted trenches to a predominance of fibric peat in rewetted trenches. AOM estimates for fibric peat show the same trend as the overall AOM depth (Figure 3.9), with the 4 year-rewetted trenches exhibiting an intermediate value between non-rewetted trenches and those that have been rewetted for 10 years. Mesic peat was not found to differ significantly between rewetted and non-rewetted trenches.

A clear vegetation succession profile was observed in 11 of the 36 cores collected in rewetted trenches, all of which were located in 4 trenches within the Rivière-du-Loup study site (rewetted 10 years). The succession profile generally consisted of a dense layer of ericaceous litter atop the residual peat, which became overlain with newly formed fibric peat as a result of *Sphagnum* colonization. Cores taken in dry areas dominated by ericaceous shrubs often had a layer of humified organics resembling a Litter-Fermenting-Humified (LFH) layer typical of upland forests, or were simply a loose layer of ericaceous litter atop the residual peat. Photo plates of selected AOM samples are presented in Appendix C.

The non-uniformity of rewetting resulted in a large range of fibric peat AOM accumulation rates throughout rewetted areas (Table 3.6); however, all estimates are an order of magnitude higher than in non-rewetted areas.

Table 3.6 Average Fibric Peat Accumulation Rates in Rewetted and Non-Rewetted Areas by UPGMA Cluster and Time since Rewetting

UPGMA Cluster	# Survey Trenches	Type[a]	Avg. Years Since Abandonment or Rewetting	Avg. Water Table ± S.D. (cm)	Avg. Fibric Peat AOM ± S.D. ($g \cdot m^{-2}$)	Avg. Fibric Peat Accumulation Rate ± S.D. ($g \cdot m^{-2} \cdot y^{-1}$)
2	7	N	41	-57 ± 20	582 ± 657	14 ± 16
2	2	R	4	-31 ± 8	1204 ± 197	301 ± 49
2	4	R	10	-41 ± 15	2777 ± 1549	278 ± 155
6	4	R	10	-7 ± 9	5638 ± 1117	564 ± 112
7	2	R	4	21 ± 12	3828 ± 1453	957 ± 363

a. N = Non-Rewetted, R = Rewetted

Cluster 6, typified by extensive cover of lawn/hollow *Sphagnum* species, is of particular interest. These are the survey trenches that were found to exhibit a succession profile, providing some measure of assurance that fibric peat AOM can be attributed directly to time elapsed since rewetting.

Chapter 4: Discussion

Changes in vegetation assemblages, above-ground biomass, and the rate and composition of accumulated organic matter provide positive indicators that restoration of block-cut sites using rewetting alone can achieve the structural goals outlined by Rochefort (2000); however, these goals have not yet been fully achieved up to 17 years following rewetting.

4.1 Community scale vegetation change

4.1.1 Comparison of current patterns of community vegetation structure in rewetted and non-rewetted sectors

Community vegetation structure is variable in rewetted sectors of the three study sites. Vegetation assemblages are better viewed as a continuum along a water table gradient regardless of treatment, ranging from tree/ericaceous shrub dominated communities at one extreme, to open *Sphagnum* and hydrophytic herbaceous dominated communities at the other. Topographical variability and the location of constructed peat dams greatly influences the magnitude of water level rise resulting from rewetting in abandoned block-cut bogs, resulting in variable surface moisture conditions (Roul 2004; Ketcheson and Price 2011). It is assumed that this variability is directly reflected in the amount of vegetation change resulting from rewetting.

Although variable, vegetation assemblages in rewetted sectors of the study sites were significantly different than non-rewetted sectors, with positive vegetation change resulting from rewetting. Cover of tree and major ericaceous shrub species found to dominate vegetation assemblages in abandoned block-cut bogs (Lavoie and Rochefort 1996) were largely reduced, with values closer to those found in the natural reference sites. This reduction results in less overstory shading for *Sphagnum* species. Cover of lawn/hollow *Sphagnum* species from the Section Cuspidata, most notably *S. fallax*, significantly increased as a result of rewetting. Despite these improvements, vegetation assemblages in rewetted sectors of the study sites remain significantly different from those found in the natural reference sites up to 17 years following rewetting. Cover of tree and ericaceous shrub species remains elevated in rewetted sectors, and the composition of *Sphagnum* species remain fundamentally different than found in the natural reference sites, which are largely dominated by hummock forming *Sphagnum* species from the section Acutifolia.

Differences in community scale vegetation assemblages at the site level were largely due to the presence of species unique to one study site, or species occurring with uncharacteristically high frequencies in one study site. These differences are likely due to localized variation in depth and pH of the residual peat deposit (Lavoie and Rochefort 1996; Girard et al. 2002), as well as the stochastic processes of seed/spore dispersal and colonization (Rydin and Jeglum 2006). Time since abandonment was not well correlated with vegetation variation; this may be because the majority of sectors were abandoned within 5-10 years of each other.

4.1.2 Assessing vegetation change over time

Vegetation change over time was variable due to the non-uniformity of rewetting. In sectors where the water level was at or just above the surface of the residual peat, survey trenches exhibited drastic vegetational change, characterized by a period of widespread tree and shrub mortality, followed by rapid recolonization by lawn/hollow *Sphagnum* species (>75%) in as little as 4 years following rewetting. Similar vegetational shifts resulting from inundation of both natural and block-cut bogs are reported in Jeglum (1975), Meade (1992), Mitchell and Niering (1993), Tuittila et al. (2000), and Roul (2004). The speed of recolonization is likely dependent on antecedent vegetation conditions; localized populations of lawn/hollow *Sphagnum* species present in ditches and low lying areas of trenches prior to the disturbance of rewetting would provide multiple loci for dispersal and colonization. In rewetted sectors where the resultant water table position was uneven or well below the surface of the residual peat, vegetation assemblages have bounced back to resemble those present prior to rewetting. In these sectors, it is important to note that vegetation assemblages may progress towards *Sphagnum* dominated species assemblages, as rewetting may have ameliorated surface moisture conditions to within hydrological thresholds for *Sphagnum* colonization (Ketcheson and Price 2011).

Vegetation assemblages in non-rewetted sectors of the study sites have also been significantly changing over the last 17 years, which may be a response to the natural attenuation of site runoff efficiency caused by slumping or vegetation infill of drainage ditches over time (Van Seters and Price 2001). As runoff efficiency decreases, the hydrological conditions within survey trenches may become more amenable to *Sphagnum* colonization (Price et al. 2003).

Overall, the trajectory of vegetation change in rewetted sectors of the study sites indicated that vegetation assemblages are becoming more similar to those found in the natural reference sites, but significant differences remain. Future monitoring and evaluation is required to determine whether rewetted areas will continue on this trajectory Specifically, future monitoring will determine: 1) the speed and extent to which hummock-forming *Sphagnum* species proliferate in areas where moisture conditions have been ameliorated to levels within hydrological thresholds for *Sphagnum* (Price and Whitehead 2001); and 2) whether hummock forming *Sphagnum* species will out-compete lawn/hollow *Sphagnum* species that currently dominate areas of shallow inundation as the thickness of accumulated organic matter (and subsequently depth to water table) increases. Money and Wheeler (1999) noted that although rewetting in old domestic peat workings in Europe was successful in establishing cover of hollow/lawn *Sphagnum* species, most sites had not shown any evidence of transitioning to later successional (hummock forming) species.

It is important to note that time scales of recovery may not necessarily be linear, as the regime shift caused by rewetting may result in positive feedbacks (Hobbs and Suding 2009). As *Sphagnum* species become established within rewetted areas, they themselves create positive feedback by further altering local moisture conditions of the peat surface, assisting in stabilizing the water table by improving storage and reducing evaporative losses (Price and Whitehead 2001). Once established, *Sphagnum* species are able to create and maintain abiotic conditions that preclude the future growth of vascular plants (Van Breemen 1995), thus maintaining dominance in species assemblages.

4.2 Above-ground biomass and accumulated organic matter

4.2.1 Above-ground biomass

Above-ground biomass results mirror the vegetational differences due to rewetting noted in Section 4.1.1. Living tree above-ground biomass was greatly reduced, and although extremely variable, values were equitable to those estimated in undisturbed bogs in other studies. In non-rewetted sectors of the study sites, tree biomass was approximately double that found in various undisturbed bogs (Dyck and Shay 1999; Campbell et al. 2000). Ericaceous shrub biomass was significantly decreased following rewetting, decreasing light competition and allowing inundation-tolerant shrub species such as *Chamaedaphne calyculata* to proliferate. This is the scenario in rewetted trenches of the Rivière-du-Loup study site, as ericaceous biomass has since rebounded 10 years following rewetting; however, values are still similar to those found in undisturbed bogs (Dyck and Shay 1999). Herbaceous and *Sphagnum* biomass have increased in rewetted sectors, likely due to the improvement of hydrological conditions and decreased light competition, more closely resembling values published in other studies of undisturbed bogs.

4.2.2 Accumulated organic matter

Rewetting shifted AOM composition from a predominance of ericaceous litter in non-rewetted sectors to a predominance of fibric peat in rewetted sectors, the depth of which appears to be increasing as a function of time. It was expected that succession profiles would be present within AOM samples collected from rewetted sectors, which would provide a definite marker in the peat profile above which accumulation could be attributed to rewetting. This phenomenon is present following other disturbances, such as in the colonization sequence of pioneer plants above an ash layer following fire (Benscoter et al. 2005). However, a clear and abrupt succession profile was only observed in survey trenches that experienced shallow inundation as a result of rewetting, leading to the rapid vegetation change described above. In survey trench groupings lacking a clear marker from which to measure AOM accumulation since rewetting, fibric peat accumulation rates (Table 3.6) should be interpreted with caution, as fibric peat AOM that may have accumulated in low lying areas prior to rewetting would be indistinguishable from that which has accumulated since rewetting. Nevertheless, antecedent *Sphagnum* abundance as indicated by cover class data (Table 3.4) can provide some insight as to the likelihood of this uncertainty. Fibric peat accumulation is an order of magnitude higher for all rewetted trenches than in non-rewetted trenches, with values approximately equal to those in published literature for undisturbed *Sphagnum* dominated bogs (Dyck and Shay 1999; Campbell et al. 2000). Campbell et al. (2000) report a pooled mean NPP of 449 ± 215 $g \cdot m^{-2} \cdot y^{-1}$ for all *Sphagnum* moss in undisturbed non-permafrost bogs and, more specifically, Grigal et al. (1985) report a pooled mean NPP of 520 $g \cdot m^{-2} \cdot y^{-1}$ for hollow/lawn *Sphagnum* species. Fibric peat accumulation values found in the survey trenches exhibiting a succession profile (564 ± 112 $g \cdot m^{-2} \cdot y^{-1}$) are congruent with these reference values. The rapid accumulation of fibric peat AOM in rewetted areas is a positive indicator towards the formation of a new acrotelm atop the residual peat.

Substantial questions remain as to whether this newly deposited organic layer will provide the hydrological functions perceived of the acrotelm in undisturbed bogs. In a restored vacuum-milled site, Lucchese et al. (2010) estimated that it would take 17 years post-restoration to develop a new organic layer thick enough to offset the water table decrease induced by the summer water deficit (approx. 19 cm thick). Although variable, this depth has already been achieved in one of the block-cut sites that was rewetted 10 years ago (Rivière-du-Loup). Additional hydrological investigation is necessary to determine whether water table fluctuations will be contained within this newly formed organic layer, above the level of the residual peat.

Chapter 5: Conclusions

Rewetting activities within the three study sites has variably, but successfully forced a shift in vegetation assemblages. This shift, typified by a transition from vegetation assemblages dominated by trees and ericaceous shrubs to those dominated by hydrophytic and herbaceous *Sphagnum* species, was apparent when comparing current patterns of vegetation community structure in rewetted and non-rewetted areas. Community scale vegetation structure showed a strong overriding relationship with water table levels throughout the study sites, indicating that rewetting is an effective management tool to influence biotic structure within these systems.

Analysis of vegetation change over time suggests that vegetation assemblages in both rewetted and non-rewetted areas are becoming more similar to those found in undisturbed bogs. Rewetted sectors showed variable response to rewetting, with rapid and drastic change in some areas, and less in others, causing more overall variability in rewetted sectors. The dominant species in rewetted trenches (lawn/hollow *Sphagnum* species) remain significantly different than the natural reference sites (hummock forming *Sphagnum* species) up to 17 years following rewetting. These differences indicate that additional time is required for the “full” recovery of biotic communities to improve to their undisturbed state. Reliance on successional processes to guide biotic recovery of degraded ecosystems requires long periods of time, likely measured in units of decades.

Changes in above-ground biomass indicated that rewetted areas are becoming more structurally similar to undisturbed bogs, with tree and shrub biomass estimates more closely resembling those reported in other studies. Shrub biomass was shown to rebound as time since rewetting increases and species compositions shift to favour hydrophytic species.

Rewetting caused a shift in accumulated organic matter from a predominance of ericaceous litter to a predominance of fibric peat. The rapid accumulation of fibric peat in rewetted areas, as well as its increasing depth as a function of time, are positive indicators towards re-establishment of the acrotelm. More detailed study is required to determine whether this ‘neo-acrotelm’ will begin to provide the hydrological functions perceived of the acrotelm in undisturbed bogs.

Overall, rewetting of abandoned block-cut peatlands has caused significant progress towards achieving the structural goals of peatland restoration as outlined in Rochefort (2000). This study adds to the body of monitoring data available for the study sites, and provides documentation of progress towards the achievement of restoration goals. Continued detailed observation of the biotic recovery of these ecosystems will provide valuable information for future restoration endeavors.

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Appendices

Appendix A Example of tree allometric biomass equations

$$\mathbf{y = aD^b}$$

Where:

y = Total above-ground biomass of tree (kg)

D = diameter of tree (cm)

a, b = derived species-specific parameter estimates from published literature

For a Black spruce (*Picea mariana*) with a diameter of 26 cm:

$y = aD^b$

$y = 0.1444(26^{2.2604})$

$y = 228.02$ kg

Parameter estimates taken from Ker (1984).

Appendix B Complete list of plant species encountered

Species Code	Species	Authority
	Tree	
Abi_bal	*Abies balsamea*	(L.) Mill.
Ace_rub	*Acer rubrum*	L.
Bet_cor	*Betula cordifolia*	Regel
Bet_pap	*Betula papyrifera*	Marsh.
Bet_pop	*Betula populifolia*	Marsh.
Lar_lar	*Larix laricina*	(DuRoi) Koch.
Pic_gla	*Picea glauca*	(Moench) Voss.
Pic_mar	*Picea mariana*	(Miller) Britton
Pic_rub	*Picea rubens*	Sarg.
Pin_ban	*Pinus banksiana*	Lamb.
Pop_tre	*Populus tremuloides*	Michx.
Pru_pen	*Prunus pensylvanica*	L.
Sor_ame	*Sorbus americana*	Marsh.
Thu_occ	*Thuja occidentalis*	L.
	Ericaceous/Shrub	
Ame_bar	*Amelanchier bartramiana*	(Tausch) Roemer.
Aro_mel	*Aronia melanocarpa*	(Michx.) Ell.
Cha_cal	*Chamaedaphne calyculata*	(Linnaeus) Moench
Cor_alt	*Cornus alternifolia*	L.
Cor_can	*Cornus canadensis*	L.
Emp_nig	*Empetrum nigrum*	L.
Gau_his	*Gaultheria hispidula*	(L.) Mühl.
Gay_bac	*Gaylussacia baccata*	(Wang.) K. Koch.
Kal_ang	*Kalmia angustifolia*	L.
Kal_pol	*Kalmia polifolia*	Wang.
Led_gro	*Ledum groenlandicum*	Retzius.
Nem_muc	*Nemopanthus mucronatus*	(L.) Trel.
Rho_can	*Rhododendron canadense*	(Linnaeus) Torrey
Vac_ang	*Vaccinium angustifolium*	Aiton
Vac_myr	*Vaccinium myrtilloides*	Michaux
Vac_oxy	*Vaccinium oxycoccos*	Linnaeus
Vac_vit	*Vaccinium vitis-idaea*	Linnaeus
Vib_cas	*Viburnum cassinoides*	L.
	Herbaceous	
Car_can	*Carex canescens*	L.
Car_oli	*Carex oligosperma*	Michx.
Car_sp.	*Carex* sp.	-
Car_tri	*Carex trisperma*	Dewey.
Cyp_aca	*Cypripedium acaule*	Ait.
Dro_rot	*Drosera rotundifolia*	L.
Epi_pal	*Epilobium palustre*	L.
Eri_ang	*Eriophorum angustifolium*	Honckeny.
Eri_vag	*Eriophorum vaginatum ssp. spissum*	(L.) Fern.
Eri_vir	*Eriophorum virginicum*	L.
Hie_sca	*Hieracium scabrum*	Michx.

Species Code	**Species**	**Authority**
Mat_str	*Matteuccia struthiopteris*	(L.)Todaro
Mel_lin	*Melampyrium lineare*	Desr.
Rhy_alb	*Rhynchospora alba*	(L.) Vahl.
Rub_cha	*Rubus chamaemorus*	L.
Sar_pur	*Sarracenia purpurea*	L.
Sci_atroc	*Scirpus atrocinctus*	Fernald.
Sol_gra	*Solidago graminifolia*	(L.) Salisb.
Tri_bor	*Trientalis borealis*	Raf.
	Sphagnum	
Sph_ang	*Sphagnum angustifolium*	(C. Jens. *ex* Russ.) C. Jens.
Sph_cap	*Sphagnum capillifolium*	(Ehrh.) Hedw.
Sph_cus	*Sphagnum cuspidatum*	Ehrh. *ex* Hoffm.
Sph_fal	*Sphagnum fallax*	(Klinggr.) Klinggr.
Sph_fim	*Sphagnum fimbriatum*	Wils.
Sph_fus	*Sphagnum fuscum*	(Schimper) H. Klinggraff
Sph_lin	*Sphagnum lindbergii*	Schimp.
Sph_mag	*Sphagnum magellanicum*	Brid.
Sph_maj	*Sphagnum majus*	(Russ.) C. Jens.
Sph_pap	*Sphagnum papillosum*	Lindb.
Sph_pul	*Sphagnum pulchrum*	(Lindb. *ex* Braithw.) Warnst.
Sph_rip	*Sphagnum riparium*	Angstr.
Sph_rub	*Sphagnum rubellum*	Wilson
Sph_rus	*Sphagnum russowii*	Warnst.
Sph_squ	*Sphagnum squarrosum*	Crome.
	Other Mosses/ Hepatics	
Aul_pal	*Aulacomnium palustre*	(Hedw.) Schwaegr.
Dic_pol	*Dicranum polysetum*	Sw.
Dic_und	*Dicranum undulatum*	Brid.
Gym_inf	*Gymnocolea inflata*	(Huds.) Dum.
Hep_sp.	*Hepatic* sp.	-
Myl_ano	*Mylia anomala*	(Hook.) S. Gray.
Ple_sch	*Pleurozium schreberi*	(Brid.) Mitt.
Poh_nut	*Pohlia nutans*	(Hedw.) Lindb.
Pol_com	*Polytrichum commune ssp. commune*	Hedw.
Pol_str	*Polytrichum strictum*	Bridel
Pti_cil	*Ptilidium ciliare*	(L.) Hampe
Pti_cri-cas	*Ptilium crista-castrensis*	(Hedw.) De Not.
War_exa	*Warnstorfia exannulata ssp. exannulata*	(Schimp.) Loeske.
	Lichen	
Cla_mit	*Cladonia mitis*	(Sandst.) Hustich
Cla_ran	*Cladonia rangiferina*	(L.) Nyl.
Cla_sp.	*Cladonia* sp.	-
Cla_ste	*Cladonia stellaris*	(Opiz) Brodo
Lich_sp.	*Lichen* sp.	-
	Non-vegetated	
B_peat	Bare Peat	-
Lit	Litter	-
Open_Water	Open water	-

Appendix C Photos of selected accumulated organic matter sample blocks

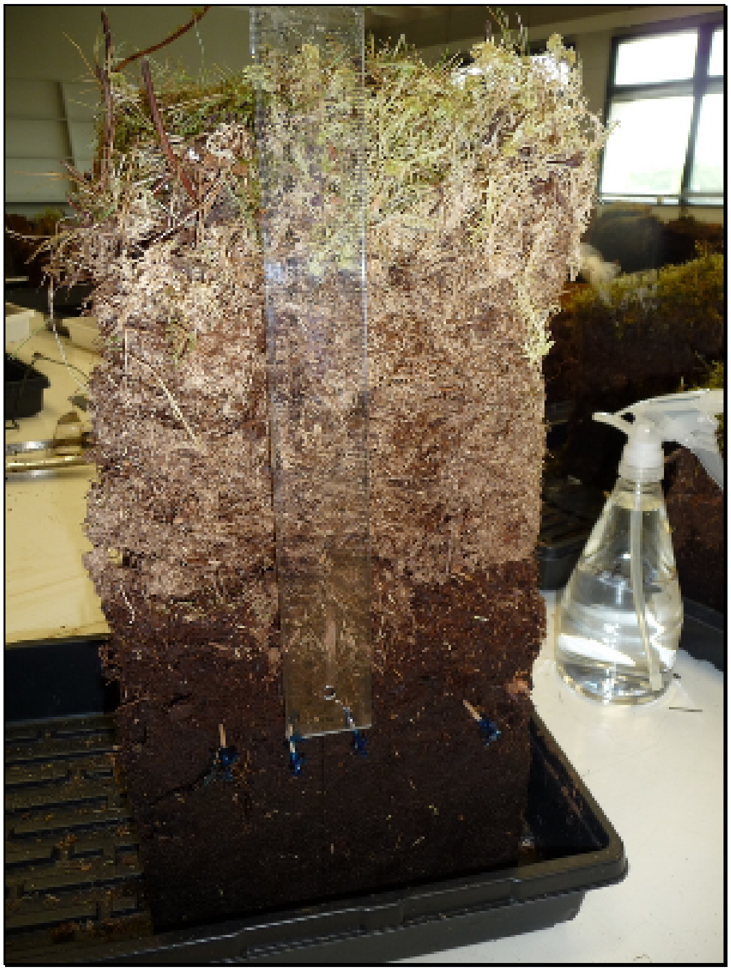

Figure C.1 Accumulated organic matter sample (UPGMA Cluster 6; 10 years rewetted) displaying thick accumulation of fibric peat atop the residual peat

Figure C.2 **Accumulated organic matter sample (UPGMA Cluster 6; 10 years rewetted) displaying a clear succession profile of ericaceous shrub litter overlain by fibric peat as a result of rewetting.**

Figure C.3 Accumulated organic mater sample from a non-rewetted trench (UPGMA Cluster 2) displaying LFH-like layer resulting from litter accumulation