AN EVALUATION OF RESTORATION TECHNIQUES FOR A SMALL SCALE ALL-TERRAIN-VEHICLE DISTURBANCE IN THE LAKE CHARLOTTE PEATLAND

by

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The undersigned hereby certify that they have read and recommend to Faculty of Graduate Studies for acceptance a thesis entitled “AN EVALUATION OF RESTORATION TECHNIQUES FOR A SMALL ALL-TERRAIN-VEHICLE DISTURBANCE IN THE LAKE CHARLOTTE PEATLAND” by Rebecca Jane Allan Mason in partial fulfillment of the requirements for the degree of Master of Applied Science.

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Abstract

A peatland near Lake Charlotte, Nova Scotia that had been damaged by all-terrain vehicles (ATVs) was identified as a compensatory mitigation site. Restoration practices commonly used for harvested peatlands were applied to small sections of ATV damaged peatland.

In the test plots, treatments of moss and shrub transplantation, fertilizer application, and straw mulch addition were applied in various combinations to determine the optimum restoration approach for specific areas within the Lake Charlotte peatland complex. The overall objective of this research was to recommend a procedure for the complete restoration of the damaged portions of the peatland. A number of different hydrological, physio-chemical and biological parameters were monitored throughout the 2009 growing season to evaluate the effectiveness of the different treatments.

In conclusion, this study demonstrated that techniques developed to restore peatlands degraded by peat extraction activities are also effective for restoring peatlands impacted by ATV use.

List of Abbreviations and Symbols Used

Al	Aluminum
ATV	All Terrain Vehicle
C	Carbon
^{o} C	Degrees Celsius
Ca	Calcium
CDN	Canadian Dollars
CH_4	Methane
cm	centimeters
Cu	Copper
Fe	Iron
FPWC	Federal Policy for Wetland Conservation
g	grams
H_2O	water
ha	hectare
IMHO	An ecosite identified by the NS DNR that is characterized as imperfectly drained, medium textured soils on hummocky terrain
IMDSM	An ecosite identified by the NS DNR that is characterized as imperfectly drained, medium textured soils on smooth or flat terrain
K_2O	Potassium oxide
kg	kilogram
Mg	Magnesium

m	meters
m^2	square meters
Max.	Maximim
Min.	Minimum
mL	milliliters
mm	milimeters
Mn	Manganese
N_2O	Nitrous Oxide
Na	Sodium
No.	Number
P_2O_5	Phosphorus pentoxide
P	Phosphorus
PVC	Polyvinyl chloride
Redox	Reduction-oxidation reaction
St. Dev.	Standard Deviation
US	United States
USA	United States of America
yr	year
Zn	Zinc

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Chapter 1: Introduction

Peatlands are unique, dynamic ecosystems that cover a significant part of Canada. Until recently, wetlands, and specifically peatlands, were thought of as wasteland and were often filled, cut over or converted to agricultural or forestry lands. It takes millions of years to accumulate several meters of peat. Disturbances to peatlands can have significant impacts, and reduce the peat accumulating capability of the system. Where large disturbances have occurred in peatlands, such as peat mining activities, the once self-sustaining diverse ecosystems are essentially bare wastelands for decades after mining has ceased (Quinty and Rochefort, 2003). It is now recognized that peatlands have significant ecological, economic and societal benefits. This has led to the implementation of policies to preserve peatland ecosystems.

‘No net loss’ of wetland policies aim to maintain the total area, and ecological functioning, of wetlands at current levels. These policies typically prescribe a mitigation sequence to accomplish this goal. The first step in this sequence is to avoid wetland disturbance altogether. When avoidance is not possible, emphasis is placed on minimizing effects, and another wetland is often created or restored to replace the impacted wetland. The implication of these kinds of wetland policies is that there have been more opportunities to restore disturbed peatlands in recent years. Considerable research has been conducted to identify the most effective way to restore peatlands that have been mined for peat (Farrick and Price, 2009; Quinty and Rochefort, 2003;

Campbell et al., 2002; Bugnon et al., 1997; Ferland and Rochefort, 1997), but very little work has been conducted to determine the best approaches for restoring peatlands that have been subjected to other types of disturbance.

In this research, a peatland near Lake Charlotte, Nova Scotia, that had been damaged by all-terrain vehicles (ATVs), was identified as a compensatory mitigation site. The Nova Scotia Department of Environment permitted a wetland alteration with the condition that the damaged peatland area be restored. Currently, there are no published methods for restoring small-scale disturbances to peatlands. In this study, restoration practices commonly used for harvested peatlands were applied to small sections of the ATV damaged areas of the Lake Charlotte peatland complex. A series of test plots were established in three different ecosites (identified as strata) within the peatland complex. Several different combinations of restoration treatments were evaluated, in order to identify an optimum restoration sequence for the area. It was intended that this research would also provide guidance for restoration of other peatlands with similar disturbances, and help prevent their net loss.

Chapter 2: Literature Review

2.1 PEATLAND ECOLOGY

A peatland is a wetland that is typically flooded for all or part of the growing season, and accumulates and stores peat. Peat forms as a result of plant growth rates exceeding decomposition rates (Crum, 1992). While herbaceous, woody, and grassy plants can all contribute to peat formation, moss is the major constituent of peat, particularly *Sphagnum* (Charman, 2002; Halsey et al., 2000). The unique biotic and hydrological characteristics of peatlands allow them to provide a variety of ecosystem services. Traditionally, these ecosystem services were not appreciated, and many peatlands were drained or excavated for fuel, horticulture, or agricultural uses. It has recently been found that peatlands can sequester large amounts of CO_2 (Tuittila et al., 1999), provide for groundwater recharge and storm water retention, and provide valuable habitat for a wide range of organisms specifically adapted to peatland environments (Mitsch and Gosselink, 2007).

2.1.1 Effects of landscape processes

Landscape processes generally refer to how large-scale environmental features, such as watersheds, impact the way environmental components (water, sediment, nutrients, organisms etc.) interact (Granger et al., 2005). Peatlands form in response to these landscape processes, and can also influence adjacent landscapes as they develop (Quinty and Rochefort, 2003).

Topography and hydrology strongly influence the locations of peat-forming systems. Usually, peat begins to accumulate in poorly drained, low-lying areas (Evans and Warburton, 2008). In very humid areas such as Atlantic Canada, peat can form on slopes of up to 20^{o}, but in drier climates peatlands usually only form in basins or valleys (Clymo, 1980). Graniero and Price (1999) determined that sub-surface topography is also an important factor in explaining peatland distribution patterns. The amount and rate of runoff, relative to infiltration, are directly dependent on underlying geology, which can influence the presence of wetlands (Winter, 2000). Another natural peat-forming process occurs around bogs, where overtime the landscape becomes overgrown with a sphagnum-based vegetation mat that begins to accumulate. Peat can also develop in areas that are saturated by glacial melt and retreat, or in river deltas (Crum, 1992).

There are two main types of peatlands; these are fens and bogs. Fens receive water from both precipitation and runoff. The latter water source contains minerals that have been absorbed through surface runoff, and as such, fens are also called minerotrophic peatlands (Quinty and Rochefort, 2003). As fens accumulate peat, they can evolve into a bog, which is raised above the surface or groundwater level, and thus only receive water through precipitation. In bog environments, conditions become acidic and *Sphagnum* moss communities replace the sedge vegetation found in fens (Quinty and Rochefort, 2003).

Peatlands are found on almost every continent, with Canada and Russia possessing about a third of the world's peatlands. (Figure 2.1.1) (Rydin et al., 2006). Boreal and sub-artic regions of North America are almost entirely covered by peatlands (Crum, 1992). Quinty and Rochefort (2003) reported that 11% of Canada is covered by peatland, comprising about 127 million hectares (Natural Resources Canada, 2009) as shown in Figure 2.1.2.

Figure 2.1.1 Peatland area per country (Rydin et al., 2006).

Figure 2.1.2 Map showing total hectares of peatland in each Canadian Province (Poulin et al., 2004)

2.1.2 Hydrology

Hydrology is the main factor that regulates peat accumulation. Peat accumulates due to saturated conditions at or near the ground surface, resulting in greater rates of growth than decomposition (Lapen et al., 2000). Groundwater hydrology has a large impact on the potential for near-surface saturation, as well as soil redox conditions, biogeochemical processes and vegetation patterns (Price et al., 2005; Lapen et al., 2000). In low topography boreal peatlands, as found on the eastern edge of North America, groundwater flow is localized, resulting in predicable interactions between wetlands and groundwater (Price et al., 2005). In these peatlands, internal water flow, both lateral and vertical, plays a large role in sustaining soil moisture, which is vital to *Sphagnum* (Quinty and Rochefort, 2003; Hemond, 1980).

WATER TABLE FLUX

The location of the water table is responsible for the creation of two distinct soil layers within peatlands; the catotelm and the acrotelm (Figure 2.1.3). The catotelm is the bottom layer of peat that is permanently below the water table (Quinty and Rochefort, 2003). Anaerobic activity creates the fully decomposed, hummified, and compacted catotelm material, and water movement is very slow in this layer. The top layer, called the acrotelm, is composed of living mosses and partially decomposed plant material. In this layer levels of saturation fluctuate, creating both anaerobic and aerobic environments. Due to the structure of the moss in the acrotelm, a large amount of water can be stored and move laterally in the top layer of peat (Baird et al., 2004). Rydin and McDonald (1985) found that *Sphagnum* carpets are able to retain large amounts of water well above the actual water table. In peatlands, the *Sphagnum* cover is the main factor controlling physical conditions, especially the water table level in the ecosystem. *Sphagnum* decomposition produces peat, which in turn alters the chemistry and pathways of water flow in the system (Crum, 1992).

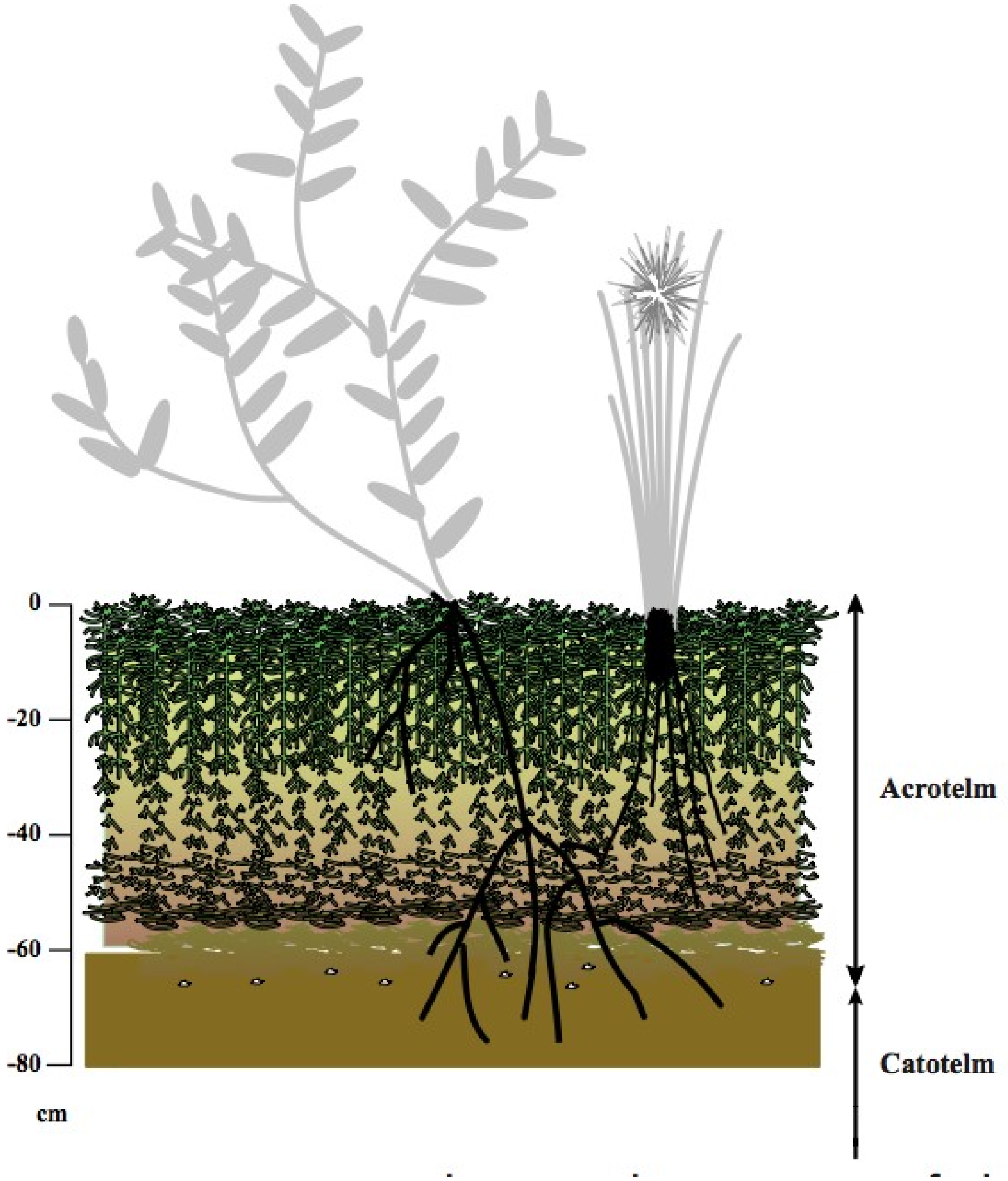

Figure 2.1.3 Layers of peat consisting of acrotelm (partially decomposed and living matter) and the catotelm (fully decomposed, hummified organic matter) (Quinty and Rochefort, 2003).

2.1.3 Soil conditions and chemistry

The chemistry of peatland soil is largely determined by hydrologic conditions, the plant material present, plant growth, animal communities and available inorganic solutes (Clymo, 1980). The hydrologic conditions create anaerobic and aerobic conditions. As the peatland develops, nutrients are depleted and the acidic flooded soils are only inhabitable by species adapted to the conditions. Therefore, peatlands are often dominated by *Sphagnum,* as well as low shrubs that are able to maintain leaves and roots above saturated soils (Crum, 1992).

Soil conditions can be used to help distinguish between peatland types, as vegetation patterns are typically related to soil chemistry. For example, a rich fen (pH ranges between 4 and 7.5) is present if the soil is rich in minerals and is vegetated by grassy plants (Crum, 1992). The soil in bogs are usually depleted of minerals and is acidic (pH ranging between 3.4 and 5.0), favouring *Sphagnum* carpets which are adapted to the nutrient poor conditions and have the ability to thrive in acidic environments (Rydin and Jeglum, 2006). *Sphagnum* mosses also contribute to soil acidity, due to their high cation exchange capacity. *Sphagnum* is very efficient at taking up nutrients such as calcium and magnesium, releasing hydrogen ions in the process (Clymo, 1983). Additionally, acidic conditions are created as the moss decays and releases organic acids (Hemond, 1980). The decomposition of peat has other effects on soil properties. Wider (1985) noted that as peat decomposes, bulk density and organic matter contents both decrease. Wind-

Mulder et al. (1996) suggest that changes in ion concentration due to peat decomposition may be the reason that magnesium (Mg) and calcium (Ca) decrease at lower depths within peat deposits. This effect may also be due to the treated mg and Ca after reduction due to no oxygen (O_2). The biological activity carried out by *Sphagnum* on the surface of peat also results in greater concentrations of potassium (K) and phosphorus (P) in the surface layer, which decreases with depth (Wider, 1985).

While *Sphagnum* is responsible for many of the physical and chemical properties of peat, peat characteristics can also change over time due to human disturbances. Electrical conductivity and pH are usually higher in areas where peat has been harvested, due to the fact that both electrical conductivity and pH increase as depth increases (Wind-Mulder et al., 1996). Wind-Mulder et al. (1996) also suggests leaching of reduced Ca and Mg from upper to lower layers. Peatlands are also efficient in helping to moderate anthropogenic pollution such as acid rain and excess nutrients. One study that examined the effects of acid rain on peatlands noted the ability of a North Eastern bog to counteract the effects of acid precipitation through sulfate reduction and nitrate uptake (Hermend, 1980). Other researchers have found that *Sphagnum* can retain excess nutrients, burying them in decomposed matter, thus controlling nutrient pathways (Li and Vitt, 1997). While peatlands are known for their unique ecological functions, they are also susceptible to change due to natural and anthropogenic factors.

2.1.4 Ecohydrology and Adaptations: Vegetation

Sphagnum mosses are bryophytes that are in a genus of their own and are well adapted to the harsh conditions often found in peatlands. There are many species of *Sphagnum* which are adapted to different physical-chemical conditions (Clymo, 1970; Hayward and Clymo, 1982). The structure of these plants, as shown in Figure 2.1.4, helps them to survive within semi-aquatic conditions that are prone to dessication. The growth of *Sphagnum* occurs at the apical bud in the capitulum head (Figure 2.1.4). The branches that hang off of the stem create a capillary action drawing moisture up to the capitulum (Hayward and Clymo, 1982). A *Sphagnum* carpet forms hummocks and hollows - areas of higher and lower microtopography. Hummocks and hollow environments provide for a cycle of regeneration within peatlands. Hollows are wetter and exhibit a faster rate of growth, and eventually evolve into hummocks. Hummocks eventually turn into hollows due to increased degradation of water stressed *Sphagnum* (Crum, 1988). *Sphagnum* carpets are very effective at storing water above the actual water table level, as the numerous branches allow for lateral flow of water (Clymo and Hayward, 1982). Even though hummocks may form well above the water table, the *Sphagnum* form such a tight and dense cover that the area exposed for evaporation is minimized (Rydin et al., 2006). Additionally, the capillarity, or flow of water, in hummocks is increased (Crum, 1988) providing water circulation throughout the hummock.

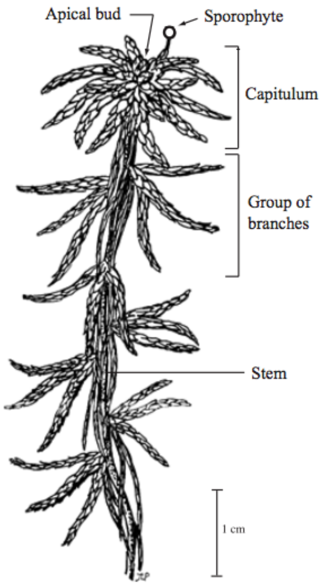

Figure 2.1.4 Sketch of *Sphagnum* (Quinty and Rochefort, 2003)

2.1.5 Peat accumulation

Peat consists primarily of partially hummified *Sphagnum,* which is composed of almost 99% organic matter (Clymo, 1980). While *Sphagnum* mosses can grow up to two centimeters a year, peat accumulation rates are only about 0.5 to 1 mm per year, due to slow rates of decomposition and compaction (Quinty and Rochefort, 2003). The top acrotelm layer is usually 30 to 50 cm deep while the catotelm can be up to 15 m deep, as a result of thousands of years of accumulation. For peat to accumulate, a series of decomposition steps must occur. First, the plant matter (usually *Sphagnum*) begins to breakdown. Leaching and microbial decomposition are the main contributing factors to this initial phase of decomposition. Next, the physical structure begins to deteriorate, which is then followed by a change in chemical state (Clymo, 1980).

2.2 PEATLAND VALUES

Peatlands provide myriad functions that are important to humans. Detailed accounts of functions and values provided by wetlands have been described by Mitsch and Gosselink (2007), however a brief overview specific to peatlands is provided below.

2.2.1 Biological and biochemical functions

Worldwide, peatlands are relatively rare, and many of the functions they provide are unique. Charman (2002) noted that the pristine state of many peatland ecosystems, and their sensitivity to disturbances, contributes to their biological significance. While even large peatlands are not highly diverse because of their unique habitat, many organisms have specifically evolved to live in these habitats. A number of plant species are only found in peatlands, or are largely dependent upon other organisms found in peatlands. These include many *Sphagnum* species, as well as some of the carnivorous plants such as *Drosera* rotundifolia and *Saracenia* purpurea (Charman, 2002).

In addition to being the primary source of peat production, *Sphagnum* also provides approximately half of the carbon accumulation in peatlands (Rydin and Jeglum, 2006). Peatlands act as carbon sinks by accumulating carbon in plant debris however, they also emit greenhouse gases, mostly in the form of CH_4 and CO_2. The balance between carbon accumulation and release is strongly influenced by human disturbance. An undisturbed fen in Finland had a net C accumulation rate of 68 g $m^{-2}yr^{-1}$ (Rydin and Jeglum, 2006). When peatlands are drained or harvested, there is typically a net release of CO_2 (Quinty and Rochefort, 2003). However, the effects of peatland drainage on net greenhouse gas emissions is quite complex. Rydin and Jeglum (2006) noted that when water levels drop within a peatland, CO_2 emissions increase, but CH_4 emissions decrease. This is due to the fact that in areas where there is more aeration, increased aerobic respiration leads to increased oxidation of CH_4 to CO_2.

2.2.2 Economic functions

The monetary value of losing one hectare of wetland in 1998 was estimated to be USD $3,650 (Wilson et al., 2001). This number is based on the average annual value of wetland services such as flood and stormwater control, water filtration, shoreline protection, and groundwater recharge. In Nova Scotia, the loss of wetlands has been estimated to cost 2.3 billion dollars a year, due to a loss of ecosystem services (Wilson, 2000). While peatlands provide a variety of ecosystem services, the most obvious economic value of peatlands is the peat itself, which can be mined for fuel, horticulture, or for the treatment of industrial and municipal wastewaters (Charman, 2002; Rock et al., 1984). In 1999, 10 million cubic metres of peat were harvested in Canada, valued at approximately $170 million dollars. This activity also provided thousands of jobs (Daigle and Gautreau-Daigle, 2001). The harvesting of peatlands has continued to increase

(Statistics Canada, 2008). Many peatlands are still being converted to agricultural land, or commercial forest by planting non-native trees.

2.2.3 Physical and hydrological functions

Peatlands retain a vast quantity of water. This storage mechanism helps to attenuate stormwater runoff in watersheds where peatlands are important landscape features. Peatlands also modify and improve water quality. The disturbance or removal of peatland environments can alter these important functions (Charman, 2002).

2.2.4 Societal functions

Charman (2002) highlighted the increasing importance of peatland societal functions in areas where peatlands are under threat due to population growth. Peatlands offer areas for recreational activities such as berry picking, bird watching, and hunting, and can provide educational and research opportunities. Peatlands can also serve as paleo-archives, preserving seeds and microorganisms that can be used to identify past climate and environmental conditions (Quinty and Rochefort, 2003).

2.3 HUMAN IMPACTS AND EFFECTS

Most peatlands are part of the boreal forest biome, and are influenced by natural disturbances such as forest fires and floods. Many peatlands are also now facing various levels of anthropogenic disturbance. Turetsky and St. Louis (2006) outline five main human disturbances impacting plant structure, hydrology, and biogeochemical cycling in boreal peatlands. These are grazing, biomass burning, flooding, draining for peat mining or agricultural use, and pollution.

Wildlife grazing usually has little impact on the functioning of boreal peatlands, however, recent overuse of peatlands for domestic animal grazing has caused erosion and ecological damage (Evans, 1997). Some land managers have found that occasional burning of peatlands improves biodiversity and increases grazing value, but this is typically a short-term effect (Hobs, 1984) and not necessarily beneficial for bogs which are characterized as having low diversity with healthy. Burning can also have a negative effect on carbon storage. Many peatlands have been flooded to create reservoirs and hydroelectric dams. Poulin et al. (2004) report that an estimated 900,000 ha of peatlands have been lost due to flooding for hydroelectric dams, mostly in Quebec, Manitoba and Alberta. Peatland flooding can cause immense greenhouse gas emissions due to decomposition of organic matter stored in peat, and removal of plants which serve as possible carbon sinks (Kelly et al., 1997).

The drainage of peatlands is probably the most significant anthropogenic impact. A drained peatland is often used for agricultural or forestry purposes, or the peat material is extracted and used for fuel or horticulture. Draining a peatland results in accelerated decomposition, increased CO_2 and N_2O emissions, and loss of biodiversity. As peat is extracted, the ecosystem changes even more, losing its ability to retain water and thereby greatly reducing the chances of natural vegetation reestablishment (Rochefort et al., 2003; Johnson et al., 2000). Additionally, climate change has a huge anthropogenic impact on peatlands, especially in the north where increased temperatures are causing loss of permafrost and releasing huge amounts of methane (CH_4). A positive feedback loop is created thereby increasing greenhouse effect even more.

In Atlantic Canada, peatlands are most often mined for peat. Peat extraction primarily impacts the vegetation and hydrology of the wetland ecosystem. Recolonization of harvested peatlands is generally limited because seed sources are usually too far away, and the mined peat fields are not conducive to seed germination (Quinty and Rochefort, 2003). Other barriers to vegetation re-establishment are: (i) greater variability in water levels, (ii) alteration of peat physical properties due to compaction, and (iii) alteration of water storage characteristics (Quinty and Rochefort, 2003).

2.4 CONSERVATION MANAGEMENT AND RESTORATION

In 1987, the Federal-Provincial Committee on Land Use identified wetland management as a significant issue in terms of land management policy (Government of Canada, 1991). However, wetlands continue to be lost and degraded through human activities in spite of the adoption of “no net loss” policies at local, state/provincial and federal levels (Granger et al., 2005). Wetland losses are often the result of a combination of anthropogenic impacts, occurring both within, as direct effect, and outside, indirect effects on the hydrology, of individual wetlands (Sheldon et al. 2005). It is also important to realize that the cumulative loss of wetlands over time can have impacts at a landscape scale.

2.4.1 North American Protection

Canada was the first country to develop a wetland conservation policy (Poulin et al., 2004). However, within both Canada and the United States, state or provincial governments actually establish and enforce laws that pertain to wetland management (Poulin et al., 2004). The Canadian Government is only responsible for wetlands occurring on federal lands (Table 1), which accounts for only 29% of all wetlands in Canada (Rubec and Hanson, 2009). Many states have produced policies related to wetland conservation, and several Canadian provinces (e.g. New Brunswick, PEI, Saskatchewan.) have wetland policies or are in the process of developing them (e.g. Nova Scotia, Alberta, British Columbia).

2.4.2 Government of Canada

The Federal Policy on Wetland Conservation, established in 1991, aims to effectively conserve wetlands in Canada in order to sustain both their ecological and socio-economic functions (Government of Canada, 1991). There are seven main strategies to help achieve the "no net loss" goals outlined in the Federal Policy on Wetland Conservation, which are outlined in the *Implementation Guide for Federal land Managers* (Rubec and Hanson, 2009). These strategies include supporting decisions with scientific research, making management on federal lands exemplary, rehabilitating wetlands, and working with local governments and community groups to promote wetland conservation. Above all, the main goal in the Canadian policy is "no net loss" of wetlands. The US Army Corps of Engineers and the USEPA endorsed the "no net loss" concept in the early 1990's and it is at this time that the three step hierarchical process of avoidance, minimization, and compensation was developed (Bendor, 2009).

2.4.3 Nova Scotia

Wetlands in Nova Scotia are managed by the provincial Department of Environment. In 2004, the Department of Natural Resources conducted a detailed inventory of Nova Scotia's wetlands. They documented 360,462 hectares of wetland, which comprises 6.6% of the total land area in Nova Scotia; three quarters of these wetlands are considered peatlands (NSE, 2009). Currently, the *Operational Bulletin Respecting Alteration of Wetlands* is the primary document used to guide the wetland alteration approval process. However, a new policy (*Nova Scotia Wetland Conservation Policy*) and implementation guide (*A Proponent's Guide to Nova Scotia Wetland Conservation Policy)* are likely to

Table 1 Examples of some wetland conservation policies and driving legislation in Canada and the U.S. ([a]Adapted from Rubec and Hanson, 2009 and [b]EPA, 2010)

Jurisdiction	**Primary wetland conservation policies**	**Policy objective**	**Responsible authority**	**Application**
Government of Canada[a]	(1) Environment Act-Federal Policy on Wetland Conservation	(1) Sustain wetland functions in delivery of government programs	(1) All Departments, Environment Canada has oversight role	(1) Federal: lands, decisions, funding
	(2) Fisheries Act and the Policy for Management of Fish Habitat	(2) Protection of habitats directly or indirectly supporting existing or potential fisheries	(2) Department of Fisheries and Oceans	(2) All waters
Nova Scotia[a]	Environment Act and Regulations	To prohibit alteration of wetlands, except by permit	Nova Scotia Environment and Labour	All freshwater wetlands and salt marshes (except federal)
USA[b]	Clean Water Act (section 404)	To regulate the discharge of dredged or fill material into U.S. waters	Army Corps and Environmental Protection Agency	All navigable waters (including wetlands)

be approved during summer, 2010 and will serve as the province's main tools for preventing the net loss of wetlands (NSE b, 2009). Under the new approach, NSE approval must be obtained for any wetland alteration that cannot be avoided, unless it qualifies under one of the exceptions (e.g., federal lands, wetlands that develop in transportation ditches, wetlands < 100 m^2). If the alteration area is less than 2 hectares then an alteration approval under the Activities Designation Regulations is required. If the alteration will disrupt an area greater than 2 hectares, either directly or indirectly, then an environmental assessment must take place, as required under the Environmental Assessment Regulations (NSE b, 2009).

2.4.4 Mitigative sequence

AVOIDANCE

The most effective way to prevent the loss of valuable wetland habitat is to avoid any activity that may impact a wetland. While avoidance is not a feasible option for every development, some planned alterations can be changed to effectively avoid impacting wetland ecosystems. Apart from the ecological benefits for conserving wetland, in many cases, it may be more economically beneficial to keep the functioning wetland in place. For example, wetlands provide important areas for groundwater recharge and water retention during storms. When these wetlands are destroyed new structures may be required to manage stormwater. Additionally, land, homes, and businesses near natural resources are usually worth more.

MINIMIZATION

As explained in the *Proponents Guide to the Nova Scotia Wetland Compensation Policy* (NSE b, 2009), minimization of unavoidable impacts occurs at all stages of the project, from planning to project completion. Some acceptable practices for minimizing effects on wetlands include the use of buffers and erosion fences, as well as prohibiting the use of certain chemicals or vehicles near the wetland.

COMPENSATION

Compensatory mitigation can be a useful tool in helping governments achieve their goals of "no net loss" (EPA, 2008). However, this option is only considered after all other measures have been taken to avoid and minimize negative effects to wetlands and other aquatic ecosystems (EPA, 2008). Compensation can be a deterrent to activities that would impact wetlands, and helps ensure that avoidance and minimization steps are actually taken (Ruben and Hanson, 2009). Compensation is used to offset losses of wetlands, and as outlined by the EPA (2008), there are three ways to provide compensatory mitigation: (i) permittee-responsible compensatory mitigation, (ii) mitigation banks, and (iii) in-lieu fee mitigation. While only the permittee-responsible form is currently used in Nova Scotia, the other forms of mitigation will be included in the new Nova Scotia policy.

Mitigation that is permittee-responsible is the most traditional, and represents the most compensatory area each year in the United States (EPA, 2008). In this case, the permittee takes on sole responsibility of compensation projects, which can occur either on-site, or in another location within the same watershed. In the U.S., this type of mitigation usually occurs simultaneously with the disturbance (Bendor, 2009). The other two forms of compensation are usually conducted off-site by a third party, where activities can include restoration, enhancement, establishment, and preservation (EPA, 2008). With mitigation banking, the compensation project is completed and then a third party can sell the credits to parties who need to meet mitigation requirements. In-lieu fee programs allow for the developing party to pay money to a public agency or nonprofit organization in order to satisfy their compensation requirement. Most often, payments are collected from several parties before the organization responsible for the mitigation has enough money to begin the project (Bendor, 2009).

Theoretically, compensatory mitigation should occur before, or at the same time as, the wetland impact. This does not always happen and temporary wetland losses can turn into net loss of area and function (Bendor, 2009). Bendor (2009) also argues that commonly applied area compensation ratios are too small and may not effectively compensate for loss of ecosystem services. Additionally, the slow rates of ecosystem re-establishment can result in temporary or permanent net wetland losses and associated economic and ecological functions (Bender, 2009).

MONITORING

Monitoring is an integral part of a wetland protection and management strategy. Governing agencies may require that monitoring take place at three geographic scales: (i) contributing landscape or regional level, (ii) management area or local level, and (iii) the site or exact location (Armstrong, 2007; Granger et al., 2005). NSE (2009) requires that a monitoring plan be provided for all alterations. In addition to baseline monitoring, followup monitoring to assess wetland function is typically required for 3 to 5 or more years.

Baseline monitoring provides an assessment of the existing condition or function of a wetland. Some aspects that are often considered in baseline monitoring are landscape variability, vegetation changes due to seasonal variation or succession, hydrology, and soil qualities. Hydrology and seasonality can affect changes in vegetation patterns, which can be assessed with baseline monitoring (Swiatek and Kubrak, 2007).

It is also important to consider the scale of the area with respect to the type of monitoring used. For example Navratil and Navratilova (2007) used both vegetation maps, which are based on field sampling of vegetation patterns, as well as GIS mapping where vegetation is mapped using remote sensing, to study vegetation changes in a wetland. The authors concluded that while both results captured the successional change towards denser vegetation types, a GIS-based approach was the most useful because it cost less and gave an easier way to identify trends. Monitoring can also be used to compare restored or created wetlands to natural ones, in order to determine if the planned functionality has been restored. Gutrich et al. (2009) monitored two created wetlands for a period of 10 and 20 years. The reported that floristic indicators, such as species diversity, percent cover, and native species, at created and natural sites, were similar in the short term (< 5 years), but the abundance of native species and percent cover were lower in the long-term at the created site. By monitoring over a long period, they were also able to determine how initial restoration efforts impacted restoration success, which helped to predict when sites would reach floristic equivalency to natural wetlands of the same type. Wetlands that were restored were characterized by significantly greater species of native plants and took only 14 years to reach a natural state, while wetlands that were created where none previously occurred took 24 years to resemble a normal functioning wetland (Gutrich et al., 2009).

2.5 RESTORATION

Restoration techniques for peatlands have only recently been developed. Peatland restoration began in Europe, mainly in Germany and the Netherlands, where extensive peatland mining degraded natural peatlands (Money and Wheeler, 1999). In North America, peatland restoration techniques have built upon European methods. The European methods focused almost entirely on hydrological restoration. The North American approaches have different goals for restoration, which include hydrological restoration, and active peat restoration (Rochefort et al., 2003). In North America, primary restoration approaches are aimed at establishing a *Sphagnum* carpet, with the ultimate goal of restoring a natural peat accumulating system (Rochefort et al., 2003). Derochers et al. (1998) observed that peatlands mined using vacuum extraction technology did not revert to functional peatlands without active restoration efforts, even after more than 20 years. Numerous studies have revealed the importance of active management in restoring biodiversity and peat accumulation capacity in harvested systems (Quinty and Rochefort, 2003; Rochefort et al., 2003; Derochers, 1998). Quinty and Rochefort (2003) developed the *Peatland Restoration Guide,* based on many years of experimental restoration studies on harvested peatlands in Quebec. The restoration principals they developed are the most widely accepted for North American peatlands, and especially for those in Atlantic Canada. The following points outline the techniques described in the manual, with supporting evidence from other studies.

2.5.1 Site preparation

The major goal of site preparation is to restore hydrologic conditions so that diaspores and plant fragments can survive. Peat extraction causes a lower and more variable water table, and the remaining peat is compressed and contains no viable seed sources for regeneration. Site preparation involves rewetting of the surface by blocking drainage ditches, and if necessary, creating berms to maintain proper wetness and raise the water table. Another aspect of site preparation involves creating a level surface, since water distribution is greatly influenced by topography. Leveling the soil in the site helps to restore infiltration abilities, and the flow of water laterally through the soil. Leveling also eliminates microtopography, or small variations in soil surface caused by tire tracks or surface flow erosion. Successful *Sphagnum* regeneration and restoration is directly related to water table level (Bugnon et al., 1997) and it appears that the best time for restoration is in the spring or summer (Ferland and Rochefort, 1997).

2.5.2 Moss collection and transplantation

As the most important objective in peatland restoration is the establishment of *Sphagnum* species, plant collection and transplantation must be focused on these species. A collection site must be identified which has the desirable species. Certain types of *Sphagnum* are better suited to transplantation, such as hummock forming S. *fuscum* and S. *rubellum* as they are suited for microhabitats present in any small depressions or ridges (Ferland and Rochefort, 1997). *Sphagnum* are collected from within 10 cm of the surface, as this typically results in the best regeneration (Rochefort et al., 2003). Quinty and Rochefort (2003) found that collecting plant fragments with a ratio of area collected to restored area of 1:10 was crucial. This helped to minimize disturbance to the collection site, thereby maintaining biodiversity and sustaining ecosystem function. In large-scale peatland restoration, both plant fragments (rhizomes, and roots) and sphagnum are collected and spread simultaneously using a mulch spreader. Other studies have separately transplanted ericaceous shrub species, and then applied layers of moss (Ferland and Rochefort, 1997).

2.5.3 Ericaceous shrub selection and transplantation

Ferland and Rochefort (1997) introduced other native species to harvested peatlands for two reasons. One was to provide protection to the moss. The other was to help restore high coverage of regionally dominant species (Ferland and Rochefort, 1997). When shrubs are transplanted separately from moss collection and spreading, plants are hand selected and planted into the ground (Ferland and Rochefort, 1997). While shrubs can serve as companion or nurse plants for moss, a landscape dominated by these species may out compete *Sphagnum* for resources, especially water. Farrick and Price (2009) observed that a dense layer of shrubs had a significant impact on soil water fluxes, and reduced *Sphagnum* regeneration in a previously cut-over bog.

2.5.4 Phosphate rock fertilization

Lack of phosphorus, and other nutrients, can restrict plant productivity in ombrotophic bogs (O'Toole and Synnott, 1971; Tamm, 1954). To promote and accelerate the process of vegetation establishment, small amounts of phosphate rock fertilization have been recommended for peatland restorations (Quinty and Rochefort, 2003 and Silvia and Pfadenhauer, 1999). Phosphate rock is an efficient fertilizer, particularly because of its slow release (Quinty and Rochefort, 2003) and effectiveness in acidic conditions (Zapata and Roy, 2004). Phosphorus has been shown to speed up the process of recolonization of true mosses and vascular plants in post-extracted peatlands (Sottocornola et al., 2007;

Ferland and Rochefort, 1997). The accelerated growth and colonization of vegetation in cut-over peatlands is believed to play an important role in minimizing the effects of wind and frost heaving on bare peat, which is among the biggest obstacles to peatland restoration (Campbell et al., 2002; Quinty and Rochefort, 2000). The accelerated establishment of S*phagnum* companion species, or nurse plants, due to fertilization can also help to provide S*phagnum* species with a more favorable microclimate (Ferland and Rochefort, 1997). Ferland and Rochefort (1997) found a greater percent cover of moss in the presence of companion species.

2.5.5 Straw mulch cover

Bare peat possesses higher temperatures, lower moisture contents and is more susceptible to drying out as compared to undisturbed peatlands (Johnson et al., 2000). The effective re-establishment of *Sphagnum,* and resulting peat accumulation, is the most important factor for successful restoration (Lucchese et al., 2009). Numerous studies have shown that a protective cover of straw mulch over moss fragments promotes vegetative growth and survivability (Quinty and Rochefort, 2003; Johnson et al., 2000). Straw is recognized as the most effective mulch for peatland restoration, as it creates a layer of air just above the surface of the peat that stays humid and fresh, contributing to moss survivability (Quinty and Rochefort, 2003). Straw is also easy to acquire and spread on fields. A minimum application rate of 3000 kg/ha is recommended to provide an insulating layer, while still allowing some light penetration. Straw is best applied over large areas with a straw spreader and over smaller areas by hand. It is important to apply the straw soon after the moss and transplants have been applied to the area, to minimize drying.

2.5.6 Monitoring

Monitoring is an important step in determining if restoration objectives are being met (Quinty and Rochefort, 2003). Observation of vegetation patterns is most widely used in monitoring of peatland restoration efforts (Crum, 1992). Monitoring of hydrologic parameters within the peatland is also useful for interpreting vegetation monitoring results (Quinty and Rochefort 2003).

Monitoring should be oriented toward assessing if restoration objectives are met. For peatland restoration the typical objectives are the rapid establishment of vegetative cover and complete moss coverage (Quinty and Rochefort, 2003). Depending on the level of restoration that is required major restoration efforts should not be monitored until after the second growing season. However, less damaged areas may show re-establishment within the same growing season. Monitoring may be required for up to 30 years to clearly establish if the new plant community is evolving towards a peat bog community (Quinty and Rochefort, 2003).

The Peatland Restoration Guide gives a detailed protocol for monitoring. In brief, it is suggested that monitoring be conducted at three different levels (site level, permanent plot level, and ground level) in order to properly assess vegetation across the entire site. At the site level, a general description of the entire site is developed, including uniformity of vegetation cover, dominant vegetation, and presence of non-peatland species. Quinty and Rochefort (2003) recommend setting up permanent plots that are monitored throughout the entire study period. The permanent plots should be 5 m by 5 m and established in areas that are representative of the entire site. When these plots are monitored, specific observations are made on percent cover of all species, and peat water content and pH at ground level. Monitoring forms recommended in *The Peatland Restoration Guide* are provided in Appendix A.

2.6 RESEARCH GAPS AND NEEDS

Most peatland restoration research has been conducted on large areas of disturbed peatland, such as sites that have been mined for peat. There are many other types of disturbances to peatlands that occur on a much more frequent basis, such as damage due to road construction or recreational activities. Linear disturbances contribute to peatland fragmentation and can alter peatland hydrology (Turetsky and St. Louis, 2006). In the past, many smaller scale, linear disturbances have not been regulated. Public education programs may help to reduce wetland disturbances, however, illegal ATV operation in wetlands will most likely continue to persist. With new “no net loss” policies being developed in many parts of North America, including Nova Scotia, the mitigation sequence of avoidance, minimization and compensation will be applied to all wetland alteration decisions. It is therefore important to have a comprehensive understanding of the impacts of small scale and linear disturbances on peatlands, and to identify effective methods of restoration.

Chapter 3: Goals and Objectives

The overall goal of this research was to develop an approach for remediating peatlands that had been damaged by ATV use. Specific objectives included:

i) Determine which restoration methods described in the Peatland Restoration Guide are effective for restoring peatlands damaged by ATV use in Nova Scotia.

ii) Provide recommendations for an effective restoration approach for the Lake Charlotte Peatland.

Chapter 4: Materials and Methods

4.1 SITE DESCRIPTION

4.1.1 Location

The Lake Charlotte Boat Launch Committee required a compensation plan for wetlands that would be altered by the construction of a proposed boat launch. The Boat Launch Committee partnered with the Lake Charlotte ATV Association, who had previously identified over 4 hectares of wetland that had been disturbed by ATV usage. The damaged areas of wetland are located in Lake Charlotte, Nova Scotia between Highway No. 7 and Abraham's Lake (Figure 4.1.1). A series of ATV trails (1.7 linear km in length) have disturbed fairly extensive areas of several wetlands in the area, approximately 95% of which are peatlands.

The Boat Launch Committee and ATV Association have proposed the creation of a new ATV trail, appropriately situated on higher ground, and a complete restoration of the old trail running through the peatland. The field experiments in this study focused on the existing ATV trail. The study area contains both private and crown lands which have been damaged by ATV trails. In some places ATV activity has severely damaged the vegetation and altered small-scale hydrologic flow processes.

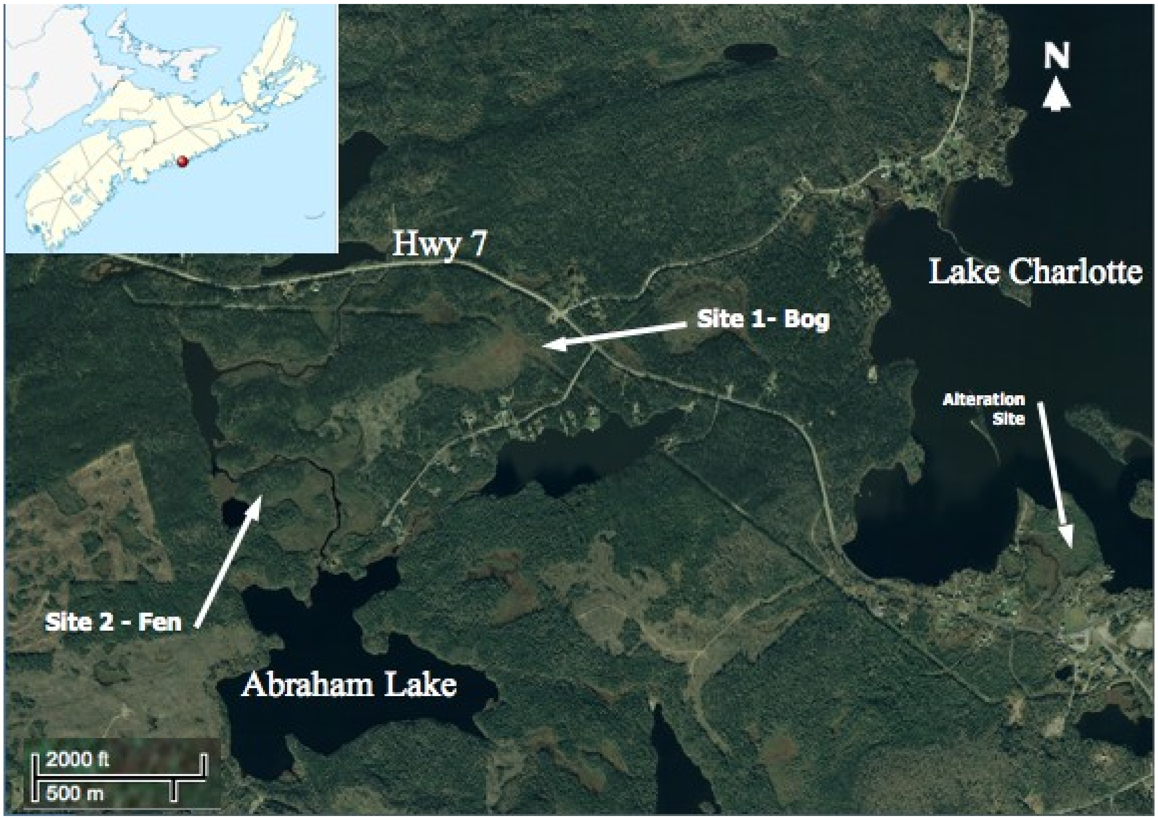

Figure 4.1.1 Location Map of Both Study Sites Adjacent to Alteration Site in Lake Charlotte, Nova Scotia

4.1.2 Site Description

Areas within the study site that are undisturbed are primarily boreal peatlands with an average peat depth of approximately 1 m. Vegetation consists of a variety of peat mosses, predominantly *Sphagnum,* but also club mosses (*Lycopodacae)* and Reindeer Lichen (*Claudonia rangiferina*). In addition to peat moss, many ericaceous shrubs such as leatherleaf (*Chamaedaphne calyculata*), Labrador tea (*Ledum groenlandicum*), bog rosemary (*Andromeda glaucophylla*), and sheep laurel (*Kalmia angustifolia* L.) are present. Black spruce (*Picea* mariana) and tamarack (*Larix* laricina) trees are found in drier parts of the fens and bogs.

Three different wetland types, in different locations within the peatland complex, were studied (Figure 4.1.2). Strata 1 (Figure 4.1.3) has a total area of approximately 15,000 m^2

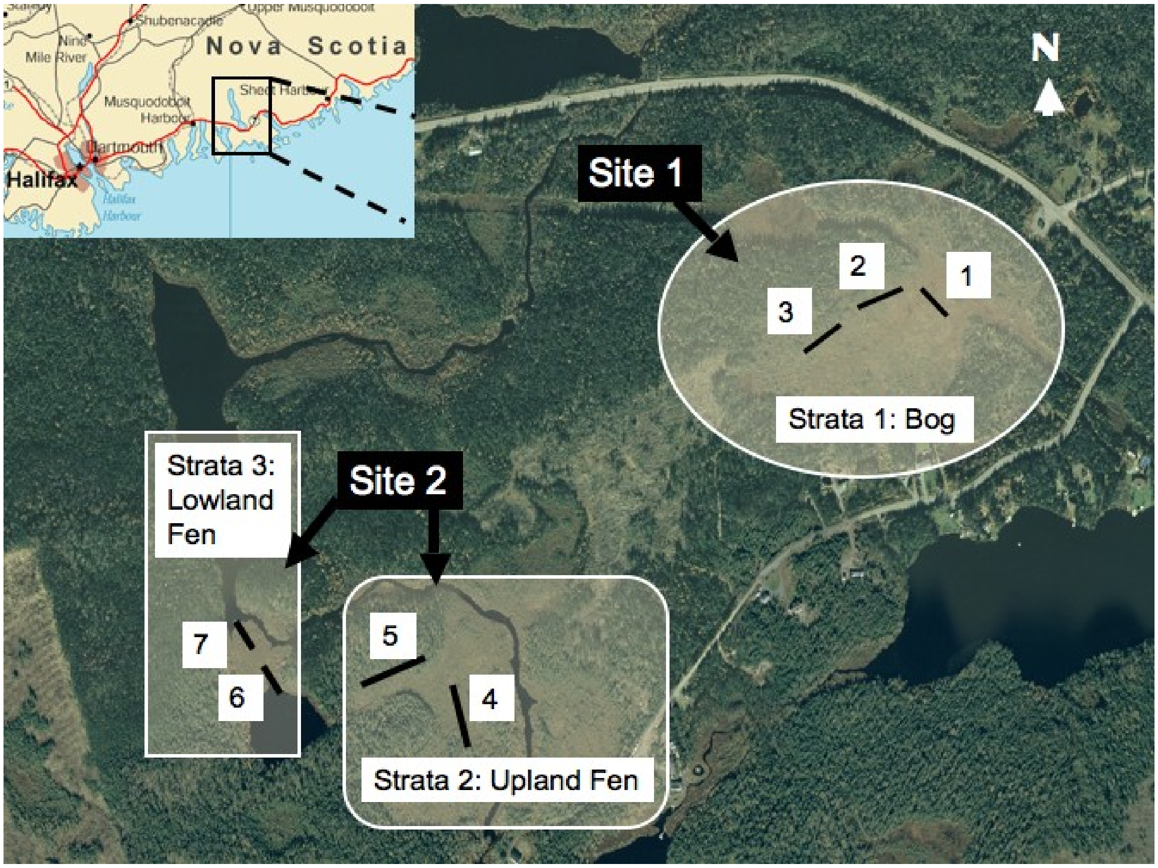

Figure 4.1.2 Map of three study sites near Lake Charlotte, Nova Scotia. Strata 1 is an open bog, Strata 2 is an upland fen and Strata 3 is a lowland fen. Seven subplots were examined across all three strata in portions of peatland damaged by ATVs.

Figure 4.1.3 Picture of Strata 1 illustrating impacts to vegetation and overall condition due to ATV activity.

and is a peat bog with low shrubs, and hummocks and hollows formed by moss species. ATVs have severely damaged portions of this bog, leaving areas completely void of any vegetation.

Strata 2 and Strata 3 (Figure 4.1.4) follow a stretch of a winter ATV trail approximately 3 km in length with an average width of 1.2 m. While some areas of the trail were completely destroyed and void of vegetation, a large portion of the trail was only slightly

Figure 4.1.4 Damaged fen area in Strata 2 showing compaction and stunted vegetation due to ATV activity.

damaged compared to the impact at the bog site (Strata 1). In the tracks, the soil was compacted and vegetation was largely absent. However, the middle of the trail was relatively undisturbed. Strata 2 is slightly elevated in topography and has a shallow peat depth. Strata 3 is an area that is very wet and is composed primarily of sedge and peat.

Due to the construction of a new trail in the summer of 2008, the use of the trail in Strata 2 and Strata 3 has decreased. Only portions of the trail can be used year round, since parts of the trail are only accessible by a frozen lake.

4.2 SITE CHARACTERIZATION

A survey of all sites was conducted in late Spring 2009 in order to identify the natural and undisturbed conditions that a fully restored site should resemble. Soil and vegetation sampling was conducted to characterize the site. At Strata 1, three undisturbed and three disturbed locations were sampled and at Strata 2 and 3, three undisturbed locations and one disturbed location were sampled because the disturbances is these strata were similar.. In all three strata, a total of 9 undisturbed locations and 5 disturbed locations were sampled. The methodologies for sampling soil and vegetation at each location is described in the following sections.

4.2.1 Soil profile

A 1.2 m long hand auger was used to determine the depth of acrotelm, total peat depth, and the depth to the mineral layer. The distinction between the acrotelm and catotelm was identified at the point where living and somewhat decomposed moss transitioned to almost completely decomposed matter. When it was possible to identify specific characteristics such as the level of decomposition, plant structure, and material extruded on passing between fingers, the acrotelm was measured on the *von Post humification scale,* which is based on the degree of decay from the top of the hummock downward (Pollett, 1968).

4.2.2 Vegetation survey

Within the same area studied for soil characteristics, a location was chosen for vegetation sampling by randomly placing a 1 m quadrat constructed of 18 mm diameter PVC piping on the ground surface. Within the 1 m quadrat, most species were measured on a percent coverage basis, except for trees (black spruce and tamarack) and pitcher plants, which were counted individually. The percentage of area covered in hummocks, and percentage of bare spots, were also estimated using a visual approach described by Schoeneberger *et al.* (2002).

4.2.3 Ecosite and Significant Habitat Classification

The Nova Scotia Department of Natural Resources (DNR) provides information on ecological land classification. This classification system identifies biological and physical elements affecting ecological structures and processes, as well as the biodiversity of ecosystems (DNR, 2003). The ecosite mapping for the Lake Charlotte wetland area is shown in Figure 4.2.1. The different colours identify the different ecosites. The three strata being studied are identified as IMSM, which is characterized as imperfectly drained, medium textured soil on smooth or flat terrain and IMHO, which is characterized as imperfectly drained, medium textured soils on hummocky terrain (DNR, 2006).

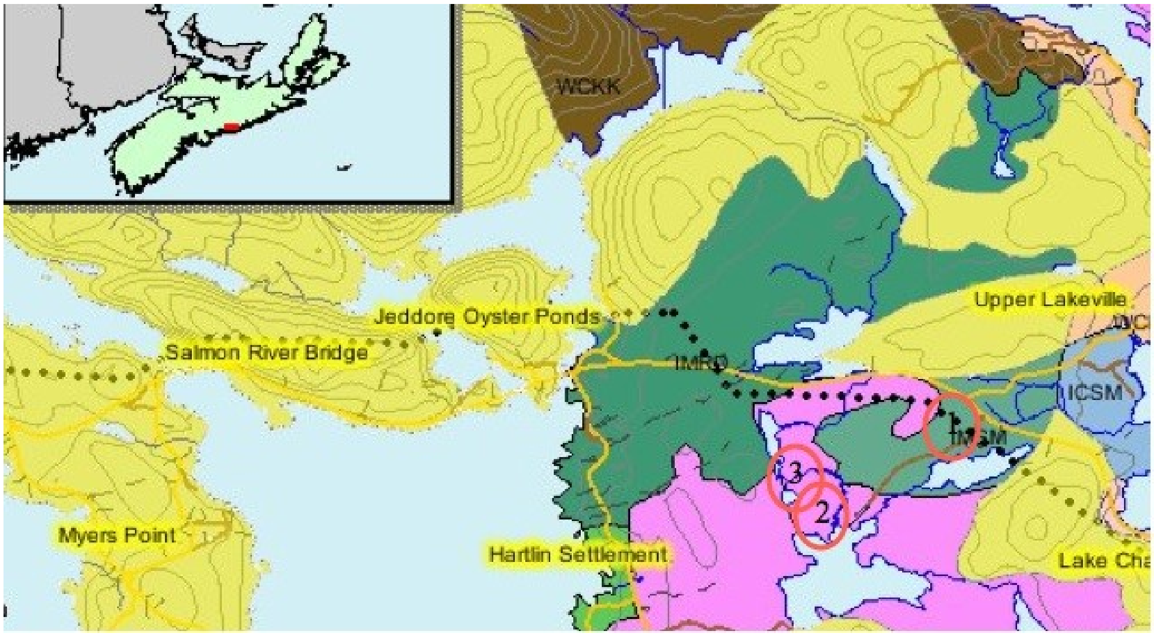

Figure 4.2.1 Ecosite map showing different DNR classifications by colour. Strata 1 is shown to be in IMSM which is characterized by imperfectly drained, medium textured soils on smooth or flat terrain. Strata 2 and 3 are located in the section IMHO which is characterized by imperfectly drained, medium textured soils on hummocky terrain (DNR, 2006)

Based on the DNR ecosite classification, as well as the differences in soil and vegetation at the three strata, there is evidence of fundamental differences in ecology among the three strata. These differences are primarily a function of varying hydrology due to location and peat accumulation. It was hypothesized that these differences would mean that the three strata would require different treatments for restoration.

4.3 EXPERIMENTAL DESIGN

Based on the three identified strata, replicate plots were constructed in each area. Two replicate plots were placed in both Strata 2 and 3 and three replicate plots were established in Strata 1, for a total of 7 plots. Several possible treatments were identified from the Peatland Restoration Guide, and an experimental design was established to study the effect of individual, and combined, restoration treatments. The main treatment variable was straw mulch cover, and sub-treatments consisted of moss spreading, ericaceous shrub transplanting, and phosphate rock fertilizer application (details included in remainder od experimental design description). In each half of the plot the sub-treatments were applied randomly in all eight possible combinations of presence versus absence of each treatment. There were two replicates per plot in terms of sub-treatments, however, when the main treatment variable, straw mulch, was added each plot contained 16 unique treatments. Two other blocks within the treatments contained hydrological (H_20) stations (Figure 4.3.1). For each plot two control treatments (one undisturbed area and one disturbed area that received no treatment) were placed close to the plot.

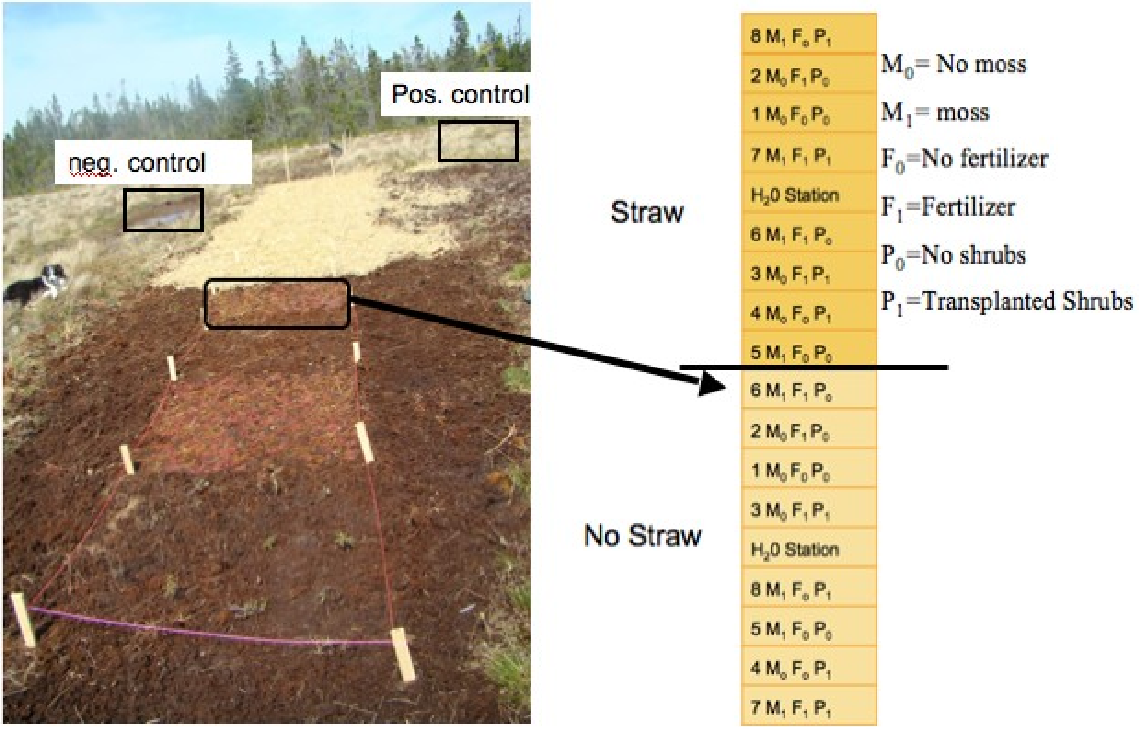

Figure 4.3.1 Plot layout and design showing randomly applied treatments of one main variable (straw) and 3 sub variables (moss, fertilizer, and shrubs). The two (positive and negative) controls for each plot are also shown. This is an example of treatments for one plot however, a total of 7 plots were created.

4.4 PLOT CONSTRUCTION

Plots were constructed between May 21, 2009 and June 9, 2009. Each plot took about 4-5 hours to complete with the help of 2 or 3 volunteers. Once the location of the plot was selected the top layer of soil (approximately 10 to 15 cm) was leveled and decompacted using garden rakes and hoes. Following these initial surface preparations, 1.44 m^2 areas were partitioned for each treatment. The geometry of each treatment area was a function of the type of damage. Strata 1 was severely damaged and so plots in Strata 1 had total treatment areas with dimensions of 1.2 m by 1.2 m. Plots that only had damage in the ATV tire tracks (Strata 2 and Strata 3) had total treatment area dimensions of 0.6 m by 2.4 m which excluded the undamaged areas between the tracks (Figure 4.4.1). Wooden stakes and construction twine were used to mark the boundaries of each plot. Plots ranged from 20 m to 40 m in length but each had a width of approximately 1.2 m (the average width of ATV tracks) and had the same total treatment area of (25.92 m^2). Each treatment was assigned a number, and using a random number table, the location of each treatment within the plot was randomly assigned.

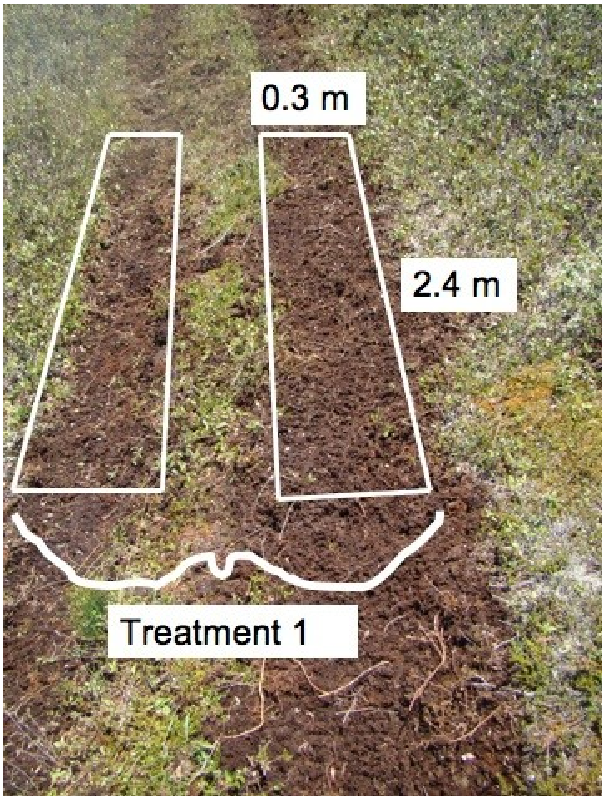

Figure 4.4.1 Diagram of treatment dimensions in Strata 2 and 3. Each treatment was applied in both of the tire tracks.

4.4.1 Determining Plot Location

The locations for the plots were chosen within each strata by choosing a representative section of disturbed trail in each strata. Once an area was assigned, it was measured and marked off. In Strata 1, three disturbed locations were randomly chosen and prepared. In Strata 2 and 3 only two locations were prepared. In addition to the treated plots, each plot also had a corresponding disturbed control area (no surface prep or treatments applied), as well as an undisturbed control area that was marked by stakes and flagging tape (no treatments applied). Both control areas were 1.44 m^2.

4.4.2 Leveling and Decompaction

The major preparation for the plots included leveling and decompacting the entire area. A buffer zone was also created around the plots. This buffer zone was created to prevent outside surface runoff from entering the plots. The buffer zone also provided an area to step on while preparing and examining the plots. In areas that were severely compacted, decompaction by loosening, and in some cases turning over soil, was also completed prior to leveling. Areas that were not severely compacted were tilled and leveled. The best tools for leveling and decompaction were a steel farm rake and a pointed garden hoe. The plots in Strata 1 had little to no vegetation prior to surface preparation, therefore any stray roots or surviving shrubs were removed. The plots in Strata 2 and 3 were generally vegetated on either side of the ATV tracks and had many roots running beneath the soil. In these cases any vegetation that was present after decompaction and leveling was left in place. Some examples of leveling are shown in Figure 4.4.2.

Figure 4.4.2 Examples of leveling and decompaction. Garden rakes and hoes were used to manually create flatter and more even terrain prior to treatment application. The top pictures show before (a) and after (b) pictures of the same area as it is leveled and staked for treatment application.

4.5 TREATMENT APPLICATION

Based on the Peatland Restoration Guide (Quinty and Rochefort, 2003) as well as work completed by Ferland and Rochfort (1997), moss application, shrub transplant, fertilizer application, and straw mulch cover were chosen as treatments. These treatments have all been carefully studied by the authors and recommended procedures and rates have been published. It was hypothesized that a combination of all treatments would provide the best restoration. Specifically, the straw mulch and fertilizer treatments were hypothesized to promote better and increased growth of moss and shrub transplants.

4.5.1 Moss Application

For the moss treatments, hummock forming *Sphagnum* moss, either brown (*Sphagnum* fuscum) or red (*Sphagnum* rubellum), were chosen, making sure that they had small capitula heads and formed tight hummocks. By pressing down on a hummock with fingertips, a hummock composed of moss that did not give way was an indication of the desirable species. Approximately 24 cm^2 sections of moss, that were 5-10 cm deep, were collected, taking care to distribute collection sites throughout the undisturbed areas and maintain the 1:10 ratio of collection site to restoration area (Quinty and Rochefort, 2003; Rochefort et al., 2003). This meant that the total amount of moss applied to one treatment was taken from an area that was only 10% of the treatment area, as suggested in the Peatland Restoration Guide (i.e. 14 cm^2 area of moss applied to 1.44 m^2). The moss was shredded by hand and placed evenly in the treatment. The application consisted of a single layer of moss fragments that covered 85% of the treatment area.

4.5.2 Ericaceous shrub transplantation

A total of 15 shrubs were evenly spaced and transplanted in areas assigned plant treatments. Healthy looking plants with green leaves were randomly collected. Seven were leatherleaf species and eight were other ericaceous species, mainly Labrador Tea, bog rosemary, and sheep laurel. The plants ranged from 10 cm to 40 cm tall. Each transplant possessed a section of root with at least several root hairs. Each plant was tagged with flagging tape to identify which plants had been transplanted (in Strata 2 and 3, shrubs already existed in the treatment area).

4.5.3 Phosphate rock fertilizer addition

Phosphate rock fertilizer (0-13-0) was obtained from an agricultural supply store. Using a laboratory scale, the fertilizer was measured into 0.024 g packets so that the correct amount could be applied quickly in the field. Each treatment area of 2.44 m^2 received 0.024 g producing an application rate of about 100 kg/ha, which falls within the recommended range for peatland fertilization (Sottorcornola et al., 2007). Since powdered formulations often cannot be spread effectively in Peatlands due to high wind conditions, beaded phosphate rock was spread evenly over the entire treatment area by hand, as recommended in the Peatland Restoration Guide.

4.5.4 Straw Mulch Cover Application

After all vegetative and fertilization sub-treatments were applied to the plots, straw was spread on the half of the plot that was randomly assigned to receive straw. Wooden boards (0.15 cm wide by 2 m long) spread across the plots were used as walkways to minimize alteration of the prepared plots while spreading the straw. Approximately 85% of the area assigned to receive straw was covered with straw. This allowed for some light penetration through the straw layer, but ensured adequate coverage of the majority of the treatment area (Figure 4.5.1). Approximately 0.4 kg was applied to each 1.44 m^2 treatment area, with the remainder of the bale spread around the plot in the buffer zone.

Figure 4.5.1 Example of straw cover with about 85% coverage over treatment. Straw was also applied to the 30 cm buffer zone.

4.6 MONITORING STATION INSTALLATION

As indicated in Figure 4.3.1, each straw and no straw section of all seven plots possessed a hydrological monitoring station. They were installed to measure the effects of straw on local hydrology, as well as on other biological and chemical properties. Additional hydrological monitoring stations were installed in two types of control areas for each plot, providing a total of four stations per plot. The control areas consisted of an undisturbed location in a natural state and a disturbed area that received no treatment.

4.6.1 Monitoring wells

Solid and slotted PVC pipes, as well as caps, for constructing monitoring wells were purchased from Aquaterra Resources located in Waverly, Nova Scotia. The PVC pipes were 25 mm in diameter and 1.5 m long, with threaded ends. Each solid and slotted pipe was cut in half and then screwed together creating a 1.5 m long well with a 0.75 m screened interval. A cap was put on the screened end of the well. A hand augur was used to make a hole approximately 1 m deep. The well was then inserted into the hole so that there was 0.7 m of screened pipe below the surface[1]. Borehole annular spaces were backfilled with native soil. A removable cap was placed on each well to prevent inconsistencies of local hydrology due to infiltration of precipitation.

4.6.2 Lysimeters

Lysimeters were placed in the hydrologic stations to measure the difference in evaporation between areas covered with straw and areas with no straw coverage. The lysimeters were constructed out of small plastic containers approximately 40 cm deep and 20 cm by 20 cm wide, which were purchased at Canadian Tire. A string was attached to two opposite sides by drilling holes in the sides of the container. In order to install the lysimeter, a square soil core was taken from the site, being careful not to compact or

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[1] All wells were constructed in this manner except for the wells for plot 5 which only had a total of 0.3 m screened portion because of shallow soils. Wells in plot 5 only extended 0.3 m into the ground.

disturb the soil layers. The soil was then gently placed in the lysimeter, so that the soil horizons were not disturbed. Each lysimeter was weighed before inserting it into the hole from which the sample was extracted. The lysimeters were checked to make sure that they were flush with the ground and the excess dirt was backfilled to eliminate empty space around it.

4.6.3 Rain gauges

At each hydrological monitoring station a '2-in-1 Rain Gauge' by Springfield (model # 90107) was installed. They were capable of recording up to 12 cm of accumulated rainfall. The rain gauges were placed in the center of the hydrological monitoring stations, where there would be no interference from vegetation. Several mL of baby oil was added to the rain gauges to prevent evaporation between precipitation measurements.

4.6.4 Re-dox Rods

Steel rods were used to evaluate water table level by observing where rust accumulated in oxygenated parts of the soil. These were used in addition to the monitoring wells because they provide a more time integrated approach. Steel rods 75 cm in length and 4 mm in diameter were inserted into the peat so that 60 cm (or as much as possible in the case of plot 5) of the rod would be underground.

4.7 PRELIMINARY MEASUREMENTS

4.7.1 Soil Chemical Analysis

A total of 21 soil samples were taken on June 27th, 2009 using a soil core. Three samples were taken from each plot: (i) one from the disturbed control, (ii) one from the study area containing all four treatments, and (iii) from the study area containing all treatments but straw. The samples were immediately put in a cooler and kept chilled until they were delivered to the Nova Scotia Department of Agriculture's Analytical Services Lab in Truro, NS. The samples were analyzed for pH, percent organic matter, P_2O_5, K_2O, Ca, Mg. Na, Sulfur, Al, Fe, Mn, Cu, Zn, and nitrate.

4.7.2 Initial leaf measurements

Plant leaf growth rate was monitored by measuring the length of the newest fully formed leaf of 3 Labrador Tea plants in each straw-plant treatment (Personal Communication, Ed Reekie, Acadia University, Wolfville, Nova Scotia). The number of small, or not fully formed leaves, were counted.

4.8 WEEKLY MONITORING

Weekly to bi-weekly monitoring of the following metrics was conducted between June 10, 2009 and October 5, 2009. Over this time period the plots were monitored a total of 17 times.

4.8.1 Visual/Photographic Inspection

A picture was taken of each treatment in every plot during each monitoring visit. The same picture location and orientation was used to provide an effective way to visually analyze differences in treatments.

4.8.2 Hydrological Monitoring Station

The hydrological stations were monitored throughout the 2009 growing season on a bimonthly basis. The main objective in setting up the four monitoring stations per plot was to be able to identify differences in surface and sub-surface hydrology between (i) unrestored disturbed areas, (ii) areas that had only been treated with surface preparation, and, (iii) areas that had been treated with surface preparations as well as straw mulch application.

MONITORING WELLS

During each monitoring visit the distance from the ground surface to the water level in each well was measured using a Dipper-T Water Level Meter (Heron Instruments, Burlington, Ontario).

LYSIMETERS

Lysimeters were pulled out of the ground and weighed on a hand scale (Luggage Scale, Travelon, Illinois) and then returned to the ground. Where straw was present, it was removed prior to weighing, and upon reinsertion of the lysimeter into the ground the area was re-covered with straw.

RAIN GAUGES

During each visit, the water level in the rain gauges was measured. The water was poured out to the side of the plot and then baby oil was replenished to the rain gauge before it was reinserted to its proper location in the plot. The rain gauges measured cumulative rainfall which occurred between monitoring visits.

RE-DOX RODS

The steel rods were pulled from the ground, noting where the rod was at ground level. The length of rod that was covered in rust was measured. The rod was then replaced to approximately the same distance in the soil as when it was taken out.

VOLUMETRIC SOIL WATER CONTENT

The volumetric soil water content was measured during each monitoring visit using a HydroSense soil moisture probe (CD620, Campbell Scientific Australia Pty. Ltd.). Measurements were taken in the monitoring stations by inserting the two 12 cm metal probes vertically into the soil. Three replicate measurements were taken during each site visit.

4.9 END-OF-SEASON MONITORING

4.9.1 Soil Analysis

At three locations within each treatment (selected by using a random number table) the top 10 cm of soil was collected. They were kept in a cooler until brought to the lab at Dalhousie University to be analyzed. The analysis of these samples is described in the following sections.

ELECTRICAL CONDUCTIVITY AND PH

In the lab, aqueous solutions were prepared by adding 200 ml of distilled water to 200 ml of gently tamped down soil. The solution was stirred well and pH of soil from each treatment was measured using a YSI 600R multi-parameter sonde.

GRAVIMETRIC WATER CONTENT

The gravimetric moisture content of each soil sample from each treatment was measured using a two-step method outlined by Karam (2008). For each treatment, a wet sample of about 50 g was measured into aluminum dishes. The samples were allowed to air dry for two days before being dried at 105°C in an oven. The samples were then weighed again and moisture loss was expressed as a percent of the oven dry mass.

ORGANIC CONTENT

The organic matter content of the soil samples taken from each treatment was determined using a method outlined by Karam (2008). The oven-dried samples used for gravimetric water content were ashed at 600°C in a muffle furnace and then reweighed to determine the percent organic content.

4.9.2 Moss

PERCENT COVER IN PLOT

The percent cover in each treatment was estimated using percentage estimates as described by Schoeneberger *et al.* 2002.

PERCENT COVER BY SPECIES AND AVERAGE HEIGHT IN QUADRAT

In each treatment, a 25 cm^2 quadrat were placed in the two best areas of coverage and the two areas with the least amount of cover (4 locations total). Within the quadrats species cover and average height was determined. The species cover was estimated, and the height was measured by placing the end of a measuring stick on the ground and reading the height of the nearest capitula head.

AVERAGE MOSS DRY WEIGHT

The quadrat used to measure the square plots in Strata 1 was 1.2 m^2. The quadrat used to measure the longer and thinner plots in Strata 2 and 3 was 0.3 m by 2.4 m. Within these quadrats, the area was divided equally between 144 sub-quadrants that were each 10 cm^2. Moss and soil samples were collected from these sub-quadrats.

The moss in each of three randomly chosen sub-quadrants was collected, placed in bags, weighed in the lab and allowed to air dry before being oven dried at 105^{o} C for 24 hours. The samples were then reweighed and the dry weights for each treatment were averaged and compared.

4.9.3 Transplanted shrubs

SURVIVABILITY

In each treatment that received shrub transplants, the shrubs were assessed for survivability. Plants were marked as either alive, dead or absent. For the plants that were still alive they were characterized as unhealthy or healthy (green firm leaves and terminal buds present).

PLANT LEAF GROWTH RATE

Labrador Tea plants in straw plots were measured for leaf growth by number and by growth rate and compared to plants in natural undisturbed areas. The leaves that had been tagged at the beginning of the season were measured at the end of the growing season. The number of newly formed leaves, as well as leaves that are not fully formed, were counted.

4.9.4 Graminoids

PERCENT COVER

The percent coverage of grasses within each treatment was estimated using percentage estimates as described by Schoeneberger *et al.* 2002.

AVERAGE HEIGHT

In each treatment, three samples of grass height were taken. A measuring stick was put down in a representative location within the treatment and the longest blade of grass in that sample was measured from the ground to the tip of the blade.

4.9.5 Drosera

AVERAGE NUMBER PER PLOT AND AVERAGE HEIGHT

In each treatment, *Drosera* plants were counted. The length of the longest leaf of the three largest plants in each treatment was measured.

4.10 STATISTICAL ANALYSIS

For all metrics taken on a bi-weekly basis in the hydrological monitoring stations (water table depth, volumetric water content, rust accumulation, evaporation), differences between treatments were statistically assessed using paired t-tests conducted with Microsoft Excel software. Conductivity, pH, and organic matter were also statistically analyzed using paired t-tests conducted with Microsoft Excel.

For the remaining end of season measurements, preliminary analysis indicated that there were no significant differences within Strata 2 or Strata 3 and so the treatment results from Strata 2 and 3 were pooled together to generate 4 replicates for statistical testing. The three Strata 1 plots were also pooled to give more replicates. Differences between treatments, and interaction effects, were assessed with analysis of variance (ANOVA), using the General Linear Model command in MiniTAB ® (a statistical software created by MiniTab Inc., State College Pensylvania. Significance of these analyses was determined using a Bonferonni correction factor of 0.01 and an F-test (significance value of 0.05) for assessing differences between means. For all analyses, assumptions of normality and constant variance were verified by looking for normally distributed data on a histogram and checking for a goodness of fit of the residuals.

Chapter 5: Results and Discussion

5.1 HYDROLOGY AND GEOCHEMISTRY

5.1.1 Water Table

The effect of straw cover on water table height was assessed throughout the 2009 growing season. Average water table levels in the three strata are presented in Figure 5.1.1. Marked differences in water table levels between straw and no straw treatments were observed (Table 2). The average depth to the water table in straw treatments in Strata 1 (Figure 5.1.1(a)) ranged from -16.1 cm to 3.4 cm. A positive value indicates that water was ponded on top of the ground surface. The range of water table depths in treatments without straw was larger, -19.8 cm to 2 cm. In Strata 1, the average depth to water in treatments covered in straw was significantly less ($p < 0.05$) than those without straw covers (Table 2). Similar results were observed in Strata 2 and 3. Water depths in Strata 2 treatments covered with straw ranged between -18.6 cm and 1 cm (Figure 5.1.1(b)). No-straw treatments had a larger range, from -27.2 cm to 0 cm. In Strata 3, straw treatment water levels ranged from -2.9 cm to 8.3 cm and no-straw treatment water levels ranged from -5.8 cm to 8.3 cm. In both Strata 2 and 3 water table levels in plots covered with straw were significantly closer ($p < 0.01$) to the surface than in plots without straw.

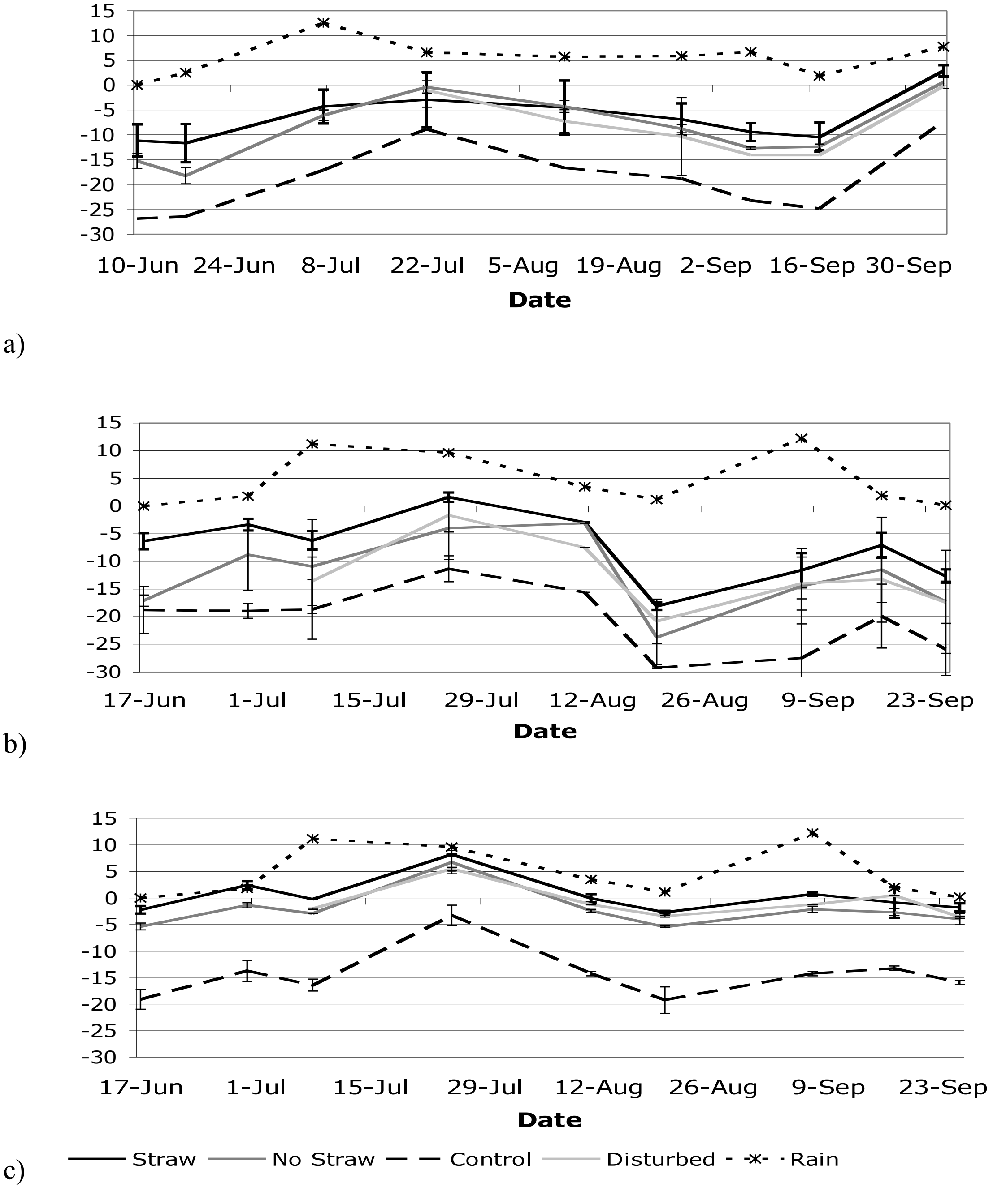


Figure 5.1.1 Average depth to water table and precipitation for strata during the 2009 growing season. Error bars represent 95% confidence intervals. a) represents Strata 1 ; b) represents Strata 2; c) represents Strata 3.

Table 2. Significance levels (p-values, or ** for $p<0.05$) of the main effects of straw on water table level in each strata

	Strata 1	**Strata 2**	**Strata 3**
Water Table	**	**	**

While there were no significant differences in water table level between the unrestored disturbed areas and areas that only received site preparation (treatment 1), visual inspection indicated that there was some change in infiltration capacity in the areas that had been prepared via leveling and decompacting. The unrestored areas were inundated with surface water for much of the growing season.

In all three strata, a relationship between precipitation and water table level was evident (Figure 5.1.1.). Examples of high water table levels in straw treatments can be seen during extreme precipitation events where water tables are above the surface of the ground, and also in Strata 3 which is characterized by a very shallow peat depth. The effect of straw on water table levels was expected, as the presence of straw helps to prevent evaporation and maintain stable temperatures (Price et al., 1998). The no-straw and disturbed control treatments exhibited similar fluctuations in water table levels. The observed lower water table level in the positive control (the area that was undisturbed and received no treatment) generally reflects the depth of the living moss carpet found in undisturbed areas of the bog. The moss hummocks were approximately 15 to 20 cm high, and therefore the measured water table level in these areas was 15 to 20 cm lower than in bare areas.

5.1.2 Volumetric Water Content

Soil water content within the hydrological monitoring stations were measured in the field on a weekly basis (volumetric) and in the lab at the end of the monitoring period (gravimetrical). For both types of measurements, there were no significant differences ($p > 0.05$) between straw and no-straw treatments, or prepared and unprepared treatments, in any plot. As well, no significant difference was observed between the two different types of control areas, disturbed and undisturbed. These results contradict the water table level results, which showed significant differences between straw and no-straw treatments. This is most likely due to the fact that peatland soils are extremely moist and small differences in moisture content were difficult to detect using the field or lab procedures employed in this study.

5.1.3 Evaporation

The results of the lysimeter measurements were inconclusive, showing no significant differences ($p > 0.05$) between any treatments or controls. It was hypothesized that there would be less evaporation in plots covered with straw than those without straw, as found by Price et al. (1998) and Petrone et al. (2001). This lack of significant effect may reflect the simple construction of the lysimeters, and measurement methodologies, as well as the fact that the 2009 growing season was quite wet. The effect of straw covers on evaporation rates is something that should be evaluated using a more sophisticated methodology, using commercial *in-situ* lysimeters or micro-meteorological techniques and under drier conditions.

5.1.4 Electrical Conductivity and pH

It was expected that the pH in disturbed areas of the peatland would be lower than in the undisturbed areas, as observed by Croft et al. (2001). However there was no significant difference ($p > 0.05$) in pH measurements, either between treatments or plots. Additionally, there was no dramatic change in pH over the growing season in any of the treatments (Table 3). In all treatments the initial and final pH varied by less than 0.3 pH units. One possible explanation for this lack of effect is that the experiment was conducted over just one growing season, whereas other experiments looked at changes in soil geochemistry over multiple years (Gilliam et al., 1999).

Table 3. pH values at the beginning and end of the season for all plots. Positive control refers to the undisturbed areas, negative controls were disturbed areas that received no treatment, treated areas have straw, fertilizer, moss and shrub treatments.

	Treatment					
	Straw, moss, fertilizer, shrubs		**Positive Control**		**Negative Control**	
	Initial	Final	Initial	Final	Initial	Final
Plot 1	4.1	4.2	4.0	4.2	4.0	4.2
Plot 2	4.1	4.3	4.1	4.3	4.1	4.3
Plot 3	4.0	4.3	4.6	4.2	4.0	4.3
Plot 4	3.9	4.0	4.0	3.9	3.6	3.7
Plot 5	3.9	3.9	4.1	3.6	3.9	3.9
Plot 6	4.7	4.4	4.1	4.3	4.2	4.4
Plot 7	4.5	4.6	4.0	4.4	4.2	4.4

*the initial pH measurements for no straw treatments were not collected

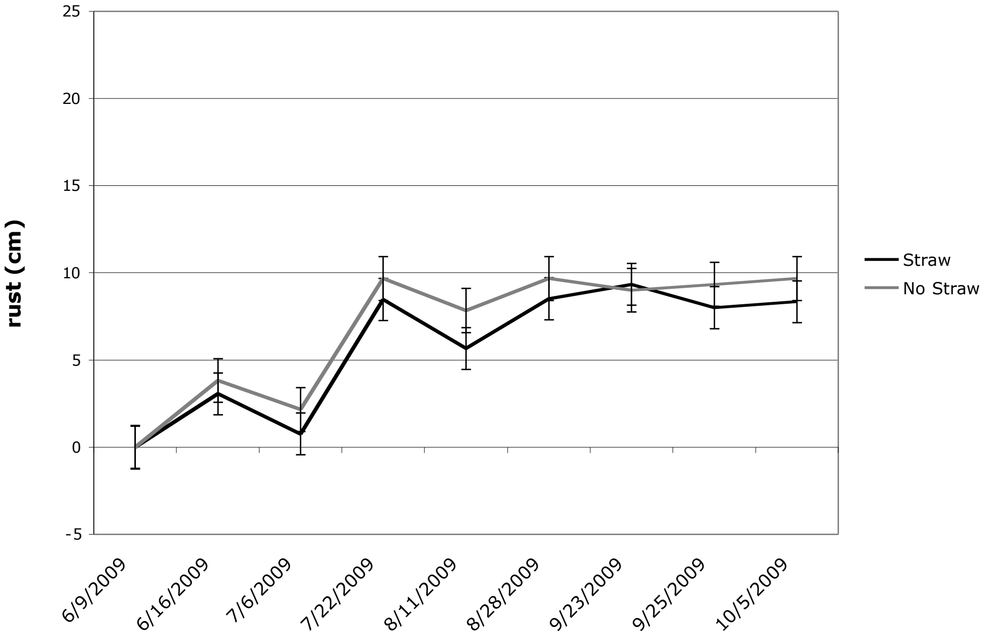
The electrical conductivity of peatland soil can be quite variable (Bussieres et al., 2008). However, it was expected that in this study disturbed areas with little to no vegetation would have greater soil electrical conductivities than areas with established vegetation, due to ion leaching in the disturbed, bare areas and vegetative uptake in the control areas (Beltman et al., 2005). The results indicated that there was no significant difference ($p > 0.05$) between the areas treated with straw, fertilizer, moss, and shrubs, disturbed areas (negative control) and undisturbed natural areas (positive control) (Table 4). Geophysical changes in soil chemistry are slow processes and it may take several seasons for a treatment effect to be detected. A more refined sampling protocol may also be required to detect differences.

Table 4. Average electrical conductivity values (µS) for each strata as determined at the end of the season. Positive control refers to the undisturbed areas, negative controls were disturbed areas that received no treatment, treated areas have straw, fertilizer, moss and shrub treatments.

	Treatment		
	Straw, moss fertilizer, shrubs	**Positive Control**	**Negative Control**
Strata 1	0.030	0.024	0.037
Strata 2	0.040	0.061	0.025
Strata 3	0.031	0.024	0.025

5.1.5 Redox

Rust accumulation on steel rods was measured at each sampling date. The measurements from the three plots in Strata 1 were averaged and are presented in Figure 5.1.2a. Measurements from the four plots in Strata 2 and 3 were also averaged and are provided in Figure 5.1.2b and 5.1.2c. Rust accumulation was used as an indicator of water table level. The depths of rust ranged from a maximum of 31.5 cm to 0 cm. Owens et al. (2008) found that rust on steel rods correlated well with water level. In this study, depths of rust accumulation between treatments were significantly different ($p < 0.05$) in Strata 1 with more oxidation occurring in treatments without straw cover (Table 5). The observations for Strata 1 are consistent with the results of the water table monitoring, providing additional evidence that the water table level was higher in plots that were covered with straw. Rust levels between straw and no-straw treatments were not significantly different in Strata 2 and 3, which could be due to the lower level of damage present in these strata versus Strata 1. There was more vegetation, specifically grass, covering all areas in Strata 2 and 3. This could have minimized the effect of the straw cover.



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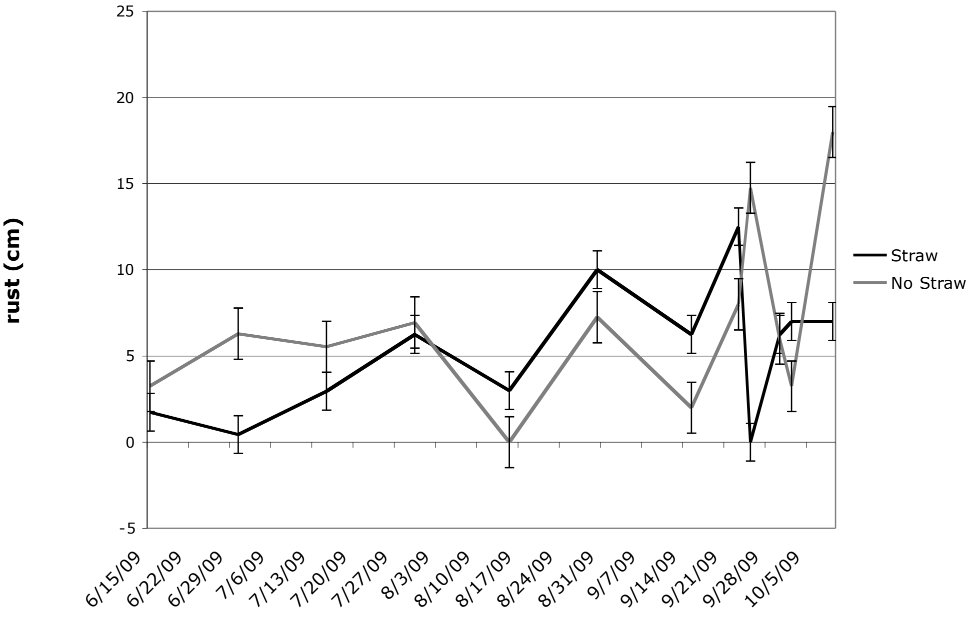

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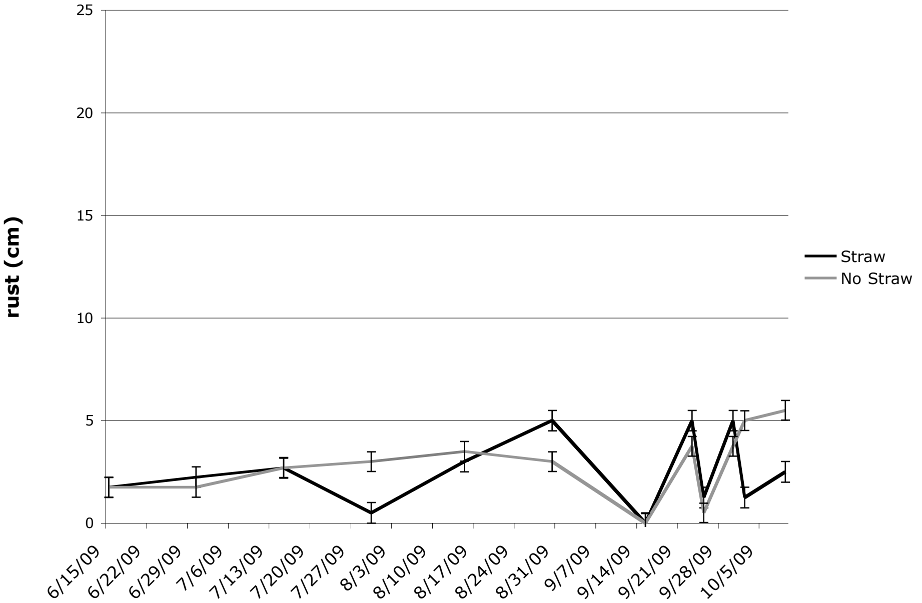


c

Figure 5.1.2 Average depth of oxidation in Strata 1 (a) and Strata 2 (b) and Strata 3 (c) as measured by rust on steel rods. Error bars represent one standard error.

Table 5 Significance levels (p- values, or ** for $p < 0.05$) of the main effects of straw on rust accumulation.

	Strata 1	**Strata 2**	**Strata 3**
Rust (cm)	**	0.17	0.37

5.1.6 Organic Matter

The lab analysis of soil organic matter showed no significant difference ($p > 0.05$) in percent organic matter between straw and no-straw treatments. Additionally, there was no significant difference ($p > 0.05$) between areas receiving all treatments and the control natural area. Measurements of soil organic matter content in all Strata ranged from 90% to 98%. Plant growth can increase the amount of soil organic matter. However, since peatland soils are composed primarily of organic matter there is typically little difference in percent organic matter between different layers of soil across a peatland (Kratz and DeWitt, 1986).

5.2 MOSS

The establishment of a *Sphagnum* cover is crucial to the successful restoration of cut-over bogs (Price et al., 1998). In this study, moss was considered to be the most important element in restoring a peat accumulating system.

5.2.1 Percent Cover

Straw had a very significant ($p = 0.0001$) effect on the area covered in moss for all strata (Table 3). The mean percent coverage in straw plots was approximately 70% while the mean percent coverage in no-straw plots was only about 43%. A maximum coverage of 98% was observed in Plot 5 (treatment $M_1F_0P_0$) in which there was no fertilizer or plants added, only moss and straw. A minimum percent coverage of 10 % was observed in the straw Plot 3 (treatment $M_1F_1P_1$) where moss was applied followed by fertilizer and transplant additions. The maximum percent coverage observed in no-straw plots was 80% in Plot 4 (treatment $M_1F_0P_1$) and Plot 6 (treatment $M_1F_1P_0$). Figure 5.2.1 and Figure 5.2.2 illustrate the pooled data for Strata 1 (Plots 1-3) and Strata 2 and 3 (Plots 4-7) respectively. In all strata, treatments covered with straw had a higher percent coverage of moss than the treatments without straw. Strata 2 and 3 had, on average, a greater percent coverage than Strata 1. While statistical analyses were only performed on treatments where moss was applied, it is also interesting to note that in Strata 2 and 3 there was a greater amount of moss coverage in straw plots where no moss had been applied. In Strata 1, areas that had not received any moss application had no moss coverage at the end of the season, regardless of straw mulch cover. This is most likely due to the fact that Strata 1 was much more disturbed than the other sites, since it was accessible year round by ATVs. Consequently, the damaged areas probably had no viable bryophyte seed bank to initiate growth. Therefore, *Sphagnum* only grew when applied. In Plots 4-7 the ATV tracks were surrounded on either side by a thick cover of sedge and grasses.

This may have provided additional soil stability (Ferland et al., 1997) to accelerate moss establishment and foster growth from seeds.

Table 6 Significance levels (p-values, or ** for p<0.05) of the main effects and interactions on moss cover and height.

Main Effects and Interactions	**Percent cover Strata 1**	**Percent cover Strata 2 and 3**	**Height Strata 1**	**Height Strata 2 and 3**
Straw	**	**	**	**
Fertilizer	0.38	0.90	0.71	0.66
Plants	0.74	0.94	0.19	0.34
Straw *Fertilizer	0.752	0.60	0.77	0.84
Straw * Plants	0.32	0.87	0.35	0.42
Fertilizer * Plants	0.24	0.25	0.35	0.84
Straw * Fertilizer * Plants	0.24	0.48	0.21	0.58

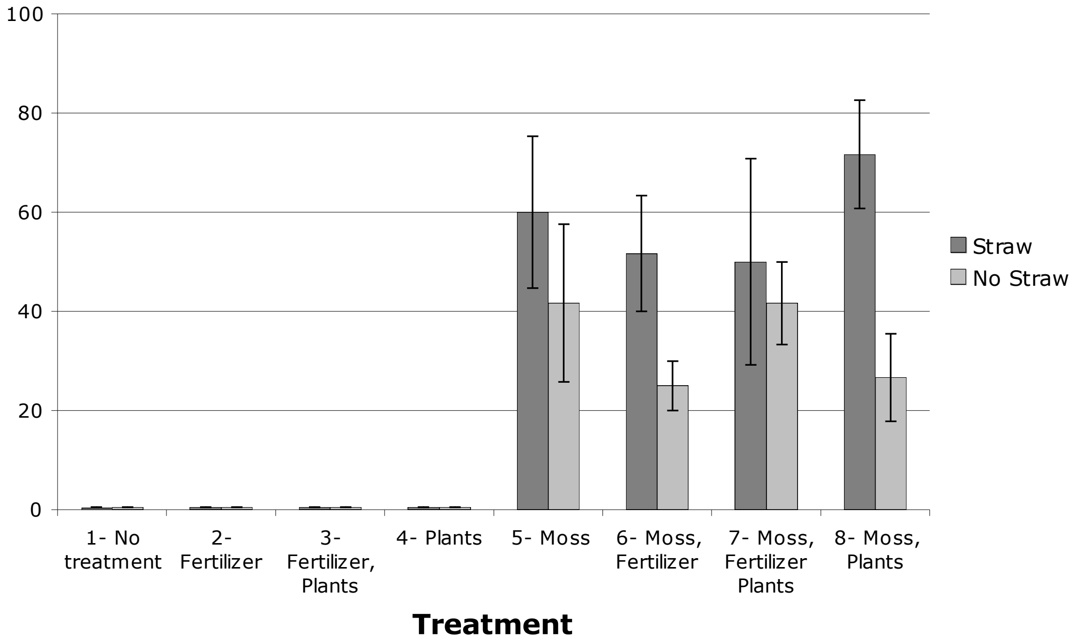


Figure 5.2.1 Average moss percent cover by treatment in Strata 1 (Plots 1-3). Error bars represent standard error of the mean.

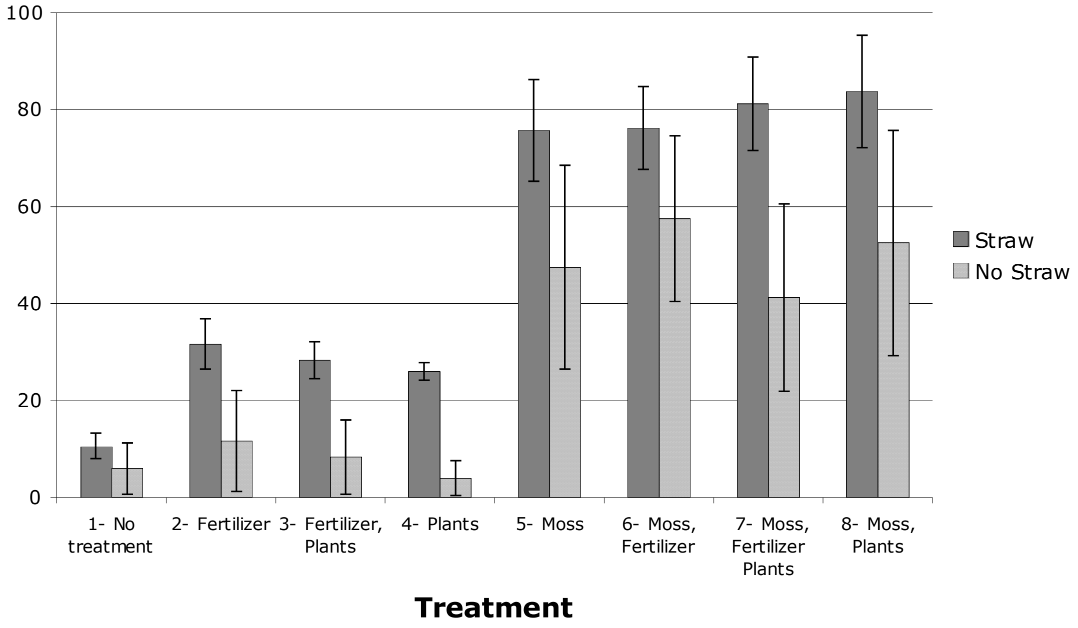


Figure 5.2.2 Average moss percent cover by treatment in Strata 2 and 3 (Plots 4-7). Error bars represent standard error of the mean.

There was no effect of fertilizer application, or presence of shrub transplants, on percent cover and moss height ($p > 0.05$). Ferland and Rochefort (1997) found that fertilization and straw mulch had a significant effect on moss growth after two growing seasons. This observed effect of fertilizer and straw mulch could be due to the fact that their experiment spanned two growing seasons, and two fertilizer additions.

5.2.2 Average height

Straw cover treatments had a very significant effect ($p < 0.05$) on the average height of moss (Table 3). The mean height of moss in straw covered plots was 1.84 cm, with a maximum height of 3.10 cm observed in Plot 6 and a minimum height of 0.93 cm in Plot 3. The mean height of moss in plots with no straw cover was 1.20 cm. The maximum height of moss in no straw plots was 2.05 cm in Plot 4 and a minimum height of 0.78 cm was observed in Plots 1 and 4. In addition to providing favorable hydrological and microclimatic conditions for moss growth (Ferland and Rochefort, 1997), the straw could have provided valuable structure and substrate for moss growth. When straw was removed at the end of the growing season, the moss had become attached to the pieces of straw, forming a thick mat.

There was no significant difference in moss height between subtreatment combinations, however it was observed that moss in Strata 2 and 3 (Plots 4-7) were on average about 0.5 cm taller than the moss in Strata 1 (Plots 1-3) (Figure 5.2.3 and Figure 5.2.4). It was surprising that the moss did not respond to the fertilizer addition, since this effect has been commonly observed in other studies (Li and Vitt, 1994). However, it is possible that the increased amount of precipitation and pooled water may have washed out and diluted the fertilizer treatments, thereby making it ineffective. To further test the effects of fertilizer treatments on moss growth, a greenhouse experiment could be used to have a more controlled environment and multiple growing seasons should be studied.

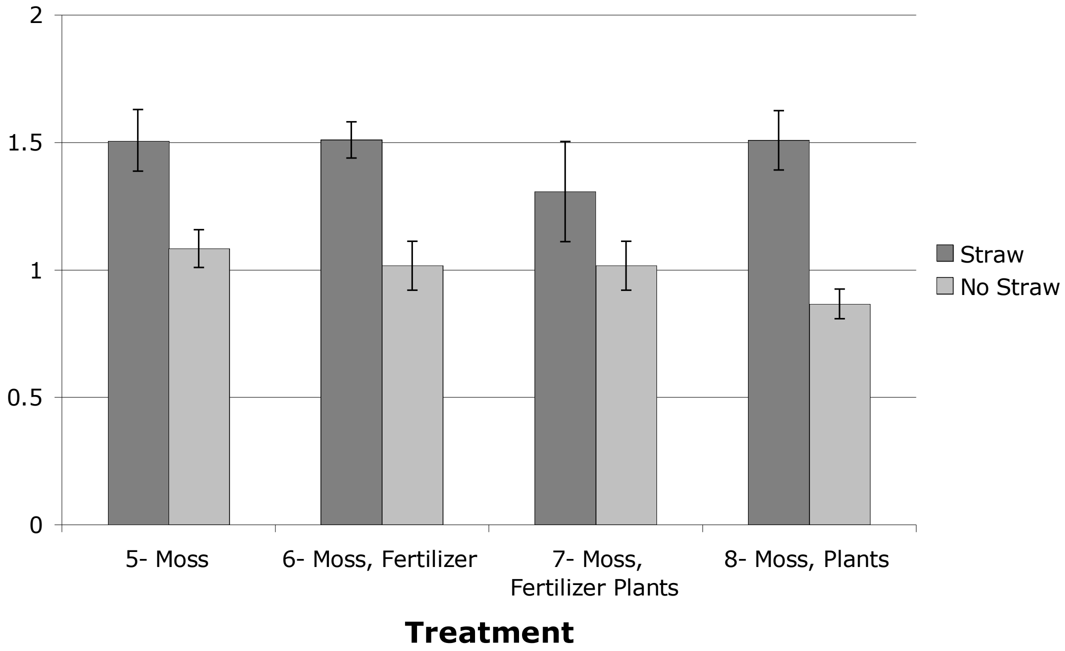


Figure 5.2.3 Average moss height in Strata 1 (Plots 1-3). Error bars represent standard error of the mean.

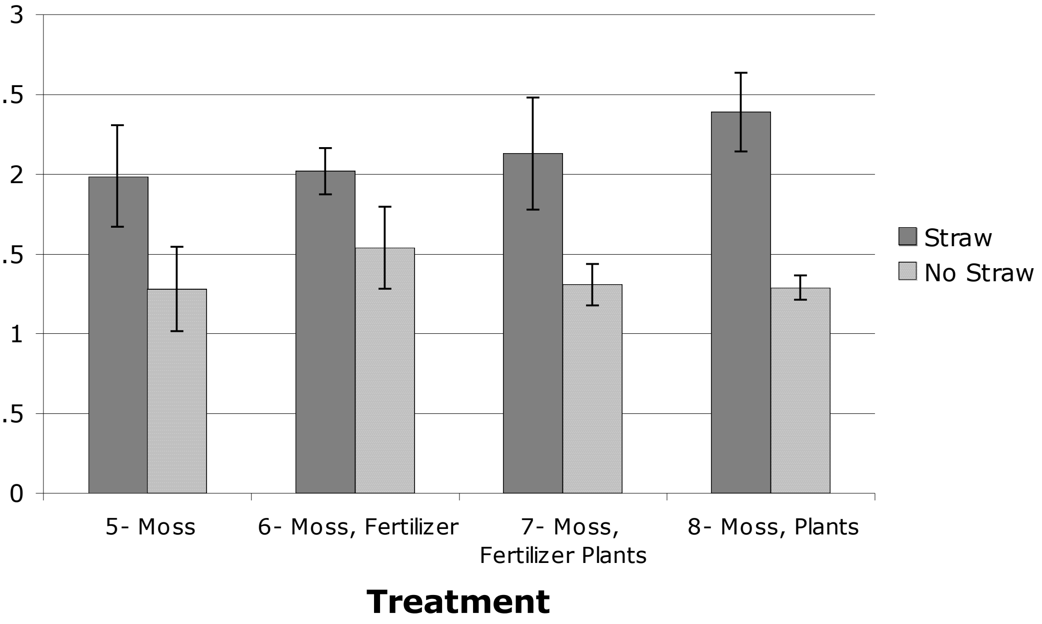


Figure 5.2.4 Average moss height in Strata 2 and 3 (Plots 4-7). Error bars represent standard error of the mean.

5.2.3 Effect of Ericoids

Dansereau and Segadas-Vianna (1952) noted that *Sphagnum* tend to grow on, and up, stems and twigs of leatherleaf plants. Ferland and Rochefort (1997) also found that vascular plants provided protection and cover for moss species. In this study however, there was no significant effect ($p > 0.05$), or interaction, between moss growth and shrubs. This could be due to the fact that shrubs were transplanted at lower densities than would be found in more natural conditions. A study (personal communication Peatland Ecology Research Group, thesis in progress) is currently in progress to determine if transplanting shrubs at higher spatial densities has an effect on the establishment of moss.

Again, the lack of observed effect in the current study could be due to the short monitoring period.

5.3 TRANSPLANTED SHRUBS

It was expected that all species of transplanted ericaceous shrubs would survive and grow in a similar manner. It was also hypothesized that survival rates in treatments with straw and fertilizer would be higher.

5.3.1 Survival

While all of the transplanted sheep laurel survived, approximately 50% of the plants were classified as unhealthy at the end of the growing season. Most of the transplanted shrubs were either leatherleaf or Labrador Tea plants, and so only these two plants were studied in greater detail. Of these two, leatherleaf had a significantly ($p < 0.05$) greater survival rate than Labrador Tea plants when all treatments were pooled together in each site (Strata 1 and Strata 2 and 3). These results are similar to other studies, which have examined ericaceous regrowth in peatlands (Sims and Stewart, 1981). Leatherleaf and Labrador Tea transplants were analyzed individually to test the effects of fertilizer and moss treatment on transplant survival (the effect of straw was not analyzed because only plants in straw treatments were studied due to time constraints) (Table 7). Leatherleaf plants had a higher survival rate, regardless of the treatment. Straw, fertilizer, and moss treatments had no effect ($p > 0.05$), however, on either Labrador Tea or leatherleaf transplant survival.

Table 7 Significance levels (p-values) of the main effects and interactions on plant survival.

	Strata 1		**Strata 2 and 3**	
Main Effects and Interactions	**Leatherleaf**	**Labrador Tea**	**Leatherleaf**	**Labrador Tea**
Fertilizer	1.00	0.35	0.25	0.27
Moss	1.00	0.15	0.71	0.55
Fertilizer*moss	0.23	0.79	0.83	0.53

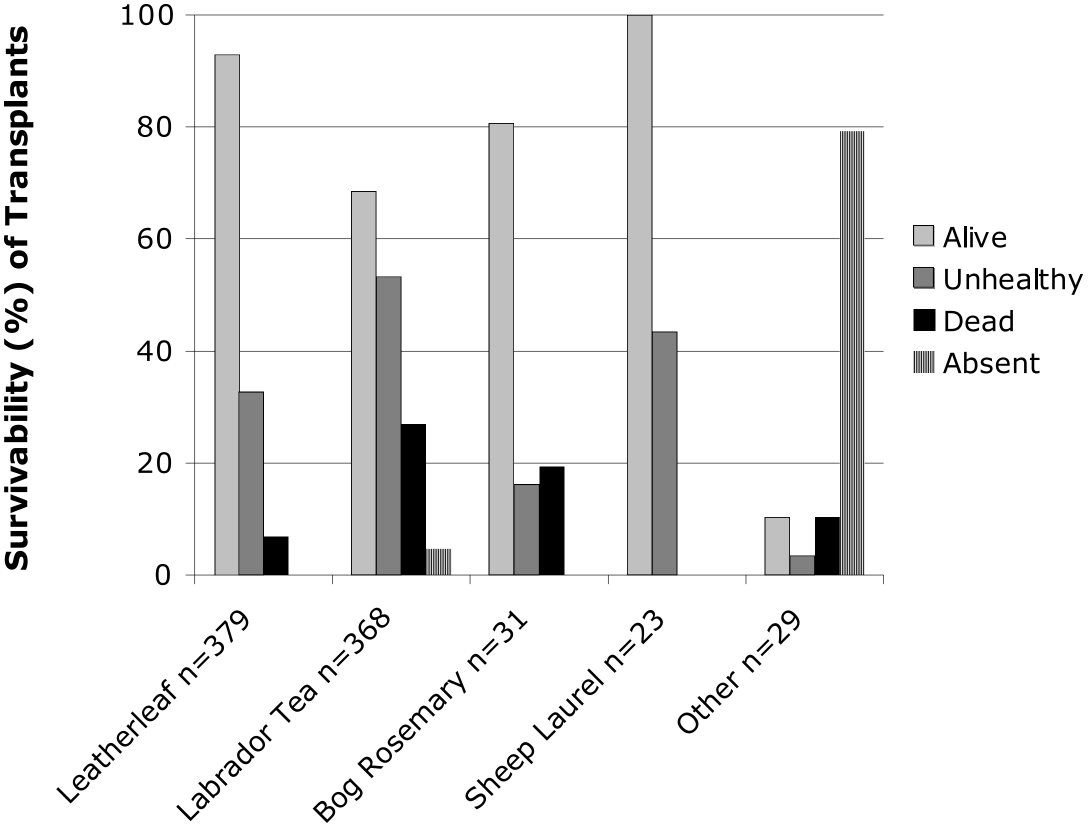


Figure 5.3.1 Survival of ericaceous transplanted shrubs by species. The number of total transplanted species of shrub is indicated by ‘n’.

5.3.2 Leaf Growth Rate

It was expected that there would be a significant effect of fertilizer on plant growth rate, based on the results of Sottocornola et al. (2007), and because bogs are known to be phosphorous limited (Ferland and Rochefort, 1971; O’Toole and Synott, 1971). No fertilizer effect on leaf growth was detected ($p > 0.05$). While fertilizer has been shown to effect plant growth, other researchers have found that bryophytes are the most affected by phosphorus addition (Sottocornola et al., 2007). This may be a reason why a phosphate rock fertilizer effect on Labrador Tea leaf growth rate was not observed in this study.

5.4 GRAMINOIDS

5.4.1 Percent cover

Overall, fertilizer had a significant effect ($p < 0.05$) on graminoid growth in Strata 1, but not in Strata 2 and 3 (Figure 5.4.1, Figure 5.4.2, and Table 9). It is interesting to note that in Strata 1 there was a significant ($p < 0.05$) negative effect between fertilizer and straw on graminoid percent cover. One possible explanation for this effect is because of the greater amount of moss observed in straw plots. In treatments where no moss was applied (treatments 1-4), fertilizer had a highly significant ($p < 0.00001$) effect on graminoid coverage. This is similar to what other research ers have found when looking at bryophyte and graminoid interactions with respect to fertilizer (Pouliot et al. 2009). A thick layer of moss can act as a nutrient-absorbing barrier by prohibiting added fertilizer from reaching the roots of vascular plants. In contrast to the fertilizer effect, straw and moss application had no effect on graminoid cover ($p > 0.05$, Table 9). The difference between observations in Strata 1 versus Strata 2 and 3 make sense because a large portion of the plots in Strata 2 and 3 were initially covered by graminoids, and so little change was detected.

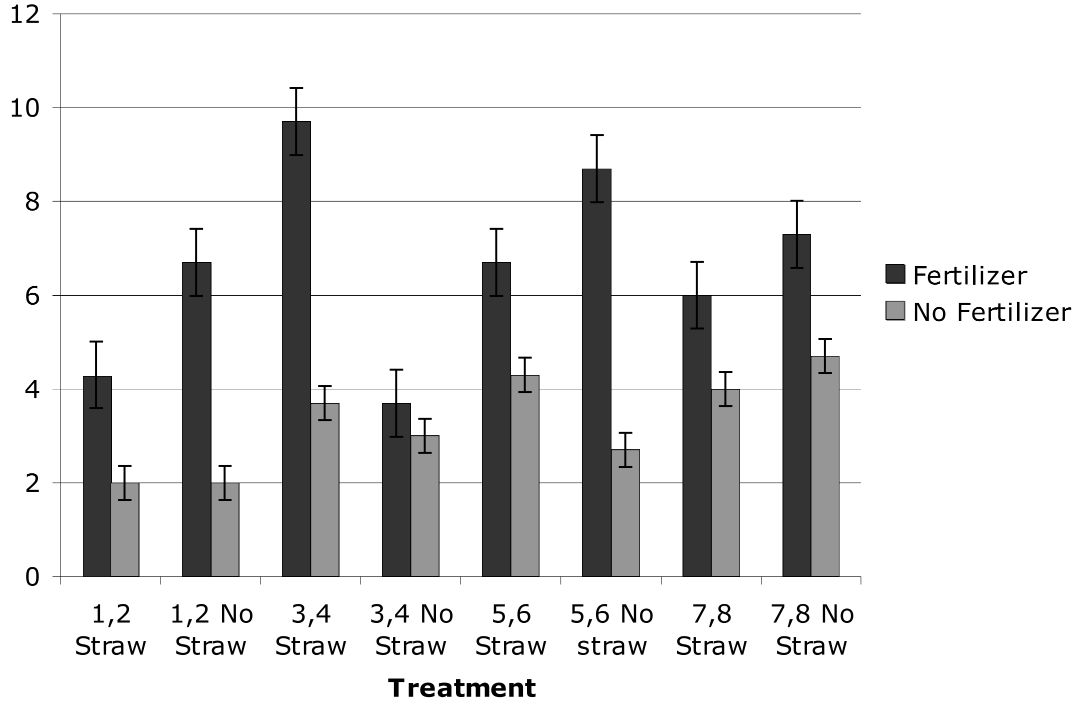


Figure 5.4.1 Strata 1 graminoid percent cover by treatment. The first column in each pair represents the treatment with fertilizer addition while the second column represents that without fertilizer. The columns are also paired with similar straw treatments. Error bars represent standard error of the mean.

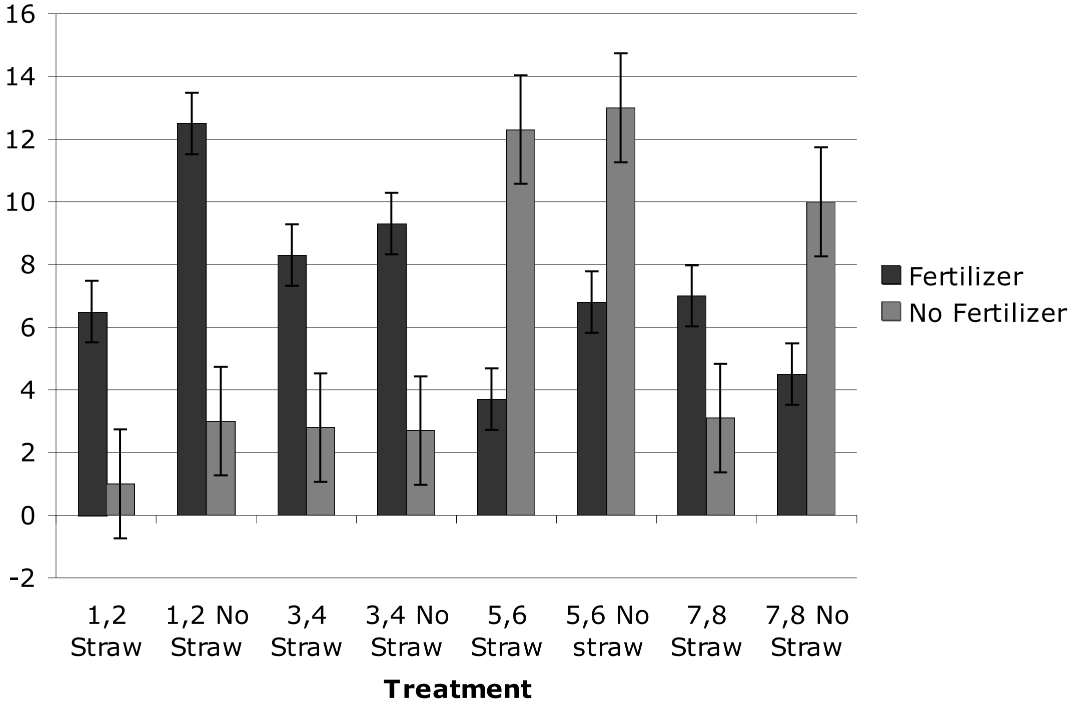


Figure 5.4.2 Strata 2 and 3 graminoid percent cover by treatment. The first column in each pair represents the treatment with fertilizer addition while the second column represents that without fertilizer. The columns are also paired with similar straw treatments. Error bars represent standard error of the mean.

Table 8 Significance levels (p-values, or ** for $p < 0.05$) of the main effects and interactions on percent cover of graminoids.

Main Effects and Interactions	**Strata 1**	**Strata 2 and 3**
Fertilizer	**	0.37
Moss	0.84	0.47
Straw	0.84	0.20
Fertilizer*moss	0.51	0.10
Fertilizer*plants	0.08	0.55
Fertilizer*straw	**	0.93
Straw*plants	0.15	1.00
Straw*moss	0.63	0.65
Moss*plants	0.57	0.96
Fertilizer*moss*straw*plants	0.91	0.83

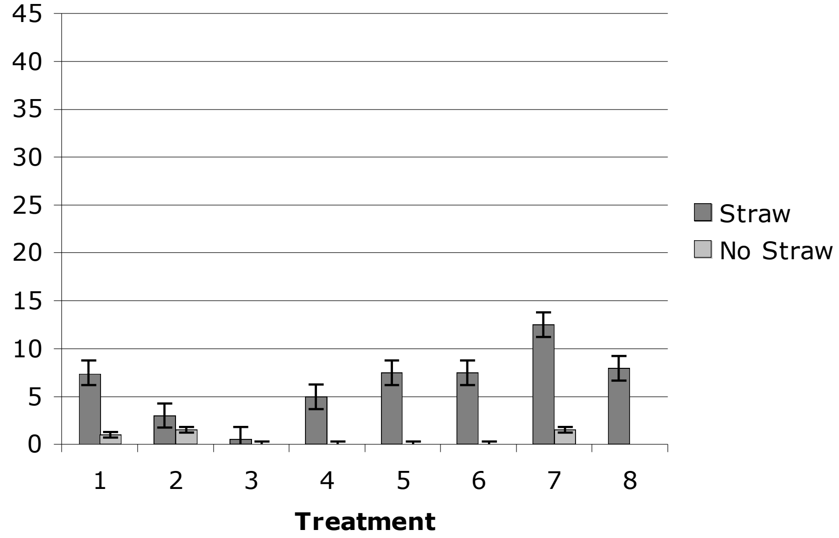
5.5 DROSERA

Drosera are carnivorous plants that are present in many peatlands. They have adapted to nutrient poor conditions and are valuable organisms contributing to species diversity. *Drosera* depend on stable hydrologic conditions (Wolf et al., 2006) and so the presence of these species in a restored site may be an indication of successful restoration.

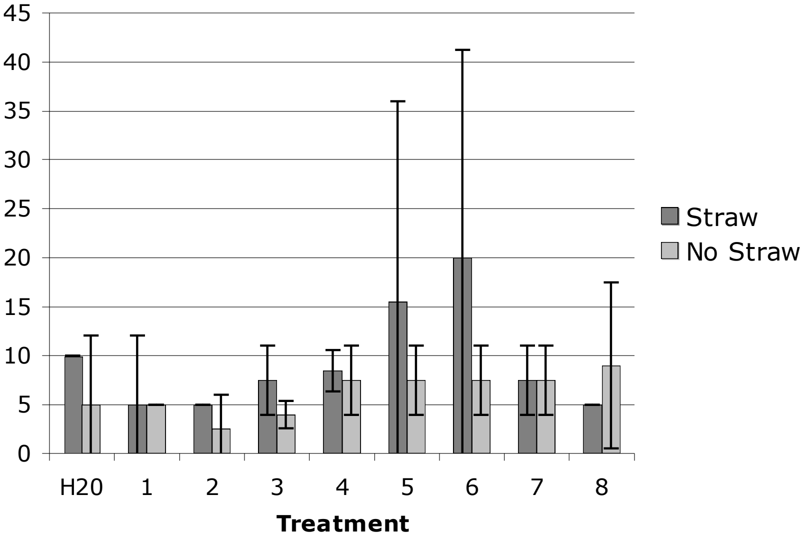
5.5.1 Frequency

In Strata 1, straw had a significant effect ($p < 0.05$, Table 5) on the number of *Drosera* plants, with more *Drosera* occurring in straw treatments. In Strata 2 and 3 however, *Drosera* were not observed in higher numbers in straw treatments. A possible explanation for these results may be related to the level of hydrologic variability between sites. At the more severely damaged Strata 1, straw may have contributed to the maintenance of adequate moisture levels, necessary for the regrowth of *Drosera sp.* (Wolf et al., 2006). Throughout the season, Strata 1 were frequently flooded and straw cover was most likely able to keep the plants afloat, allowing them to capture food. In Strata 2 and 3, the fen-like conditions were more favorable to *Drosera* (higher mean number of plants observed). The sedges found in the disturbed areas of Strata 2 and 3 probably provided necessary structure to allow *Drosera* plants to maintain proper saturation conditions where the plants have adequate access to water but are not completely submerged (Fontaine, et al., 2007). Fens dominated by sedge are known to be favorable to *Drosera* species (Wolf et al., 2006). A significant ($p < 0.05$) fertilizer effect was detected in Strata 2 and 3, with more Drosera occurring in fertilized areas. A possible reason for this observation is that the fertilizer appeared to promot graminoid growth, which provided more favourable conditions for *Drosera*. However, a fertilizer effect was not detected in Strata 1.

Other researchers have also found conflicting results with respect to fertilizer effects on *Drosera.* Sliva and Pfadenhauer (1999) observed a greater establishment of *Drosera rotundifolia* in areas that had been fertilized with phosphorus, but Stewart and Nilsen (1992) found that phosphorus addition reduced the growth of *Drosera*. The carnivorous *Drosera* plants are able to obtain nutrients from insects and so may not be as dependent upon added nutrients.



a)



b)

Figure 5.5.1 Frequency of *Drosera* plants observed by treatment and Strata. Treatments receiving straw are treatments 2, 3, 6, and 7. Error bars represent one standard deviation. a) Strata 1, b) Strata 2 and 3.

Table 9. Significance levels (p-values, or ** for p<0.05) of the main effects on Drosera Frequency

Main Effects and Interactions	Strata 1	Strata 2 and 3
Moss	0.17	1
Plants	0.86	0.29
Fertilizer	0.97	**
Straw	**	0.66
Fertilizer*moss	0.23	0.28
Fertilizer*plants	0.72	0.12
Fertilizer*straw	0.10	0.11
Straw*plants	0.10	0.26
Straw*moss	**	0.69
Moss*plants	0.16	0.66
Straw*Fertilizer*Moss*Plants	**	0.22

5.5.2 Leaf length

There was no significant difference ($p > 0.05$) between leaf lengths of *Drosera* plants for any treatments. Other studies that have examined the effects of phosphorus addition on *D. rotundifolia* growth also have not detected any change in leaf size due to fertilization, but rather a change in number of leaves and leaf mass (Svensson, 1995). It is not surprising that fertilization was observed to have a greater effect on moss and grass growth than that of *Drosera,* because fertilization is shown to benefit generalist competitors, not the carnivorous *Drosera* (Wolf et al., 2006).

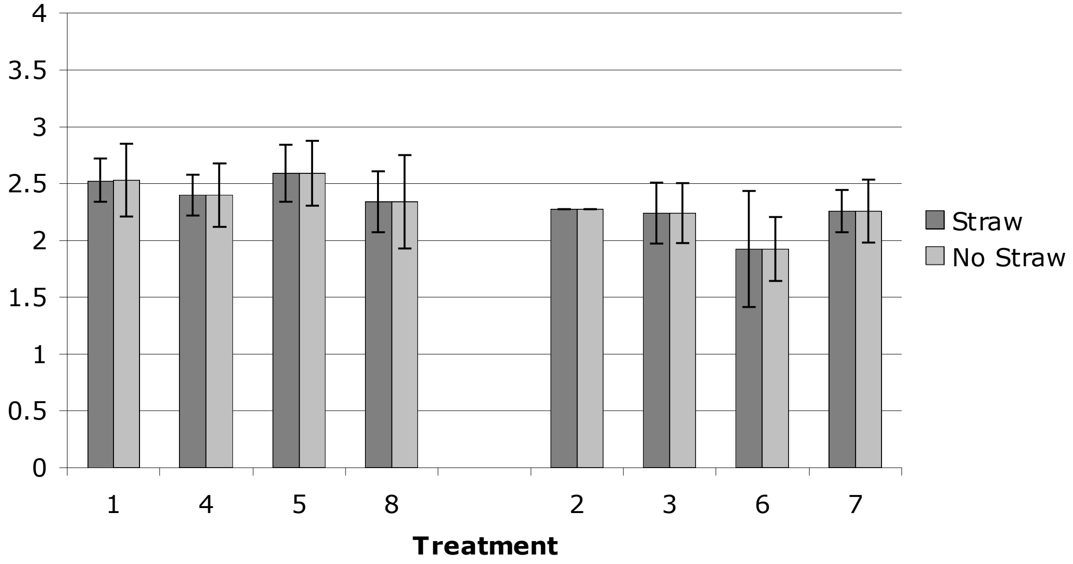


Figure 5.5.2 Average Length of *Drosera* Leaves across all three strata. Error bars represent standard error of the mean. Treatments 1, 4, 5, and 8 received no fertilizer while the others were treated with phosphorus. *Note there was very little error in treatment 2.

Chapter 6: Conclusions

6.1 SITE PREPARATION

The benefits of field preparation such as leveling and decompacting, and its contribution to restoration success, were evaluated in this study. While there was no significant effect on measured water table level between the prepared and unprepared sites, visual inspection showed that water was more often pooled on the surface in the unleveled and unprepared areas.

6.2 EFFECTS OF STRAW MULCH COVER

In areas covered with straw (approximately 1700 kg ha^{-1}), the depth to water table was significantly less than in areas without straw cover, indicating that straw helped to keep the water table closer to the soil surface. The effect of straw cover on evaporation rates, VWC, pH, percent organic matter, and electrical conductivity were inconclusive, but results showed that the depth of oxidation was significantly less in areas covered with straw.

Straw cover had significant effects on both moss growth and percent cover. Areas covered with straw had a mean percent cover of 70% and height of 1.8 cm, while areas without straw had a mean coverage of 44% and height of 1.2 cm. In addition to providing favorable conditions for moss growth, straw probably provided stability and structure for the moss fragments. There was no significant effect of straw on the survival or growth of transplanted ericaceous shrubs, however in some plots the presence of straw increased the frequency of the carnivorous plant *Drosera.*

6.3 EFFECTS OF FERTILIZER

The effects of phosphate rock fertilizer application (100 kg ha^{-1}) on moss and ericaceous shrub transplant survivability and regrowth was also assessed. While no significant effect on moss or shrubs was observed, fertilizer did significantly impact the presence of graminoids, which may contribute to the success of moss colonization and may limit the need for repeated application of straw mulch. Fertilizer seemed to have little effect on the growth or survival of any other plants.

6.4 VEGETATION APPLICATION

In areas where *Sphagnum rubellum* or *Sphagnum fuscum* moss fragments were applied (85% coverage), there was significantly more *sphagnum* coverage than in areas where no moss was applied. The transplanted ericaceous shrubs, mainly *Chamaedaphne calyculata* and *Ledum groenlandicum* possessed high mortality rates and had no contribution to moss growth.

6.5 EFFECTIVE TREATMENT COMBINATIONS

The main objective of this research was to recommend a procedure for the complete restoration of the Lake Charlotte Peatland. In each ecosite (Strata 1, 2 and 3) it is recommended to use the same procedure. The recommended procedure for the remaining disturbed areas should be to prepare the area with leveling, and decompact the soil. Moss fragments should be applied, and phosphate rock fertilizer should be added with an application rate between 100 kg ha^{-1} and 200 kg ha^{-1}. Finally, straw mulch should be spread over the entire site at a rate of approximately 1700 kg ha^{-1}.

6.6 NEW FRONTIERS IN PEATLAND RESTORATION

This study provides new information on peatland restoration to damage caused by ATV use in bogs and fens in Nova Scotia. The method outlined in this thesis suggests that slightly different techniques (hand application of moss, shrubs, fertilizer, and mulch) than those used for areas damaged by peat harvesting (mechanical spreading of vegetation, fertilizer, and straw) will be most effective for repairing ATV damage in peatlands. This work describes a technique for restoring linear disturbances to peatlands that are inexpensive at low cost and requires minimal manpower.

6.7 Recommendations

1. Even though a procedure for restoration of peatlands damaged by ATV trails in Lake Charlotte, Nova Scotia has been evaluated and some recommendations can be provided based on this research, further monitoring over another growing season is needed to effectively determine the success of these restoration techniques. A longer-term monitoring program would provide more information on hydrologic conditions over time as well as a time frame for establishing a thick moss carpet and new growth of other peatland species. Key things to monitor should include the establishment and depth of moss cover and establishment of plant community in relation to reference sites.
2. More research conducted in each ecosite would provide an opportunity to better distinguish specific characteristics (e.g. peat chemistry, topography, or geologic data) of each strata, to help determine the best way to adapt these approaches to similar ecosites in other locations.
3. The creation of a regional database including information about the site and its disturbances as well as methods, costs, and success of restoration would be beneficial for sharing ideas about approaches to restoring peatlands that would also benefit compensatory mitigation projects required in peatlands for regulatory purposes.

4. Other research studies should be conducted on other types of small-scale linear peatland disturbances such as forestry vehicle tracks, power lines, and hiking trails.

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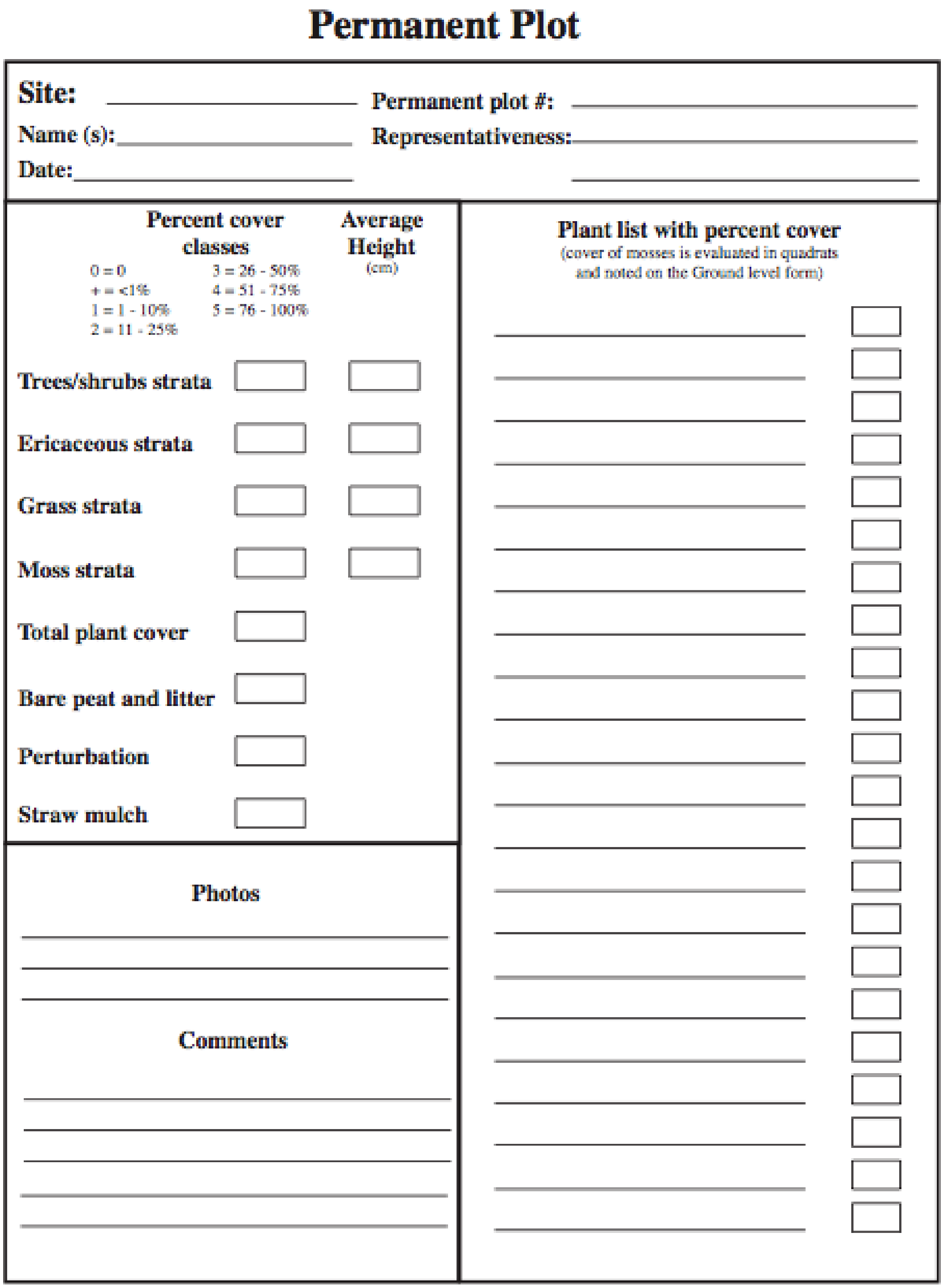
Appendix A



Permanent Plot

Site: ______________________ **Permanent plot #:** ______________________

Name (s): ______________________ **Representativeness:** ______________________

Date: ______________________ ______________________

	Percent cover classes	Average Height (cm)
	0 = 0 + = <1% 1 = 1 - 10% 2 = 11 - 25% 3 = 26 - 50% 4 = 51 - 75% 5 = 76 - 100%	
Trees/shrubs strata	☐	☐
Ericaceous strata	☐	☐
Grass strata	☐	☐
Moss strata	☐	☐
Total plant cover	☐	
Bare peat and litter	☐	
Perturbation	☐	
Straw mulch	☐	

Photos

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____

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Comments

____

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____

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

______________________ ☐

______________________ ☐

______________________ ☐

______________________ ☐

______________________ ☐

______________________ ☐

______________________ ☐

______________________ ☐

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Ground level
Percent cover of mosses in quadrats

Site: ______________________ **Date:** ______________________

Permanent plot #: ______________________ **Name (s):** ______________________

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

Notes:

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

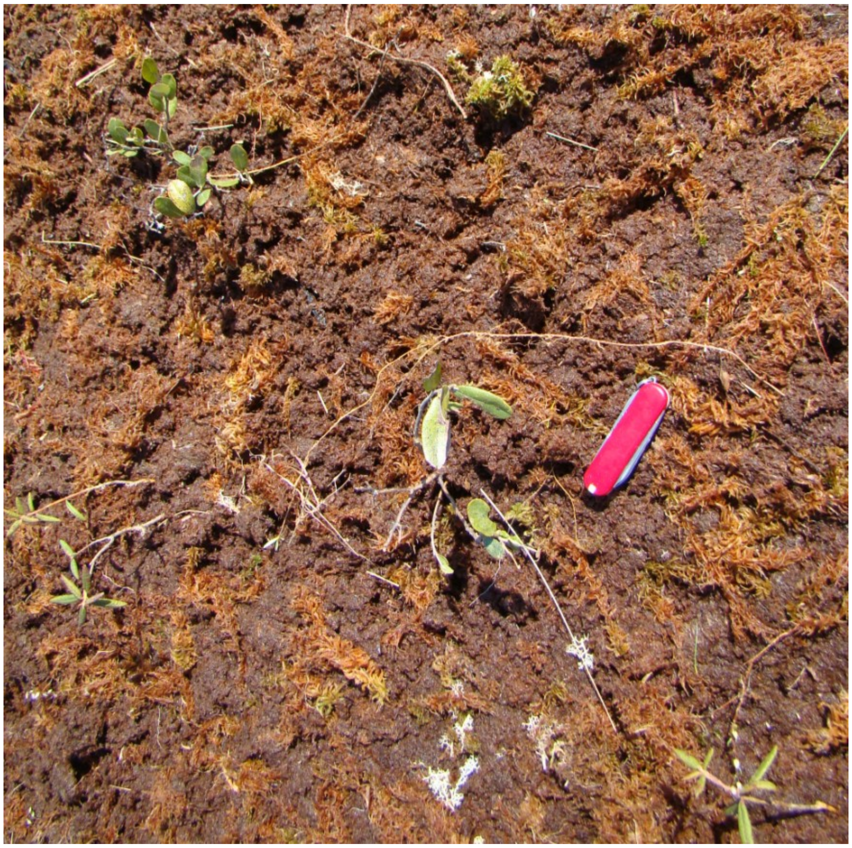
Appendix B

Initial shots prior to restoration

Plot Construction

Moss Application

Ericaceous Shrub Transplantation



Plot 1

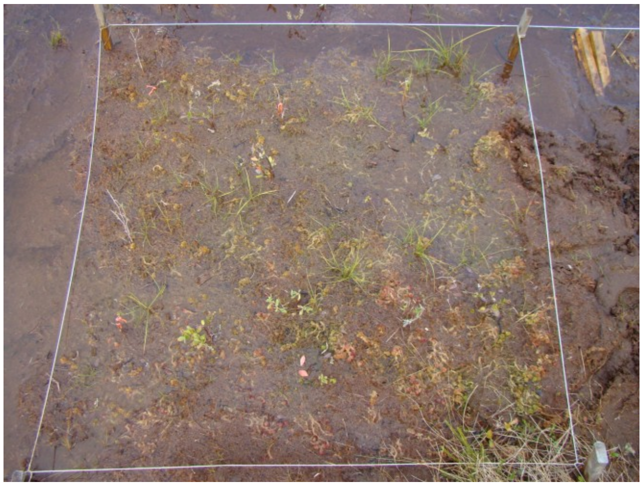
7.5.09

7.29.09

10.5.09

Treatment 7 No straw

7.5.09

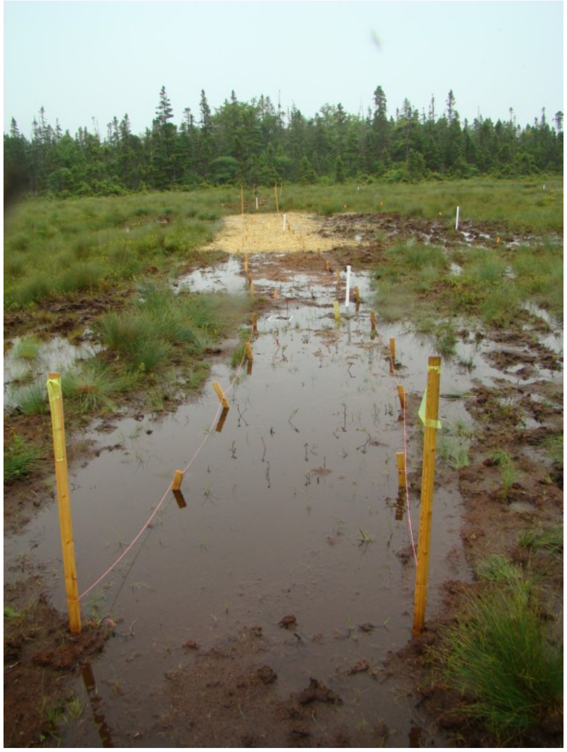


10.5.09

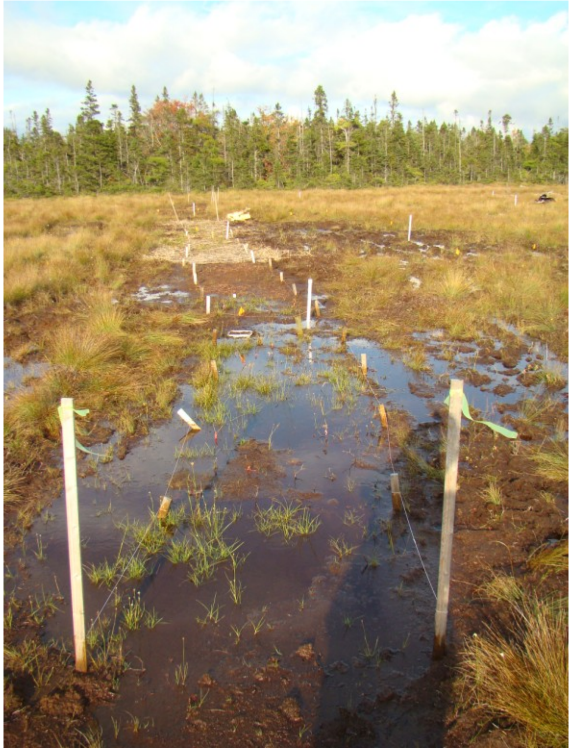
Disturbed

7.5.09 10.5.09

Plot 2

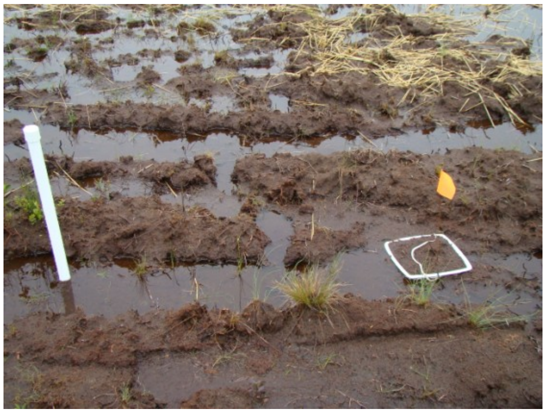


7.22.09



10.5.09

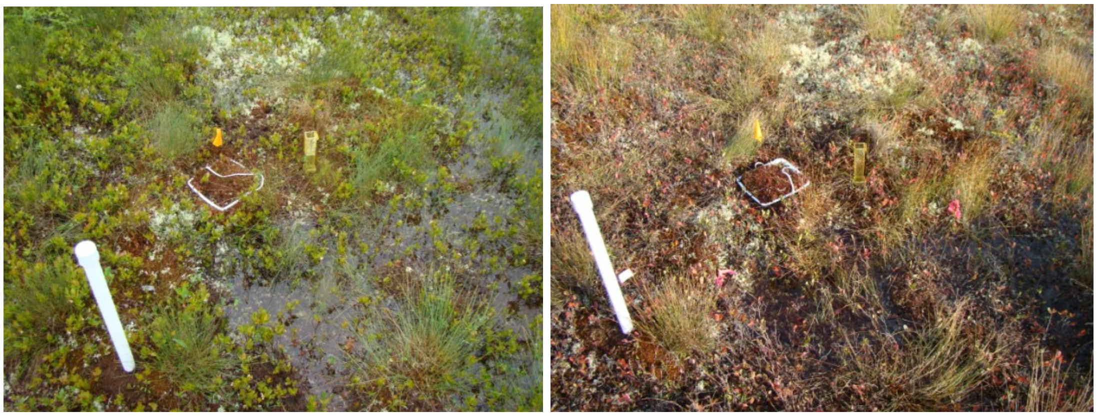
Disturbed



7.22.09

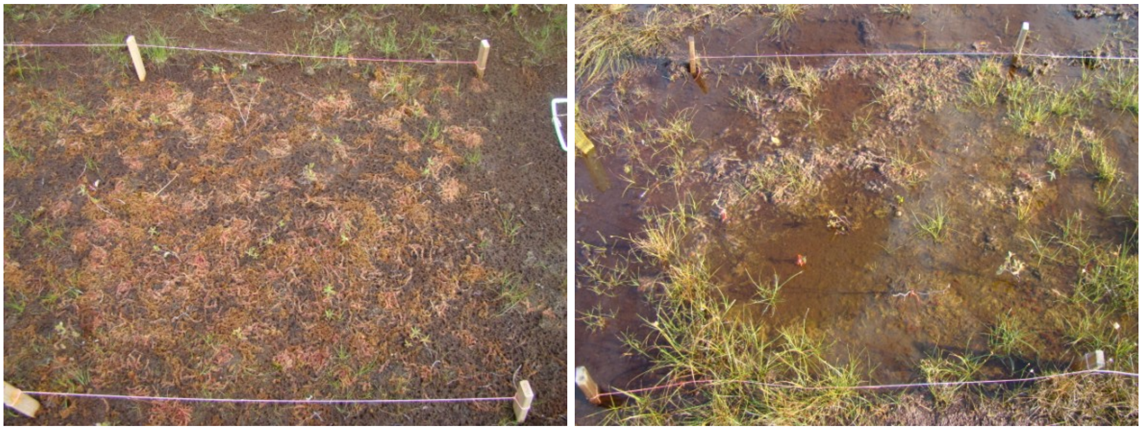
10.5.09

Control



7.22.09 10.5.09

Treatment 7 No straw



7.5.09 10.5.09

Treatment 7 with straw


10.5.09

Plot 3


7.5.09 9.17.09

Control

Disturbed

7.22.09

9.17.09

Treatment 7 No Straw


7.5.09


10.5.09

Treatment 7 With Straw


10.5.09

Plot 4

6.15.09

9.23.09

Control

6.15.09

9.23.09

Treatment 7 No Straw

6.15.09

9.23.09

Treatment 7 With Straw

9.23.09

Disturbed

6.30.0-9

9.23.09

Plot 5

7.25.09

9.23.09

Control

Treatment 7 No Straw

6.15.09

9.23.09

Treatment 7 with Straw

9.23.09

Disturbed


8.11.09

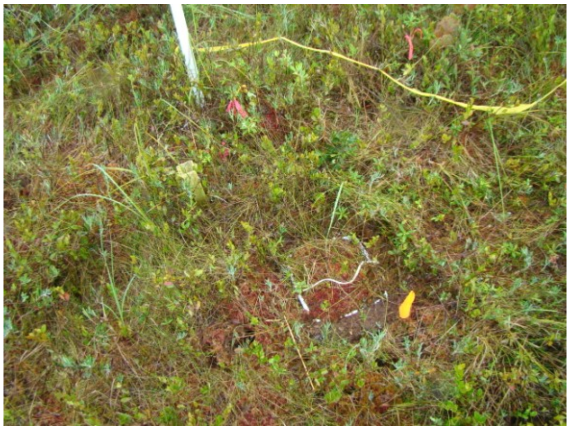

9.23.09

Plot 6

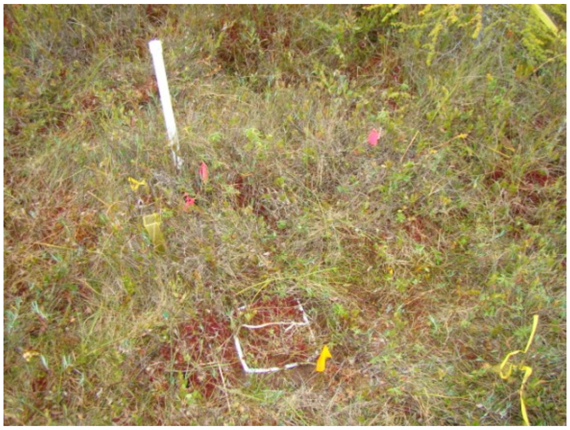

6.15.09


10.1.09

Control



8.11.09



10.1.09

Treatment 7 No Straw

6.15.09

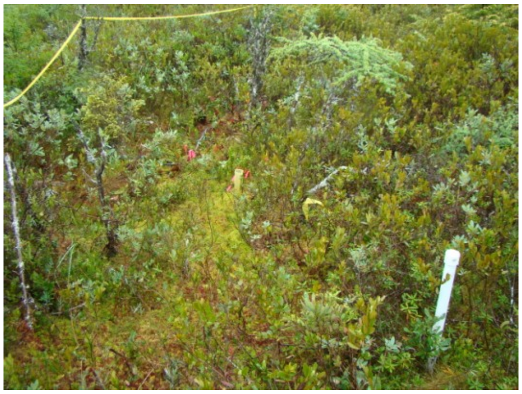
10.1.09

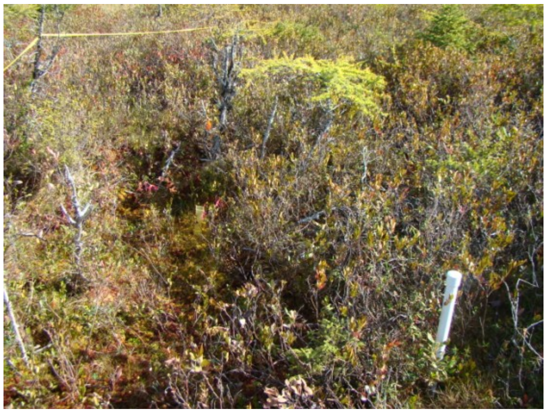
Treatment 7 With Straw

Plot 7

6.15.09 10.2.09

Control





Treatment 7 No Straw

6.15.09

10.2.09

Treatment 7 With Straw

10.2.09

Disturbed

8.11.09

10.2.09