Plant-environment relationships in a disturbed wetland system

by

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Abstract

Efforts are increasing to mitigate pressures on wetlands from human disturbance. Conservation of these systems requires expansive knowledge of ecosystem structure and underlying environmental gradients exerting control over plant distribution. A multitude of environmental gradients important in undisturbed wetland systems have been studied extensively. The most important have been shown to be: acidity/base richness, nutrient status, water level fluctuations, and organic matter accumulation (Bridgham et al., 1996). Human modification of wetland hydrology may alter the relationships between species distribution and underlying environmental gradients. It is therefore important to study the plant-environment relations in disturbed systems to collect baseline data and subsequently monitor changes in the system.

The primary aim of this thesis was to examine which environmental gradients were important in the distribution of wetland species in a disturbed stream fen/mound bog system. The study area, Blaney bog, is a wetland that has been modified by the construction of a dyke/canal system dividing the area into two separate sections. Aerial photographs and primary survey showed that four plant community types dominate the Blaney bog landscape: *Kalmia occidentalis, Phalaris arundinacea, Spiraea douglasii*, and *Carex* spp.. In accordance with the primary aim, a dipwell network was established in the four plant community types. Soil water was sampled from the dipwells for a ten month period, peat cores were collected and the vegetation was surveyed at each site. In addition to the initial 16 dipwell sites, 22 sites were added to the study. At these additional sites the same vegetation and soil data was collected however because the sites lacked dipwells, the water was sampled only once. Data analyses addressed the inter-relations between the water and soil variables and plant community composition. Non-parametric analyses of variance were used to examine if the differences between plant community groups were significant. Spearman's correlation coefficients were calculated to examine relationships between environmental variables. All variables were also analyzed simultaneously using the Nonmetric Multidimensional Scaling method.

Results showed that the Kalmia sites were the most representative of poor fen sites. Sites in the other three plant communities varied in their chemistry compared to the expected range found in undisturbed fens. Water components were much more variable than the soil components. The bog-fen gradient was clearer in the pH values, cation concentrations and nutrient status in the soil compared to unclear patterns in the water data. Although total soil nutrient concentrations may not be reflective of nutrient availability, overall the soil components are much more static and present a clearer picture of site conditions at Blaney bog. The disturbance caused by the dyke/canal system and possibly ongoing influx of drainage waters from neighboring agricultural land, are thought to substantially affect the hydrology of this wetland. Effectively, the water table and chemistry are much more dynamic than in undisturbed wetland systems. This study recommends that future monitoring Blaney bog should focus on the soil component rather than the water component and should further investigate the effect of water table fluctuations on plant distribution.

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Finally, a great thank you to my family and friends for their limitless love and support.

Chapter 1: Introduction

Historically, the greatest threats to wetlands have been conversion to agricultural land, urban growth and industrial expansion, resulting in approximately one seventh of Canada's total wetland base drained or lost to other functions (Government of Canada, 1991). Millions more hectares have also been seriously degraded or are at risk as a result of cumulative effects of pollution, competing and incompatible uses and other intrusions affecting the quality and character of wetlands (Lynch-Stewart et al., 1999). Nevertheless, many important functions of wetlands are being recognized: unique habitat, water quality improvement, water storage and absorption, flood control and possible sinks of excess atmospheric carbon (Tiner, 1999). Depending on the intensity of disturbance and specific management objectives, wetland systems are increasingly being protected, restored or recreated. As a result, successful management of these highly threatened ecosystems has become an important topic in recent decades.

Wetlands are complex systems where limiting environmental conditions are closely related to distinct vegetation patterns. Vegetation patterns in wetland complexes generally show plant communities separated by relatively abrupt boundaries with transition zones spanning only a few meters. The observed zonation is thought to reflect underlying environmental gradients. Gradients associated with hydrology, nutrient availability and acidity/base richness have been shown to have close links to plant community structure and ecosystem function in wetlands (Bridgham et al., 1996). The observed environmental gradients in turn correspond to changes that occur during wetland ecosystem development, particularly the accumulation of organic matter which has substantial effects on hydrology, nutrient status and acidity/base richness of the system.

The body of literature on disturbed wetlands is smaller and tends to focus on effects of peat extraction and rehabilitation strategies (Maltby, 1996). Inferences are made about biogeochemistry, hydrology and plant communities, which are presumed to be true without supporting data, relying on the theoretical framework set out by wetland ecologists. However, studies that have focused on affected sites show that disturbing a site may alter the chemistry and consequently the relationship between vegetation and the underlying chemical gradients (Charman, 2002; Haslam et al., 1998; Keddy, 2000; Maltby, 1996). This information is essential as efforts to mitigate, conserve, or restore disturbed wetlands are increasing. Management of wetlands will be more successful if the ecological relationships are known and efforts to monitor changes in the system are based on a solid understanding of baseline conditions.

The primary aim of this thesis was to carry out a base-line study to provide a reference point from which trends in ecosystem change can be monitored and predicted. Specifically, this study investigated the reasons for the pattern and species composition of the various plant community-types in a disturbed stream fen/mound bog complex and examined which environmental gradients were important in the distribution of these wetland species. The research questions were:

- What environmental factors are important in the distribution of wetland species?
- Which environmental factors have been affected by human modification of the study area?
- Which environmental factors can be used as parameters for a monitoring program of further changes to the study area?

In accordance with the primary aim, analyses of chemical variation of the soil water and soil extracts were carried out across the range of plant community types. Soil water sampling spanned a 10 month period to account for seasonal variation and to assure sufficient chemical information. Although most wetland studies focus on water chemistry (Mitsch & Gosselink, 2000), the soil component was also studied to enable analyses of soil nutrient status and base richness in the wetland. Analyses address the inter-relation of the variables measured and their implications in terms of plant community composition and environmental processes within the wetland. The relationships between environmental variables and wetland plant distribution were compared to studies on natural wetlands. A comparison was made between plant communities and their environmental conditions relative to plant community characteristics in natural conditions based on the literature.

Based on these comparisons, the environmental variables examined are discussed and ranked with respect to their tendency to be altered in disturbed wetlands (dynamic components) and those that are less affected by the disturbance and better reflect conditions in undisturbed sites (static components). It is argued that the static components are more suitable indicators for monitoring site conditions because these reflect changes in the long-term and are less prone to seasonal short-term fluctuations. An ecological indicator is a "characteristic of an ecosystem that is related to, or derived from, a measure of biotic or abiotic variable, that can provide quantitative information on ecological structure and function" (Tiner 1999). Indicators provide a useful measure based on baseline conditions where they are used to characterize current status and then to track significant change or trends in change from baseline conditions. Indicators used for monitoring ecosystem state should be representative of ecosystem condition; responsive to change; repeatable; cost effective; and easy to measure.

Thesis objectives

The specific objectives are to examine the following aspects of vegetation and chemistry:

1. Distribution of characteristic species across the different wetland communities (vascular and bryophyte components)
2. Distribution of major elements across the wetland communities
3. Distribution of nutrients across the wetland communities, and
4. The difference in seasonal variation in water levels and chemistry.

Thesis framework

This introductory chapter includes a literature review relevant to organic wetlands. The study area is described in detail in Chapter 2. Chapter 3 is a detailed account of the methods used in this study. The results are presented in Chapter 4 and are discussed in light of work that has been done in this field. Finally, in the concluding chapter the study is summarized with respect to characteristics of each plant community type and the environmental components are reviewed with respect to their suitability in assessing site conditions.

Literature review

Wetland definition and classification

Wetlands have been broadly defined as areas with a high water table or standing water, unique soil conditions and vegetation adapted to wet environments. Wetlands are ubiquitous and abundant in the Canadian landscape. Northern boreal and subarctic wetlands that are mostly peatlands cover approximately 1.1-1.2M km^2 or 150 million hectares, representing 24% of the world's wetlands (Government of Canada, 1991). Because of the large variety of these types of ecosystems, from estuaries to peatlands, several formal detailed definitions have been developed for scientific and management purposes. Among the most internationally accepted definitions is the Ramsar Convention on Wetlands which states: "wetlands are areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt including areas of marine water, the depth of which at low tide does not exceed 6 meters" (1971). In Canada, the formal definition of wetlands, first developed by the National Wetlands Working Group is: "land that is saturated with water long enough to promote wetland or aquatic processes as indicated by poorly drained soils, hydrophytic vegetation and various kinds of biological activity which are adapted to a wet environment" (Warner & Rubec, 1997; Zoltai & Vitt, 1995). All current definitions of wetlands emphasize three key characteristics, hydrology (the degree of flooding or soil saturation), hydric soils and hydrophytic vegetation (Tiner, 1999).

In most wetland classification systems, hydrology is used as the diagnostic functional parameter with characteristic vegetation and soils as indicators of these systems (Tiner, 1999). Formation and ecosystem development are also defining characteristics important in wetland classification and delineation (Mitsch and Gosselink 2000). The Canadian wetland classification system is a practical hierarchical system subdivided into: *classes* based on properties that reflect the origin of the wetland system; *forms and subforms* based on surface morphology, water type and mineral soil morphology; and lastly *types* based on the characteristics of the vegetative communities (Warner and Rubec, 1997). Although based primarily on physical parameters, this system indirectly recognizes a hydrogeomorphic and ecosystem development approach (Warner and Rubec, 1997). In the classification scheme there are two main categories: organic wetlands (peatlands characterized by more than 40cm of peat accumulation on which organic soils develop) and mineral wetlands (wetlands characterized by Gleyosolic soils or peaty phases of these soils where due to edaphic or climatic reasons peat does not accumulate). The three categories of organic wetlands are: 1) bog- peatland receiving water only from precipitation and not influenced by groundwater with sphagnum dominated vegetation; 2) fen- peatland receiving water rich in dissolved minerals with vegetation cover composed dominantly of graminoid species and brown mosses; and 3) swamp- peatland with waters rich in dissolved minerals and dominated by trees, shrubs and forbs (Warren and Rubec, 1997).

Although classification is useful as a starting point in wetland studies, the defined categories attempt to delineate stages that in reality exist along a successional continuum unique to these systems. All systems vary in their approach and some believe that "no single system can accurately portray the diversity of wetland condition. Some important ecological information inevitably will be lost through classification"(Keddy, 2000). The distinctions between bog and fen are strongly debated, particularly in relation to the boundaries based on differences in chemistry, a function of hydrology, which in turn translates into differences in plant composition (Wheeler and Proctor 2000).

In the existing literature on wetland terminology there is a wide variation in conditions used to distinguish fen from bog. Damman (1995) and Wheeler and Proctor (2000) have recently reviewed the literature and suggest that the classic definition of bog associated with a topographical unit (raised bog) be adjusted to represent vegetation units that are not necessarily raised bogs. In this scheme, ombrotrophic and minerotrophic bogs are possible. Also fens can range from eutrophic reedlands, to mesotrophic small sedge fens and fen carrs, to nutrient poor fens. Zoltai and Vitt (1995) proposed similar distinctions based on distribution and characteristics of Canadian wetlands.

Ecosystem development and structure

In general, peatland ecosystem development results from a specific mix of climate, hydrology, topography and vegetation that favor constant conditions where precipitation exceeds evapotranspiration and peat accumulation is greater than decomposition. The three major formation processes are: 1) *terrestrialization* where filling in of a lake eventually produces a bog; 2) *paludification* where overgrowth of peatland vegetation spreads to adjacent terrestrial areas; and 3) *flowthrough succession* where peatland development modifies surface water flow (Moore and Bellamy 1974).

The pattern of peatland formation is easily retrievable from its peat stratigraphy which holds a vast amount of information on historical changes in climate, geology and successional patterns in plant communities. Studies of sediments and peats reveal a common successional sequence from reedswamp of Phragmites and large Carex species, to shrub fen communities and lastly Sphagnum- dominated bog where the accumulating peat forms mounds above the water level (Walker 1970; Moore and Bellamy 1974).

During peatland development, slowing of decomposition rate causes organic matter content to increase, thereby increasing the soils capacity to adsorb and exchange cations, consequently causing a concurrent decrease in the pH level of these ecosystems (Moore and Bellamy 1974). At the same time, nutrient availability in peat changes from eutrophic (rich in nutrients), to mesotrophic and finally nutrient-poor oligotrophic. Peat accumulation above the water table causes the formation of a specific microclimate with low nutrients and low pH, which favors Sphagnum-dominated flora and eventually a positive feedback system isolated from surface and subsurface water and nutrient renewal (Glaser et al. 1997).

Accordingly, development and structure of a bog ecosystem largely depends on soil and water chemistry. Waterlogged, acidic, nutrient deficient environments of peatland systems provide habitat only to biota that are adapted for these specific conditions. The transition in environmental conditions has also been found to be pronounced in bryophyte species with a decline in brown mosses and increasing sphagnum cover (Gignac et al., 1991; Gorham & Janssens, 1992). There exists a strong interdependence between peatland vegetation and environmental conditions where plant communities have significant influence over soil development and soil water chemical properties. In turn, pH, available nutrients, cation exchange capacity and mineral concentrations, among other factors, influence plant community types and productivity.

Important environmental factors in wetland studies

Hydrology and the Water table

Wetland hydrology is fundamental in determining and maintaining the complex feedback loops between the physical, chemical and biological processes of wetlands (Hughes & Heathwaite, 1995). The hydrology of wetlands is influenced by local climate (precipitation, temperature, wind and insulation), geomorphology (landform and soil parent material) and topographic position. The water balance is a fundamental characteristic of hydrology and key indicator of the dynamics of water supply and loss in systems. The water balance in wetlands is positive where the inputs exceed the outputs. Hydrological inputs include precipitation, groundwater inflows and surface runoff. Outputs include runoff, seepage to groundwater or from interception and evapotranspiration. Not all types of flows are relevant to all wetlands. For example true raised bogs only receive precipitation as the major water supply, whereas fens, may receive rainfall, surface runoff and groundwater inflows. Storage is also key to maintaining a positive water balance. Characteristics such as topography, subsurface soil, geology and groundwater status define storage capacity of a wetland (Heathwaite, 1995). Annually, storage capacity in wetlands remains fairly constant unless human modification significantly impacts the hydrological balance of the wetland (Heathwaite, 1995). The water table can be used as a measure that summarizes all the inflow, outflow and storage information of a wetland.

The hydrological status of wetlands can be expressed by describing changes in the water table or hydroperiod. Although helpful, hydrological status is not an accurate estimation of the amount of water held within a peatland, as the peatland surface itself rises and falls in relation to the underlying mineral ground (Charman, 2002). Water table fluctuations occur over various timescales and in response to cyclical factors as well as particular hydrological events (Charman, 2002). Generally, groundwater levels in wetlands show seasonal variation with relatively high and constant levels in winter and spring, followed by decline in summer to a minimum in late summer and a rise again in the fall reaching the winter level around mid-winter (Gilman, 1994). Extreme rainfall events may skew this seasonal pattern by recharging the wetland and decreasing the decline in the water table during the summer months (Gilman, 1994). Diurnal cycles also superimpose the typical seasonal patterns with a "saw tooth" pattern due to increased evaporation during the day (Gilman, 1994). Overall, water table data tends to be skewed with values within a small range near the maximum for most of the year with larger changes for only short periods of time (Charman, 2002). In flow-through fen systems the changes in the water table are generally minimal even in summer months because of the inflow of water from streams flowing through the system (Patten, 1990). In bogs the water table also tends to be consistently high because of capillarity (Clymo, 1992).

High water table influences the wetland system by creating reduced oxygen conditions (anoxic) to which wetland species are adapted and can thrive (Gilman, 1994). Fluctuations in the water table directly affect soil properties: large oscillations in water table depth and high water movement allow for higher rates of organic matter decomposition and thereby limit build-up of organic matter and peat formation (Hughes & Heathwaite, 1995). On the other hand, a constant high water table results in waterlogging which promotes anoxic conditions and thus a low rate of decomposition, leading to build-up of organic matter and in some systems peat growth (Heathwaite, 1995). Seasonal changes in waterlogging conditions in wetland systems influence nutrient transformations and cycling. Higher summer temperatures cause higher evaporation from the substrate and water surfaces. Also, the higher temperatures allow for more active growing of the macrophyte biomass which enhances evapotranspiration rates causing further substrate dryness (Ross, 1995). Due to effect of water table fluctuations on organic matter accumulation and soil and water chemistry, data on these variables can expand the understanding of a wetland system.

Organic matter accumulation

The types of soil that arises in any environment is a function of parent material acted upon by organisms and climate and conditioned by relief over time (Sprecher, 2001). In peatland systems, the peat is the dominant substrate. Peat is a generic term for relatively undecomposed organic soil. According to most definitions, generally peat contains 22-40% organic carbon.

The two major categories in soils are: organic and mineral soils. Organic soils form from plant material and are black, porous and light in weight. These soils are common in wetlands because organic matter fragmentation and decomposition rates are low in frequently inundated areas. Mineral soils form from rocks or alluvial, aeolian, lacustrine, or glacial material and hence consist of varying amounts of sand, silt, and clay. Mineral soils are ubiquitously distributed throughout various ecosystems including wetlands. In soil science, organic carbon levels higher than 17% distinguish organic soils from mineral soils while peat may have a more specific organic carbon content (Buol et al., 1997).

The defining characteristics of a peatland are its accumulation of soil organic matter, which exerts important control of hydrology, biogeochemistry and plant community composition. Peat accumulation is primarily controlled by decay not production. Therefore environmental controls over decomposition are important in these systems. Decomposition is primarily controlled by the carbon quality of the organic substrates, aeration, temperature, and hydrology; where decomposition rates are lowest under anaerobic conditions and lower temperatures (Bridgham et al., 1996). Studies have found significant interactions between carbon and nutrient mineralization rates, temperature, aeration status, and carbon quality in a range of peatland soils (Bridgham et al., 1996). Verhoeven et al. (1994) in studies of North American and Dutch wetlands found substantially lower decay rates in bogs compared to other peatlands and mineral soil wetlands. Low nutrients and high organic matter were thought to be dominant factors explaining the low decay rates. Szumigalski and Bayley (1996) found higher decomposition rates to be associated with plant material higher in nitrogen content such as Carex spp. compared to mosses.

Acidity/base richness

The variation in base-richness of mire waters and peats is widely considered to be the primary influence on the floristic composition of wetland vegetation and is reflected in the bog-poor fen-rich fen gradient (Wheeler and Shaw, 1995). Vitt et al. (1990) in a study of Alberta fens found that pH and base cations of surface waters showed high negative correlation along the rich fen-bog gradient. Other studies of North American and European wetlands have shown similar results (Glaser et al., 1997; Proctor, 1994). The acidity of these systems depends on the balance between metallic cations and strong acid anions. pH values and mineral cation concentrations have been consistently associated with plant communities in numerous peatland studies (Mitsch & Gosselink, 2000). pH, per se is not directly important within the range of pH 4-7.5, however it has a profound effect on nutrient availability. Adaptation to growth in low pH systems may depend on tolerance to high metal (Al, Fe, Cu, Mn and Zn) concentrations (Bridgham et al., 1996).

Nutrient status

Trophic status of a peatland is determined by the availability of nutrients with the gradient from oligotrophic or nutrient poor to mesotrophic and finally eutrophic or nutrient rich. Nitrogen and phosphorus have been shown to be important nutrients in controlling plant-community structure and diversity. General relationships are difficult to demonstrate because one time or total concentration measurements of nitrogen and phosphorus do not adequately represent the availability of these nutrients and because of complicated interactions with local hydrology. In general, decreasing percent organic matter and N:P ratios and increasing total soil nutrients characterize the ombrotrophic to minerotrophic gradient (Bridgham et al., 2001).

Nutrient-availability and acidity gradients are not necessarily concurrent and numerous recent studies of North American and European wetlands question the assumption that vegetation gradients follow base-rich/pH gradients. Vitt et al. (1995) study of 100 fens in Alberta showed pH and calcium concentrations differentiated among wetland vegetation types, however nutrient concentrations showed either no relationship or a slight decrease along the bog-fen gradient.

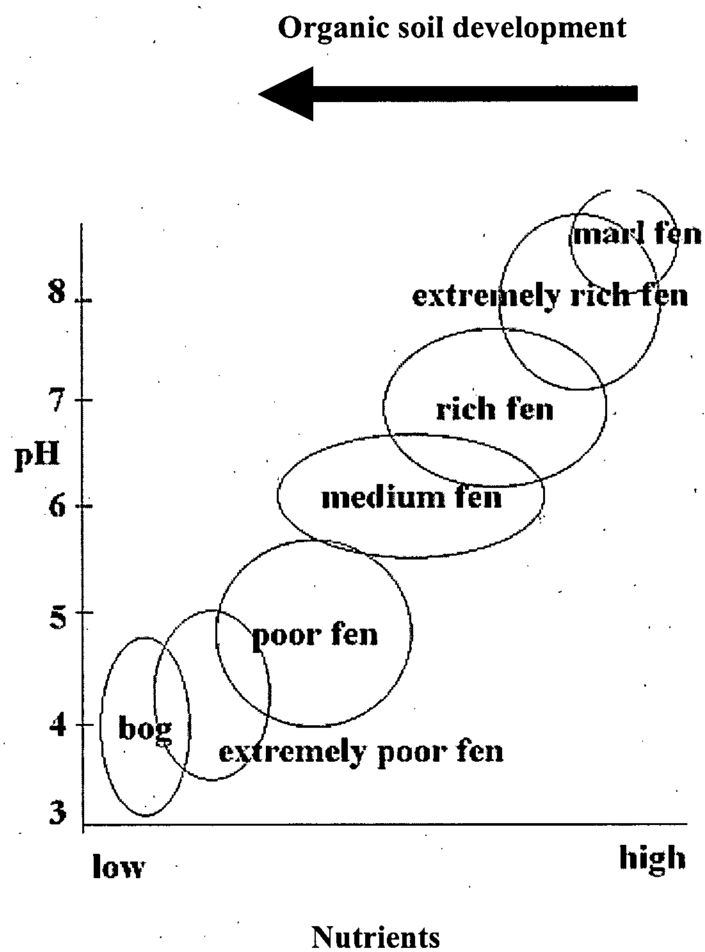
Bridgham & Richardson (1993) showed that pH and exchangeable base cation concentrations in soils did not differentiate among plant community types, and that nutrients were better predictors of community type. Bridgham et al. (1998) studies of Minnesota wetlands showed that more minerogenous (minerotrophic and eutrophic) sites have larger total soil nitrogen and phosphorus pools, but turnover is slower compared to ombrogenous (oligotrophic) sites. Because of the difference in turnover rates, nitrogen availability was higher in minerogeous sites, whereas phosphorus availability was higher in ombrogenous sites. In European wetlands studies of phosphorus release and nitrogen mineralization, bogs were found to have higher release rates than fens (Verhoeven et al., 1990). Other studies on soil nutrient availability and plant-nutrient response found similar patterns (Updegraff et al., 1995; Wheeler and Proctor, 2000; Wheeler and Shaw, 1995).

Plant-nutrient response patterns raise the question of which nutrients are most limiting in wetland systems. European literature suggests that either nitrogen or phosphorus limit wetland systems (Verhoeven et al., 1996). Some studies found that fen communities were phosphorus limited. North American studies also show variety in nutrient limitation and most commonly find co-limitation, suggesting that multiple gradients exist in wetlands and the recommendation is that more work has to be done in the area (Bridgham et al., 1996).

Summary

Wetland studies have shown that multiple gradients exist in wetlands. The important gradients have been shown to be associated with hydrology, organic matter accumulation, alkalinity/acidity and nutrient status (Figure 1-1). These environmental gradients are not necessarily consistent and recent studies show that the nutrient status of the peat may be the primary environmental gradient underlying wetland species distribution and the alkalinity/acidity or base richness gradient may be secondary. The complexity of multiple gradients influencing wetland systems necessitates baseline data on the water and soil components in addition to species data. The understanding of the complex inter-relations between wetland species distribution and environmental variables are further complicated by human modification.

Figure 1-1. Diagram of the relationship between organic soil development, nutrient availability, and acidity as reflected in peatland community type and dominant vegetation.



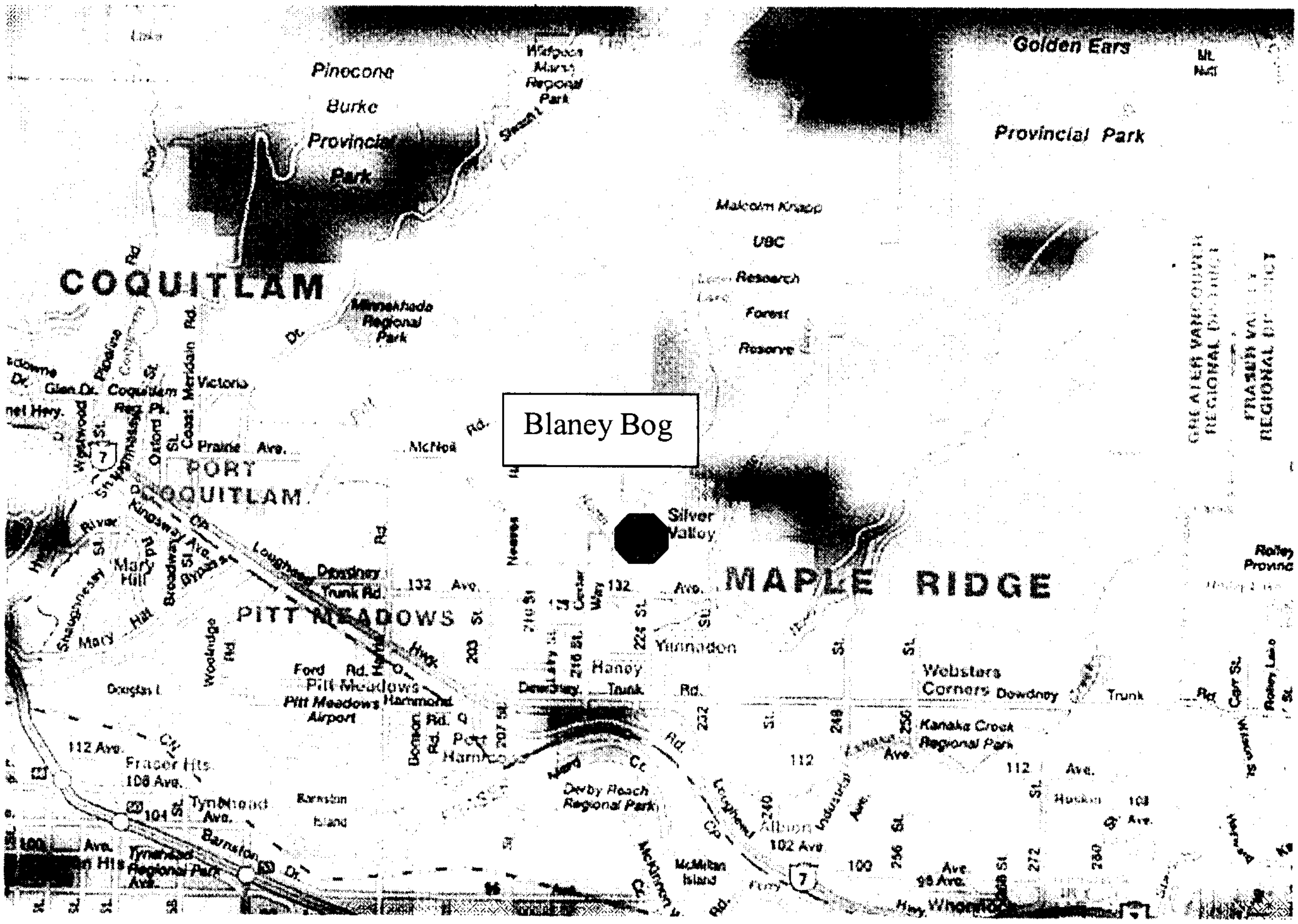
Ombrotrophic **Minerotrophic**

Sphagnum-dominated *Shrubs, sedges, brown mosses* *Grasses*

Chapter 2: Site description

Blaney Bog complex, Blaney Bog and associated organic complex, is a protected bog-fen wetland system located on 224th Street in the 13600 block in Maple Ridge, British Columbia (Figure 2-1). This site is considered to be high in conservation value and has recently been acquired from private owners to protect it as a conservation reserve. The extent of baseline knowledge is very limited as little research has been done at the site. Piteau Associates (2001) completed a small study of the geological setting and hydrology of the site. (Gebauer, 2002) compiled a review of the literature related to Blaney Bog on the plant communities, wildlife and other pertinent ecological data. GVRD staff also compiled data associated with the site for the acquisition process (McKenna, 2001). This research was not based on direct data collection from the site but secondary sources from government agencies, naturalist groups and local residents interested in the site. Direct studies on the site include a student study on the small mammal population and another study on the Greater Sandhill Crane population both carried out in recent years (Gebauer, 2002). The description below is a summary of the information that is available on Blaney Bog.

Figure 2-1. Location of Blaney Bog in the Lower Fraser Valley of British Columbia.



Physical Setting

The bog complex is situated along the southern flank of a relatively steep, bedrock-controlled, upland area (UBC Research Forest, Golden Ears Provincial Park and the Silver Valley community). The northern and eastern margins of the bog complex are moderately steep to steeply sloping in the direction of the complex, on the other hand, the southern and western sides are nearly flat and extend approximately 2km towards the Alouette River (Piteau Associates, 2001). A recently developed extensive cranberry operation spans the western edge of the bog complex (Gebauer, 2002). The bog is comprised of two landscape elements: mound bog-stream fen complex covering the eastern and southern portions (114ha) and a relic stream fen in the north-western section (33ha) partially isolated by a rudimentary dyke during the summer months (McKenna, 2001). Peat bog habitats are more prevalent in the eastern and southern sections (Gebauer, 2002). The overall area encompasses 147ha.

Climate

According to Glooschenko (1993) the area is classified as "The Pacific Temperate Wetland Region", where characteristic wetlands include conifer swamps, domed or flat bogs and flat fens. The climate is characterized by high precipitation (mean annual total precipitation 95 cm and 70cm snowfall), mild winters (mean daily January temperatures -3°C) and warm summers (mean daily July temperatures 16°C) (Glooschenko et al., 1993).

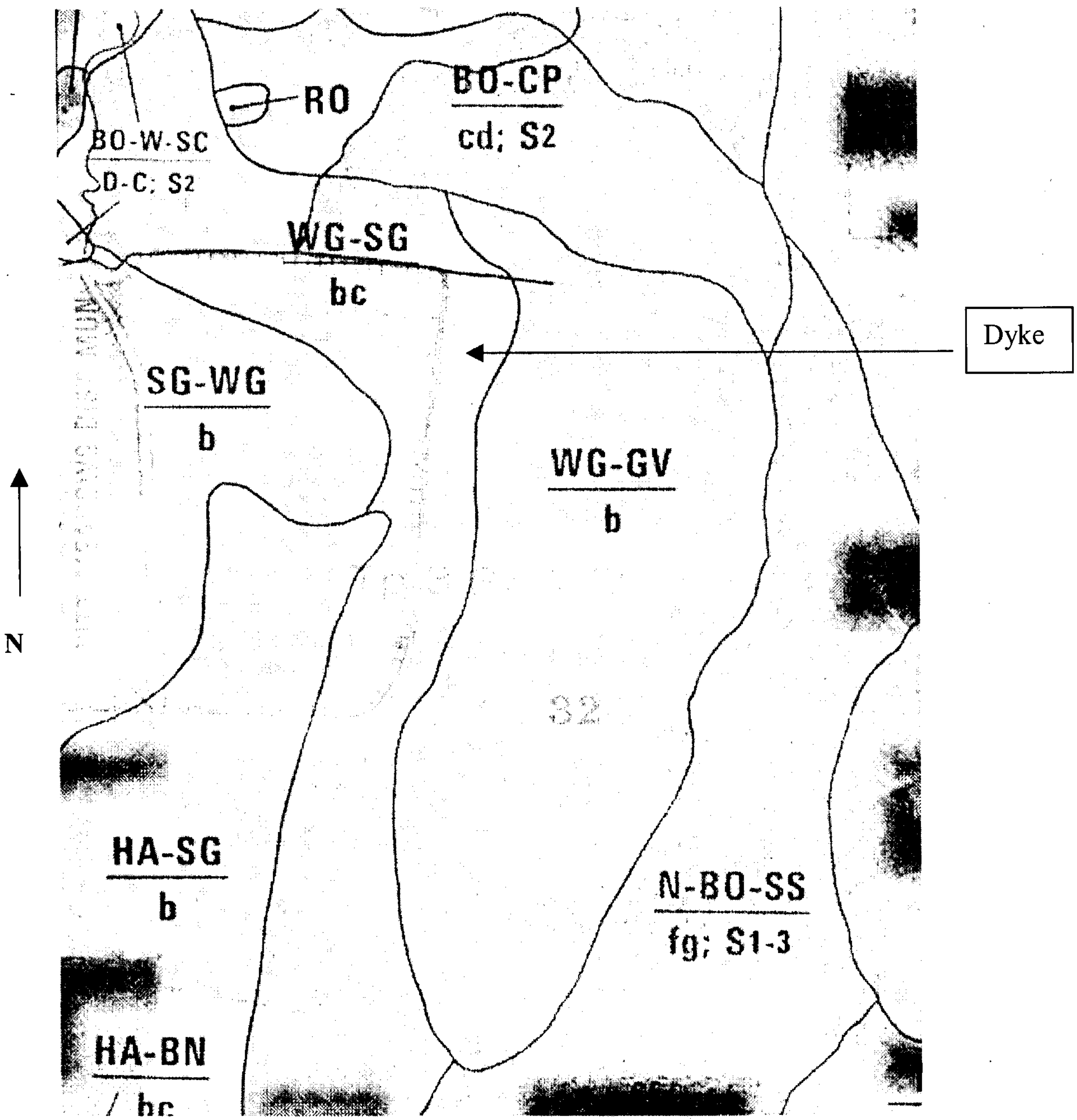
Geology and soils

The area is underlain by bedrock from the Coast Intrusions Group and associated rock types of felsic granitic lithologies with some gabbro (Piteau Associates, 2001). These rocks are variably overlain by glacial and post-glacial sediments. The western half is covered by overbank sediments and floodplain deposits which are generally comprised of fine-textured silty sand and silt with corresponding low-permeability (Piteau Associates, 2001). The remaining areas are covered by organic peats typical of bog environments (Piteau Associates, 2001).

The soils map of the area indicates that there are four different types of soils in the Blaney Bog area. In the northeastern, eastern and southeastern sections the predominant soils are Widgeon-Terric Humisol/Glen Valley-Typic Fibrisol. Along the middle from north to south the soils are Widgeon-Terric Humisol/Sturgeon-Rego Gleyosol. In the southwestern and western sections they are Hammond Rego Humic Gleyosol/ Sturgeon-Rego Gleyosol. Along the western edge the soils are Sturgeon-Rego Gleyosol/ Widgeon-Terric Humisol (Figure 2-2) (Luttmerding, 1980):

- Sturgeon-Rego Gleyosol (SG): medium textured mixed floodplain deposits, poor to very poor drainage and high groundwater table subject to flooding.
- Hammond Rego Humic Gleyosol (HA): medium textured floodplain deposits, poor to very poor drainage.
- Widgeon-Terric Humisol (WG): 40-160cm of organic deposits over medium textured mixed floodplain deposits, very poor drainage and high groundwater table.
- Glen Valley-Typic Fibrisol (GV): more than 160cm of undecomposed organic matter, mainly reeds, sedges, and grasses, very poor drainage and high groundwater table.

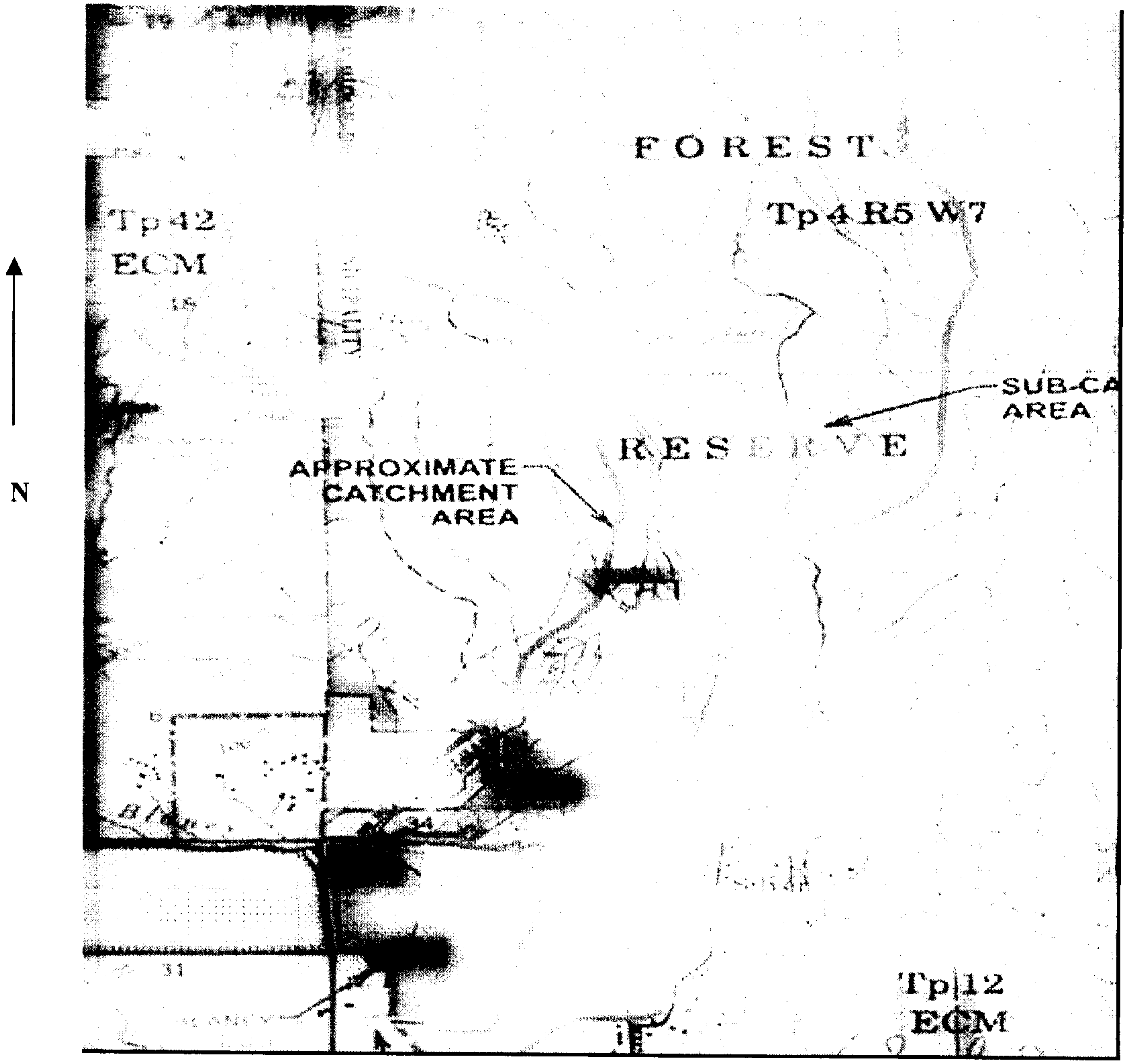
Figure 2-2. Soils map of Blaney Bog area (Luttmerding, 1980). **The dyke in Blaney Bog is represented in the diagram.**



Water features

Blaney Bog hydrology has been altered through agricultural activities and residential development. The surface drainage was severely altered prior to 1940 as a result of construction of a dyke/canal system which enclosed a 700m wide section of the bog (Piteau Associates, 2001). All of the creeks associated with the bog originate in the upland areas to the north and east of the bog. Blaney Creek and Spring Creek run east to west along the northern boundary of the bog. Blaney Bog is affected by Blaney Creek at normal flow and flood levels. Flooding occurs on a regular basis due to tidal action and in spring during the Fraser River freshet (Gebauer, 2002). Anderson Creek enters the bog complex from the east and forms a dentritic pattern over the northeastern section. Towards the western section the flow is altered because of the dyke/canal (Piteau Associates, 2001). The stream fen component of the mound bog/stream-fen complex is predominantly associated with Anderson Creek and its tributaries and the relic stream-fen encompasses a portion of the historic channel of the creek. The two sections are temporarily connected during winter flooding (Adams, 1999). Donegani Creek flows along the northern margin and skirts around the northwestern corner (Piteau Associates, 2001). Springs have been identified along the eastern slopes of the complex. This possibly represents a significant source of water during the summer (Piteau Associates, 2001). Overall Anderson Creek likely represents the significant source of water flowing through the bog complex and Blaney Creek predominantly influences the northern perimeter.

Figure 2-3. Water features of Blaney Bog (Piteau Associates, 2001).



Conservation value

Ecological

Blaney Bog is a unique ecosystem, it represents the only documented bog-fen system within the Fraser Lowlands that includes a mound bog-stream fen complex (Adams, 1999; Ward & McPhee, 1994). Blaney Bog is part of the tidally influenced Pitt River Valley wetlands, which at onetime comprised the largest inland wetland habitats on the British Columbian coast. Human activities have severely reduced the integrity of these ecosystems (Gebauer, 2002). As one of the last sites representing these characteristic wetlands, Blaney Bog and its diversity of habitats supports a diverse assemblage of fish and wildlife species. The wetland provides high over wintering habitat for salmonoids and breeding habitat for a number of rare and endangered wildlife species (Gebauer, 2002). Blaney Bog provides some of the best habitat for species such as the red-listed Pacific Water Shrew, Peregrine Falcon and the Greater Sandhill Crane, and the blue-listed American Bittern (Gebauer, 2002). Other species include Green-backed Heron, Great Blue Heron, and Red-legged Frog (Gebauer, 2002). Blaney Bog and associated creeks are particularly valuable as rearing habitat for anadromous fish species such as the blue-listed Cutthroat Trout, Coho Salmon, and Chum Salmon making it one of the most important freshwater wetlands for salmon rearing the Lower Fraser River (Gebauer, 2002).

Socioeconomic

Blaney Bog also represents significant value to local groups. There exist historic records of the Katzie First Nation using Blaney Bog as a source of berries and other plants such as wild cherry for dying wool (Whiteside, 2001). Naturalist groups frequent the site for wildlife viewing and many local residents use the area for light recreational activities. The bog is vital to the functioning of the flood abatement strategy of the district planning and engineering offices.

Management Strategy

In 2000, GVRD Parks acquired 91ha of Blaney Bog to protect its unique natural character in order to ensure that the bog and associated wetlands are preserved for future generations to appreciate (McKenna, 2001). The acquisition did not encompass the bog complex in its entirety especially along the eastern boundary. In the acquisition process, preliminary concept plans were prepared to identify potential upland areas that might also be of interest by way of development agreements or purchase (Piteau Associates 2001). These steps were taken in recognition of the sensitivity of this wetland complex, which could be significantly impacted by future development proposals around the perimeter of the park, particularly in the uplands. There is a lack of current baseline data on Blaney Bog and little understanding of this ecosystem and its catchment area. GVRD is currently exploring the potential for enhancement of Blaney Bog and associated wetlands and is initiating primary engineering and planning assessments. As part of a long-term management strategy, various options are being examined: rehabilitation activities; maintaining, breaching or removing the dyke system; and adjusting water levels (McKenna, 2001). Recreation facility development is not being considered within the park boundaries due to the sensitivity of the ecosystem. Existing recreational use is limited to walking on the dyke. However various concept plans are being explored to link trail right-of-ways and open space resources in the area to make the site more accessible to the public without damaging the integrity of the system (McKenna, 2001). Any plans considered are subject to environmental and economic feasibility and public stakeholder involvement. GVRD, as the management body responsible for Blaney Bog, is eager to work with partners including the public, government and any other interested parties. As part of this initiative the Blaney Bog committee was formed and as a group they are interested in the sustainable management of Blaney Bog. Membership is made up of concerned citizens, and representatives from GVRD, District of Maple Ridge, Habitat Conservation and Stewardship Program, Alouette Field Naturalists, Pitt Polder Preservation Society, and the Alouette River Management Society.

Chapter 3: Methodology

The study was designed to accommodate accessibility problems and limited knowledge of the study area. As a result, the approach and field study evolved throughout the 10 month period, as more was learned about the study area.

Current color air photos (2000, GVRD) were examined in order to classify the Blaney Bog complex into biophysical units based on surface morphology visible as tone patterns or vegetation zones (Figure 3-1). A ground survey was carried out to verify the unit boundaries and units were characterized according to the dominant vegetation. In addition, historic black and white and color air photos (1947, 1957, 1967, 1974, 1984, 1999, UBC Department of Geography) were examined for changes in the plant communities throughout the bog complex over the past fifty years. Delineated biophysical units, representing a spectrum of plant communities in species composition, were used to stratify the study area for the purpose of sampling. Using the biophysical units, 12 sites representing 2 different types of plant communities spread throughout the western and northern sections of the bog were chosen for more detailed study. Due to the lack of accessibility of the study area, ease of access was among key factors considered in the selection of site placement in the biophysical unit as such, most sites were placed close to the road, trail or some other access point. A schematic diagram shows the layout of the study area including the dominant water features with the location of all the sites (Figure 3-2). The sites are coded according to the dominant vegetation present at each site.

Figure 3-1. Air photo of Blaney Bog (GVRD, 2000). Red circles represent GVRD automated pressure transducers.

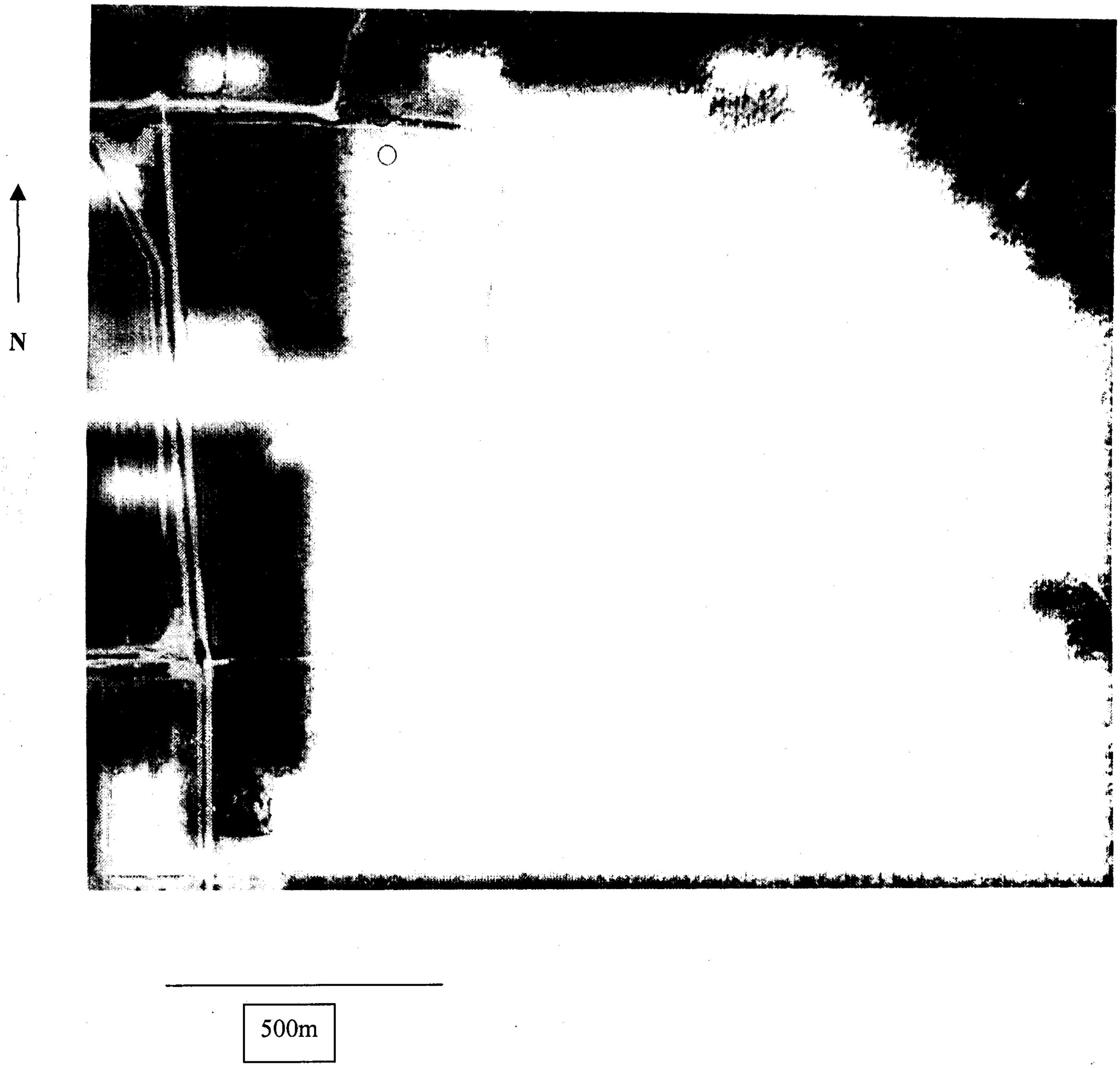
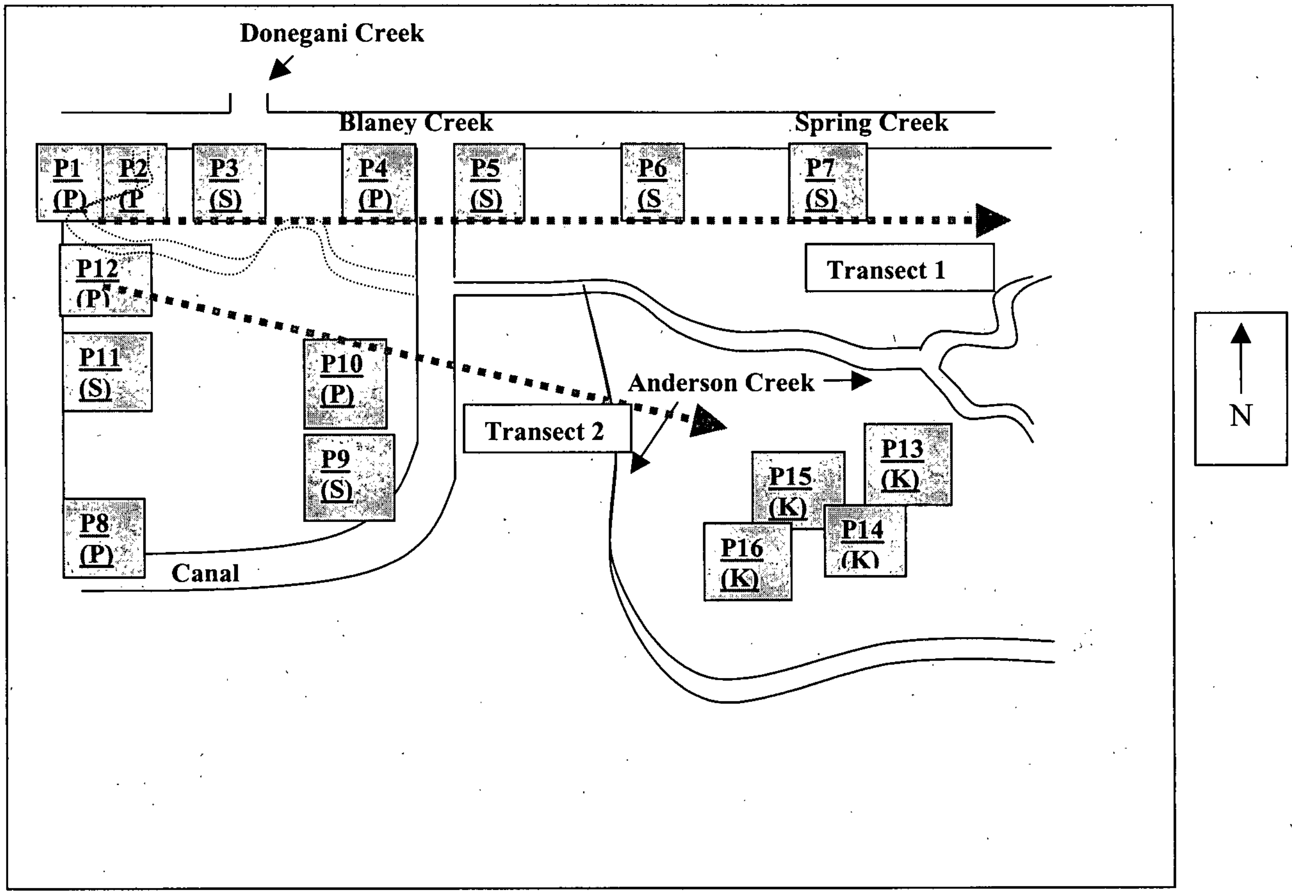


Figure 3-2. Schematic diagram of Blaney Bog with the dipwell sites labeled as P1-P16 in green boxes and red dotted lines representing transects 1 (sites T1.1-T1.10) and 2 (sites T2.1-T2.15). Sites are coded according to plant community type (P= Phalaris; S=Spiraea; and K=Kalmia). The Sedge sites are located along Transect 2.



A network of dipwells was established at the 12 sites (P1-P12) throughout the study area in November 2002. The dipwells consisted of 7.5cm in diameter and 1.5m long PVC pipe open at both ends with perforations 1.0cm in diameter every 10cm from top to bottom alternating on opposite sides. At each location, a hole was excavated using an electric auger and the dipwell was inserted 1.2m below the surface. The top was covered with a plastic bag and sealed off with a rubber band to keep out litter, rain and any other debris as well as to avoid unrepresentative readings caused by recent rainfall or drip from vegetation (Brooks & Stoneman, 1997; Gilman, 1994).

The number of sites was later expanded to the eastern section where 4 more sites representing one additional plant community were added (P13-P16). These sites were not chosen using the same method because the dipwells were already present at the sites. In April 2001, 4 dipwells were installed by a Trinity Western student for a research project (Marianne Huizing). The dipwells were 3.2cm in diameter and 1.4m long PVC pipe, with perforation intake length 27cm and height above ground 20cm.

In March 2003, 25 additional sites were added to the research design in order to expand the study and produce more data on the biophysical units already represented and addition plant communities that were not originally included (T1.1-T1.10 and T2.1-T2.15). Using the current air photos, two transect lines were established. The first transect was along the northern perimeter of the Blaney Bog complex and created a continuum of sites between P1 and P7 extending to the most eastern edge of the northern perimeter (Figure 3-2). 10 additional sites were chosen along the first transect using the same method used for the original sites. However, instead of inserting a dipwell, the site was marked by a stake and a water sample was either taken from the surface water, or if the water level was below ground, by digging a pit to reach the water table. The second transect was established between site P12 crossing the center of the enclosed area to the canal and continuing on the other side of the canal towards site P16. In this case 15 additional sites were created using the same method as in Transect 1.

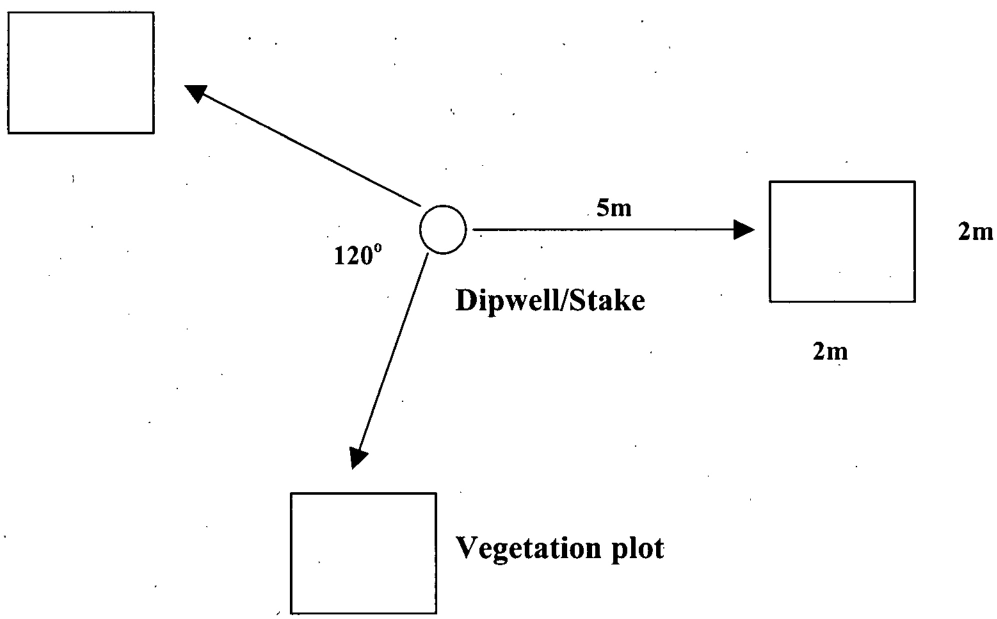
In addition, data on water level changes measured in millimeters from two automated pressure transducers (Figure 3-1) (owned and operated by the Greater Vancouver Regional District Parks Department) were collected from October 2002 to August 2003. Data on hourly rainfall in millimeters was collected from the GVRD weather station located at SDM44-Katzie PS, S. end of Maple Meadows Way.

Vegetation Component

Field Sampling

A detailed survey of Blaney Bog vegetation was undertaken in June and July 2003. Plant composition and abundance were measured in three 2x2m^2 plots at each dipwell site. Furthermore, all transect sites were surveyed for species presence/absence and the following sites were surveyed using the same methods as at the dipwell sites: T1.5, T1.6, T2.2, T2.4, T2.7 , T2.8 and T2.10. All the sites were not surveyed in detail to reduce repetitive data. The three plots were placed in a 5m radius circle around the dipwell or transect site marker; starting at 0°, every plot was placed 120° from the previous turning in a clockwise direction (Figure 3-3).

Figure 3-3. Schematic diagram of the vegetation plots in relation to the dipwell or stake.



Plant community data: A list of vascular plants and bryophytes was compiled for each quadrat and percent cover was estimated for each species. Percent cover was estimated using the Domin-Krajina cover scale where the range 0-100 per cent is partitioned into ten classes with smaller graduations near the bottom of the scale (Table 3-1) (Kent & Coker, 1992). Using a cover scale instead of estimating percent cover is suggested to minimize subjectivity and estimation error (Barbour et al., 1999). Voucher specimens were collected for taxa that could not be identified in the field and taken to the University of British Columbia herbarium. Taxonomy and nomenclature follows Douglas et al. (1998-2002) and Hitchcock et al. (1977) for vascular plants and Lawton (1971) for bryophytes. Total cover for each species for each site, both vascular and bryophyte species, were calculated by taking the mean from the three quadrats.

Table 3-1. Domin-Krajina scale (Barbour et al., 1999).

Cover Class	Range of % cover	Mean
10	100	100
9	75-99	87.0
8	50-75	62.5
7	33-50	41.5
6	25-33	29.0
5	10-25	17.5
4	5-10	7.5
3	1-5	2.5
2	<1	0.5
1	<<1	0.1

Data analysis

Vegetation data was entered into the ecological data handling software program PC-ORD (McCune & Grace, 1999). All species were included in the analysis. Species abundances were converted from the Domin scale to mean percent cover value (Table 3-1). Mean percent cover values and frequency were calculated for each species according to sites grouped into plant community type. Species richness and species diversity (Shannon's diversity index) were also calculated for sites grouped according to plant community type (Barbour et al., 1999).

Water component

Hydrologic Measurements

For all 16 dipwells, the depth of the water table was calculated by measuring from the top of the dipwell to the ground surface and subtracting that from the top of the dipwell to the water level. The measurements were done using a steel measuring tape. The height of the dipwell above ground was measured each time to account for the movement of the peat surface. Field visits were made bi-weekly in November 2002, and monthly from December 2002 to August 2003.

Water-Quality Measurements

Water sampling was conducted concurrently with water level measurements. pH, electrical conductivity and temperature were measured in the field using a portable meter (Oaklon waterproof pH/conductivity deluxe meter kit, model 300, mode no. WD-35631-60). Samples from the dipwells were extracted using a polyethylene tube hand-pump. Each sample was poured to fill a 250mL acid washed plastic bottle, sealed, labeled and stored in a cooler for laboratory analysis the next morning.

In the laboratory, an aliquot of 50mL of each sample was filtered using a Whatman 42 filter and the filtrate was divided into two subsamples. One subsample was analyzed for nitrate, orthophospahate and ammonia using ion chromatography (Quickchem FIA+ 8000 series, Lachat Instruments). The lowest detection limit was 0.05ppm for all three. The other subsample was acidified with 5mL trace metal grade (nitric acid) and then analyzed for various elements using inductively-coupled argon plasma spectrophotometry (ICP). The tested elements and respective lowest detection limits in brackets were the following: Al (0.05), As (0.5), B (0.05), Ba (0.5), Ca (0.5), Cd (0.2), Co (0.2), Cr (0.2), Cu (0.05), Fe (0.2), K (0.5), Mg (0.25), Mn (0.025), Mo (0.2), Na (0.5), Ni (0.5), P (0.2), Pb (0.5), Se (0.5), Si (0.6), Sr (0.025), and Zn (0.05). The elements included in the analysis were available through the ICP method. Only those elements that showed concentration levels consistently above detectable limits were included in further analyses.

Soil component

Field and laboratory

Soil description and characterization were carried out in March and April 2003 at all dipwell sites and plots along two transects in Blaney Bog.

A peat corer (Mark Bustin Earth and Ocean Sciences UBC) was used to extract a 0-50cm in depth core with minimal compaction. All samples were sealed, transported and stored in plastic piping until they were analyzed in the lab. Once opened, images of the cores were taken with a digital camera. The peat samples were left for a minimum of five days to air dry in a well ventilated area of the lab. The peat samples were then subsampled using sedimentary structures based on color differences (Munsell color chart). The samples were separated into depth increments and accordingly ground with a mortar and pestle. 1g of each horizon was weighed out in a porcelain crucible and oven dried at 100^0 C overnight. The next day each sample was weighed again to determine water content. These same samples were used to determine Carbon and Nitrogen concentrations by combustion in a Leco furnace.

The remaining subsamples of each horizon were used to determine soil pH. Soil pH was measured using a glass electrode inserted into 1:5 (if subsample was too small 1:10) dilution of soil with deionized water that had been stirred intermittently for approximately 30 minutes, then allowed to equilibrate for another 30 minutes. After this procedure the soil suspension was transferred to plastic containers quantitatively and oven dried at 60^0C until dry and then for another 12 hours.

These dry samples were used for further analysis to determine total concentrations of N (nitrogen), P (phosphorus), K (potassium), Ca (calcium), Al (aluminum), Mg (magnesium), Na (sodium), Mn (manganese), Fe (iron), Cu (copper), S (sulfur) and Zn (zinc) using inductively coupled argon plasma (ICP) unit following sulfuric acid-hydrogen peroxide digestion (Parkinson and Allen 1975).

Data analysis

A data matrix was prepared by taking all sites sampled including dipwell and transect sites and summarizing values for each variable for each horizon separately. For Leco and ICP analyses, duplicates were averaged and the mean was entered into the matrix. Certain elements that were included in the ICP analysis did not show levels higher than the lowest detectable limit, these elements were not included in the data matrix. In the case of copper and zinc most samples had levels higher than the detectable limit, however if the concentration was lower than the lowest detectable limit, the concentration value was divided by two. In order to summarize the horizon data at each site, weighted averages (weighted by length of each horizon in the core) were calculated for each variable. The weighted averages matrix is included in Appendix III. Soil organic matter (SOM) data from separate horizons were used to examine differences in SOM content with peat depth.

Statistical analysis

The Kruskal-Wallis non parametric test was used to test for significant differences among means of the water chemistry variables for the four different plant community types. Mann-Whitney U test was used for pairwise comparisons between groups for variables that demonstrated significant differences from the Kruskal-Wallis to specify which groups were significantly different. Spearman's correlation coefficients were calculated for selected water and soil variables. For the water variables the coefficients were based on the mean for the 10 month study period. Only p-values less than 0.05 are reported as significant. All statistical analyses were done using the SPSS program.

Multivariate analysis

The vegetation data were ordained using Nonmetric multidimensional scaling (NMS). NMS is an ordination method well suited to ecological data and has been shown to be superior to other ordination methods (McCune & Grace, 2002). The method involves an iterative search for the best positions of sampling units in a given number of dimensions (axes) such that the distances between sampling units pairs are in rank order with their differences in species composition while minimizing stress of the final solution. Stress is a measure of difference between dissimilarity (distance) in the sampling units in the original data and dissimilarity of the same units in the reduced ordination space. The NMS analysis involved an initial test which used a random starting configuration, the Sorenson distance measure, and 30 runs with the real data using a step-down in dimensionality from 6 to 1. In addition, 30 Monte Carlo simulations were run with random configurations of the dataset to compare the stress of the solutions ($p=0.02$). Based on the findings in the initial test, the data was rerun using the Sorenson distance measure, and the chosen starting configuration and dimensionality found in the initial test. Three dimensions and 400 iterations were used in the final analysis.

Values for all environmental variables were log transformed except for pH. Then the environmental variables were correlated to the three Axis of the ordination solution to infer relationships between site characteristics in terms of species composition and environmental data. This is a form of indirect gradient analysis. Direct gradient analysis, Canonical Correspondence Analysis, was also performed on the same data set and the results were similar. This indicates that the environmental variables measured explained most of the variation in the species data (van Groenewoud, 1992). Only the NMS results are included in the results/discussion section.

Chapter 4: Results and Discussion

Vegetation component

The initial survey of dominant vegetation at Blaney Bog identified 4 plant community types: Phalaris, Spiraea, Kalmia, and Carex spp. (Sedge). A plant community is a general term that can be applied to mixtures of plant species occurring in close spatial association (Barbour et al., 1999). Species that are associated with a certain set of conditions are termed indicator species of those conditions (Tiner, 1999). The detailed survey of vegetation identified 24 sites and recorded 51 species present: 30 vascular plant species (59%) and 21 bryophyte species (41%). The list of all species encountered during sampling is given in the synoptic table (Table 4-1). The characteristic species of each plant community will be described in this section.

Kalmia dominated group

The Kalmia sites include the following: P13, P14, P15 and P16 (n=4). The *Kalmia occidentalis* sites are dominated by Sphagnum species, particularly *S. capillifolium* and *S. magellanicum*, conifers such as *Pinus contorta* and *Tsuga heterophylla* and ericaceous shrubs such as K*almia occidentalis*, *Ledum groenlandicum*, and *Vaccinium oxycoccos.* The Kalmia sites are characteristic poor fen or mesotrophic bog sites with Sphagnum dominated flora (Damman 1995; Zoltai and Vitt, 1995; Wheeler and Proctor 2000). Bog in this case refers to a vegetation unit/habitat category, not the classic topographical unit that is associated with a "raised bog"

Table 4-1. Synoptic table of the plant community types according to the sites surveyed in Blaney Bog. Mean cover values (%) and frequency class in corresponding plant community. Frequency classes: I=1-20%, II=21-40%, III=41-60%, IV=61-80% and V=81-100%.

Plant community	***Kalmia***		***Phalaris***	***Sedge***		***Spiraea***	***Total***
Number of sites surveyed	**4**		**8**	**3**		**9**	**24**
Species richness	**28**		**13**	**16**		**15**	
Species diversity (H')	**2.60**		**0.94**	**2.18**		**2.25**	
Betula sp.	0.6	II	-	-		-	
Carex pauciflora Lightf.	0.1	II	-	-		-	
Drosera rotundifolia L.	0.8	III	-	-		-	
Empetrum nigrum	0.1	II	-	-		-	
Eriophorum chamissonis C.A. Mey.	3.1	IV	-	0.1	II	-	
Gaultheria shallon Pursh	0.1	II	-	-		-	
Kalmia occidentalis Small	15.0	V	-	-		-	
Ledum groenlandicum Oeder	26.1	V	-	-		-	
Lysichiton americanum Hult. & St. John	0.1	II	-	-		-	
Myrica gale L.	4.5	III	-	-		41.5	I
Pinus contorta var. contorta Dougl. ex Loud.	1.3	III	-	-		-	
Pteridium aquilinum (L.) Kuhn	7.3	II	-	-		-	
Rubus chamaemorus L.	0.7	III	-	-		-	
Thuja plicata Donn ex D. Don	1.9	II	-	-		-	
Tsuga heterophylla (Raf.) Sarg.	0.2	III	-	-		-	
Vaccinium oxycoccos L.	7.5	V	-	-		-	
Aulacomnium palustre (Hedw.) Schwaegr.	1.9	II	-	-		0.1	I
Hylocomium splendens (Hedw.) Schimp. in B.S.G.	0.1	II	-	-		-	
Pleurozium schreberi (Brid.) Mitt.	0.7	IV	-	-		-	
Polytrichum juniperinum Hedw. Spec. Musc.	0.2	III	-	-		-	
Rhytidiadelphus triquetrus (Hedw.) Warnst.	0.1	II	-	-		-	
Sphagnum capillifolium (Ehrh.) Hedw.	13.8	V	-	-		-	
S. fimbriatum Wils. ex Wils. & Hook. in Hook.	0.6	II	-	-		-	
S. henryense Warnst.	0.2	III	-	-		-	
S. magellanicum Brid.	13.6	V	-	-		-	
S. pacificum Flatb.	0.8	V	-	-		-	
S. palustre L.	0.7	III	-	-		7.5	II

S. warnstorfii	0.2	III	-		-		-	
Comarum palustre L.	-		0.1	I	-		0.1	III
Equisetum sp.	-		0.1	II	-		0.1	I
Phalaris arundinacea L.	-		68.8	V	15.4	IV	27.1	IV
Brachythecium frigidum (C. Muell) Besch Mem. Soc. Sci. Nat. Cherbourg	-		1.1	I	0.1	II	0.1	I
Polytrichum commune Brid.	-		0.1	I	-		0.5	II
Carex canescens	-		1.1	I	2.7	V	0.1	III
Carex rostrata	-		0.1	I	7.5	V	-	
Carex sitchensis	-		-		18.3	IV	-	I
Galium aparine L.	-		0.1	II	0.7	IV	-	
Juncus effusus L.	-		-		0.1	II	-	
Lysimachia thyrsiflora L.	-		-		0.1	II	-	
Scirpus cyperinus (L.) Kunth	-		7.8	IV	8.8	V	1.3	III
S. squarossum	-		-		0.7	III	1.3	III
S. subsecundum	-		-		1.9	IV	0.1	I
Calamagrostis canadensis (Michx.) Beauv.	-		0.1	I	0.1	II	17.5	
Spiraea douglasii Hook.	-		1.2	III	11.7	IV	65.4	V
Amblystegium serpens	-		0.1	I	0.6	II	0.5	III
Campylium stellatum	-		0.1	I	0.6	II	3.0	V
Dicranum scoparium Hedw.	-		-		-		17.5	I
Eurhynchium spp.	-		-		-		2.5	II
Plagiothecium undulatum (Hedw.) B.S.G. Bryol. Eur. Fasc.	-		-		-		2.5	
Ulota obtusiuscula (C. Muell and Kindb. In Mac. Cat. Can. Pl.)	-		-		-		1.3	II

which, by definition, is ombrotrophic (Wheeler and Proctor, 2000). Similar to other studies of bog systems, at the Kalmia sites of Blaney Bog, Sphagnum moss generally appears in combination with other acidophilic plants such as sedges, cotton grass, ericaceous shrubs, and coniferous tree species (Bridgham et al., 1996). The species that occur at other sites in addition to sites P13-P16 are *Myrica Gale*, *Eriophorum chamissonis*, *Sphagnum palustre* and *Aulacomnium palustre*. *Myrica Gale,* is a moderate-rich fen species. The percent cover of *Myrica Gale* is considerable at site T2.10 (Figure 3-2) which is in close proximity to the *Kalmia occidentalis* sites. The bryophyte *Aulacomnium palustre* is common throughout organic wetlands (Gignac et al., 1991). Species richness and diversity in the Kalmia site were highest of the four plant community types.

Phalaris group

The Phalaris sites include the following: P1, P2, P4, P8, P10, P12, T1.1, T1.2, T1.6, T1.7, T2.1, T2.2 and T2.3 (n=13). In this group, *Phalaris arundinacea* was the dominant species with 69% as the mean cover at all sites. *Scirpus cyperinus* and a few other species were also present but in low cover. Bryophyte cover was lacking. These sites are characteristic of reed fens which are commonly considered extreme-rich fens (Damman 1995; Zoltai and Vitt, 1995; Wheeler and Proctor 2000). These are generally eutrophic sites, often species poor with some ruderal species present but lacking in bryophyte cover (Wheeler, 1999). Species richness and diversity in the Phalaris sites were lowest of the four plant community types.

Sedge group

The Sedge sites include the following: T2.4, T2.5, T2.6, T2.7, T2.9, T2.13, T2.14 and T2.15 (n=8). The species characteristic of the Sedge group overlapped somewhat with the Phalaris sites. The sedges that dominated these sites were *Carex rostrata* and *Carex sitchensis.* Also abundant were *Carex canescens, Phalaris arundinacea, Scirpus cyperinus* and *Spiraea* *douglasii*. Mounds of *Sphagnum squarrosum* and *S. subsecundum* and brown mosses such as *Amblystegium serpens* and *Campylium stellatum* were also present. These species reflect small sedge fens, which are considered transitional communities between reedlands and poor fens (Damman, 1995; Walker, 1970; Wheeler and Proctor, 2000; Zoltai & Vitt, 1995). Small sedge fens are characterized by Carex spp. and forb species with a prominent ground layer of brown mosses such as *Campylium* sp. Species richness and diversity were intermediate in this group compared to the other sites.

Spiraea group

The Spiraea sites include the following: P3, P5, P6, P7, P9, P11, T1.3, T1.4, T1.5, T1.8, T1.9, T1.10, T2.8, T2.10, T2.11 and T2.12 (n=16). The *Spiraea douglasii* group was characterized by >50% cover of this species. Also common were *Phalaris arundinacea* , *Comarum palustre,* the sedges *Scripus cyperinus* and *Carex canescens,* mounds of *Sphagnum squarossum* and brown mosses such as *Amblystegium serpens* and *Campylium stellatum.* The species characteristic of these sites are considered indicators of shrub fen which are moderate-rich fen sites transitional between reed fen and poor fen (Damman, 1995; Walker, 1970; Wheeler and Proctor, 2000; Zoltai & Vitt, 1995). Although sites T2.10, T2.11 and T2.12 shared the high *Spiraea douglasii* cover value with this group, they differed with the other Spiraea sites with rather a high abundance of *Calamagrostis canadensis* and *Myrica gale. Calamagrostis canadensis* is known as a widespread fen species (Wheeler, 1999). Species richness and diversity were intermediate in this group compared to the other sites.

The Water Table

According to the automated dipwells installed by GVRD, precipitation levels in the area greatly influence Blaney Creek levels and Blaney Bog water levels (Figure 4-1). Precipitation levels were recorded to be high from November to April and decreasing from April to low summer levels. In August precipitation levels were very low.

In this study, substantial fluctuations in the water table were noticeable throughout the study period. From November to April the water table fluctuated between 2.6cm and 19.4cm below the surface, these fluctuations seem to respond to replenishment from rainfall events. The rise in water levels may also be attributed to flooding by neighboring land managers who pump water into adjacent ditches that overflow in times of excess rain in an attempt to drain their lands. On the other hand, the water table drops substantially to 55.5cm below ground from April to August. The drop in the water table is fairly gradual until July, however August levels are extremely low due to lack of precipitation and hot summer temperatures. Figure 4-2 shows the average for all dipwells for each sample date.

Figure 4-2. Average below ground water levels during the study period.

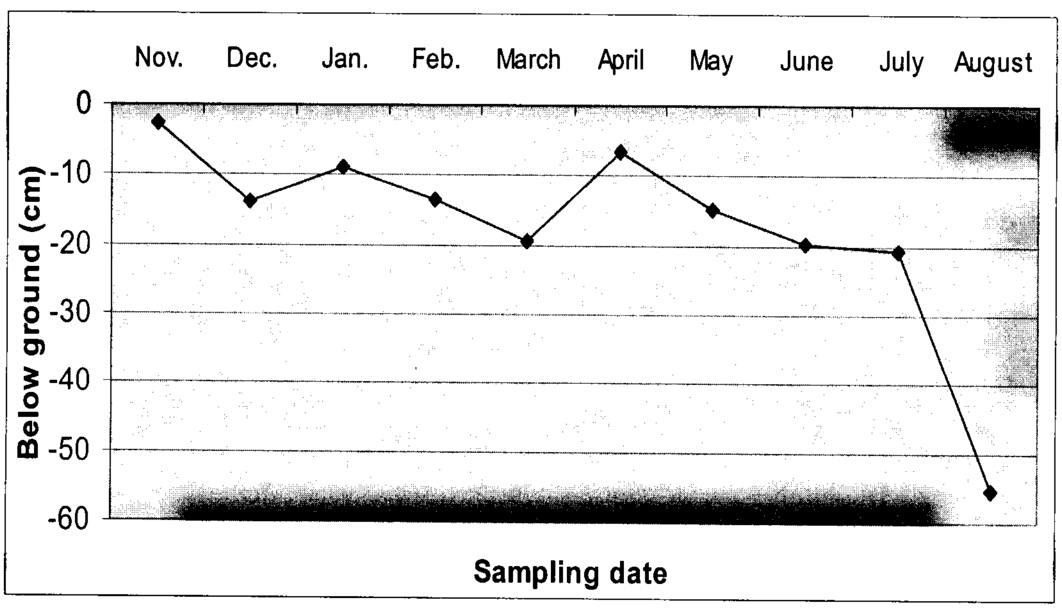
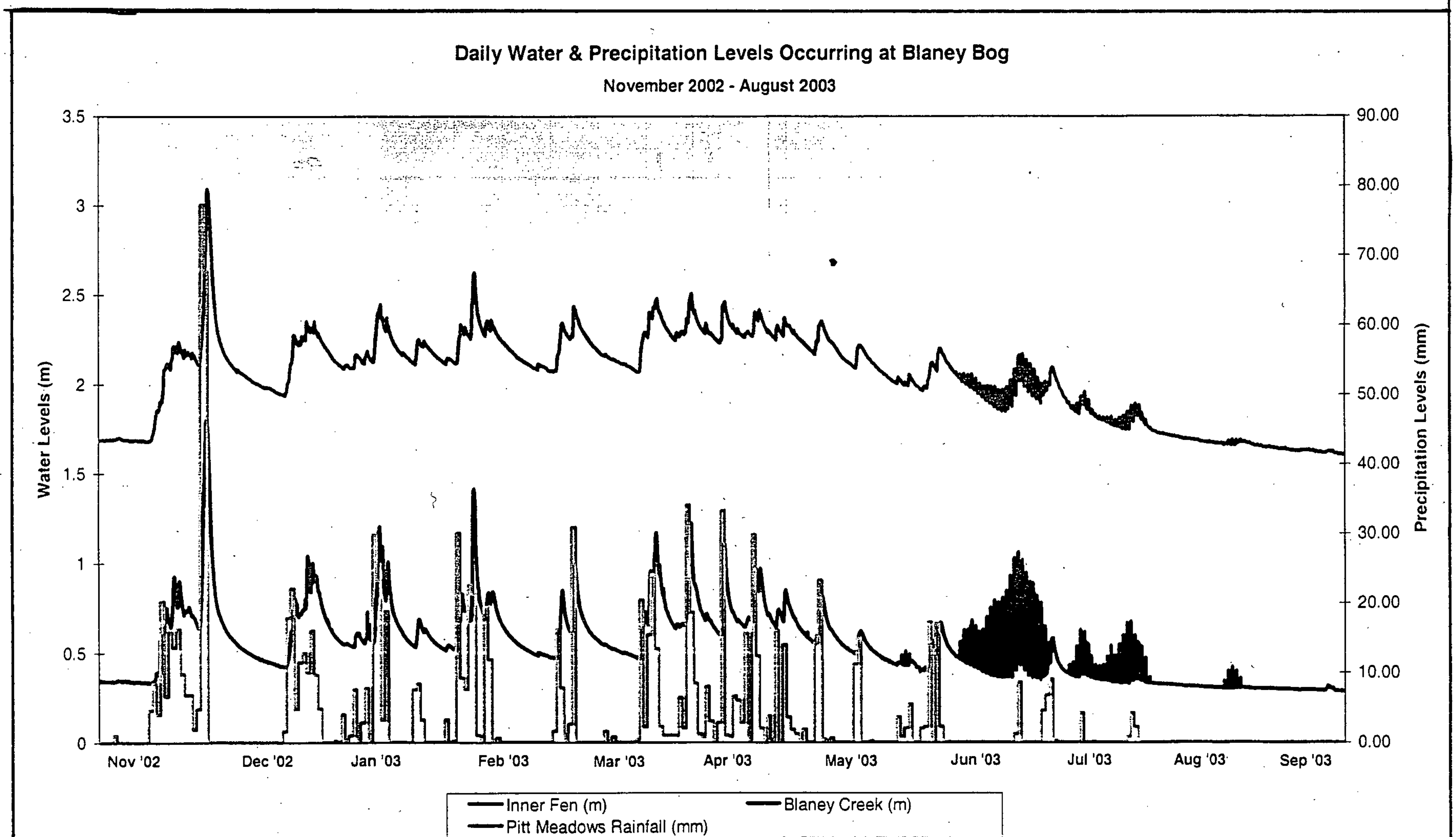


Figure 4-1. GVRD data on precipitation, Blaney Creek and Blaney Bog water levels from November 2002 to September 2003.

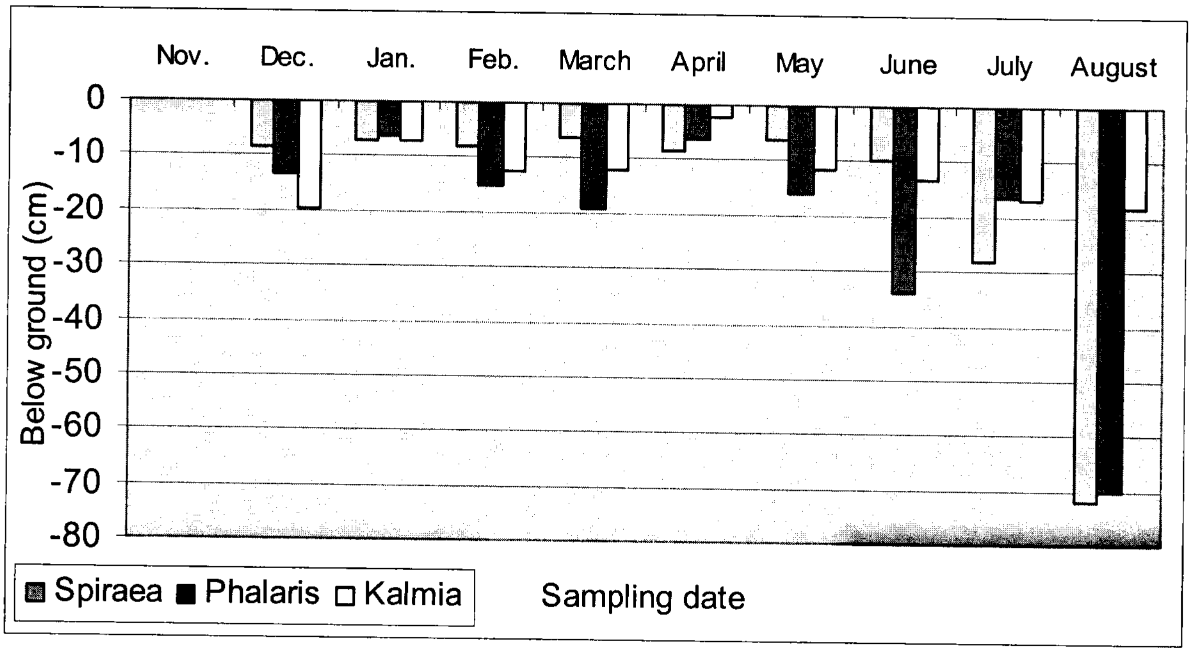


The average water table depth does not adequately represent the variation among the 16 dipwells located throughout the study site. A closer look at the fluctuations in the water table shows that the Phalaris and Spiraea sites are more prone to fluctuations in the water table than the Kalmia sites (Table 4-2). The Kalmia sites seem to be buffered against lack of precipitation, the summer minimum water levels were recorded at 30.0cm below ground. On the other hand, both the Phalaris and Spiraea sites dropped from flooded conditions to low levels in August of more than 80cm below ground. The lowest record of the water level relative to the ground surface was 112.0cm below ground in a Spiraea site (P3).

Table 4-2. Minimum, maximum, mean and median below ground water levels (cm) for all the dipwell sites and summarized according to plant community group for the 10 month study period.

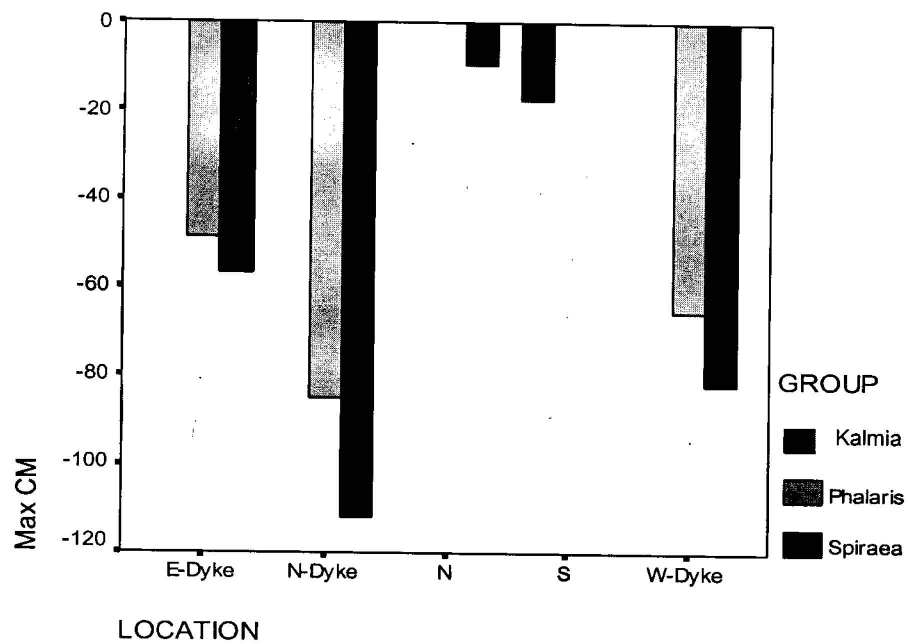
	Max	*min*	*mean*	*median*
P1	-0.2	-75.0	-22.3	-26.5
P2	-0.3	-65.0	-24.9	-33.1
P3	-0.4	-112.0	-38.1	-40.3
P4	-0.3	-82.5	-25.0	-29.7
P5	-0.2	-29.7	-16.1	-17.6
P6	-0.1	-12.9	-6.6	-7.5
P7	0.0	-9.7	-2.5	-1.1
P8	0.0	-77.0	-3.4	-0.1
P9	0.0	-57.0	-4.0	-2.2
P10	0.0	-49.0	-2.0	0.0
P11	0.0	-72.0	-7.6	-7.6
P12	0.0	-55.4	-2.2	-1.9
P13	-3.1	-30.0	-13.4	-16.0
P14	0.0	-17.5	-8.2	-8.2
P15	0.0	-19.9	-8.7	-9.3
P16	-0.6	-25.0	-15.5	-15.6
Spiraea	0.0	-112.0	-12.5	-7.6
Phalaris	0.0	-82.5	-13.3	-14.2
Kalmia	0.0	-30.0	-11.4	-12.4

Figure 4-3. Median below ground water levels for each dominant vegetation group for all sampling dates throughout the study period.



It is important to note that since Blaney Bog is a disturbed site, spatial layout of the sites and the effects of the dyke/canal have to be considered. Sites P1-P4 and P8-P12, which are located in the enclosed section (Figure 3-2), experience greater drops in the water table than the sites in the open section of Blaney Bog (Table 4-2). Within the enclosed section, the Spiraea sites show greater drops in water levels than the Phalaris sites (Figure 4-4).

Figure 4-4. Greatest depth of water level below surface for each group clustered according to location in Blaney Bog from the 10 month study period. (Abbreviations represent E-Dyke= eastern section of the enclosed area; N-Dyke= northern section of the enclosed area; W-Dyke= western section of the enclosed area; N= northern section of the open area; and S=southern section of the open area)



Variations in water level fluctuations when locations are considered suggest that the dyke/canal have an impact on the hydrology in the study area. Water levels in the northeastern and eastern sections are affected by precipitation, surface runoff, groundwater flow and open water meandering from east to west. In these areas the water levels do not drop substantially in the summer months even though precipitation input is low. The small fluctuations in water levels in the open section are similar to observations in other fen systems where flow-through fens tend to have relatively stable water-table levels. In these fens systems water level records show high levels with a narrow range in summer water levels (Heathwaite & Gottlich, 1993). Point to point variation in mire systems is often small and exceeded by temporal variation.

The western section is enclosed by the dyke, and in the summer months the only inflow of water is from precipitation events and groundwater seepage. The effect is lower summer water levels with a gradient from the east to west and the lowest records in the northern end of this enclosed section. There is evidence of many relict streams in this section that used to flow from east to west and southeast to northwest and the drainage of this area explains this gradient in summer minimum water levels. Lack of flowing water and connection to the eastern open section seem to have an effect on minimum summer water levels.

In the winter season when precipitation input is considerable, the enclosed section is flooded from both the eastern and western ends. On the eastern side the water levels in the canal occasionally rise above the surface and flood the adjacent area. On the other hand, areas adjacent to the road on the western end are in danger from flooding as a result of over-pumping from the neighboring cranberry operation. The extent of the flooding on the eastern and western ends is unknown because water levels were only measured monthly.

Community limits of wetland vegetation have been shown to be influenced by occasional extreme minima and maxima, average minima and maxima, the frequency and duration of fluctuations and average water levels (Wheeler, 1999). In addition, water tracts and microtopography of hummocks and hollows has a strong effect on distribution of wetland species showing striking zonation patterns related to these areas (Keddy, 2000). In the case of Blaney Bog it is difficult to interpret the role of the water table in the distribution of plant species. Although there does seem to be a difference between the Kalmia sites and the Spiraea and Phalaris sites, it is difficult to say whether this is related to vegetation or location because all the Kalmia sites surveyed are in the open section. In fact, Kalmia associated species are absent in the enclosed section (dyked). On the other hand, Phalaris sites are absent from the open section. Historic air photos dating back to the 1940s show changes in vegetation patterns are substantial in the enclosed section and small in the open section. The only noticeable changes in the open section are close to the intersection between Anderson Creek and the canal. These patterns suggest that hydrological modification caused by the dyke/canal has had effect on the plant communities in Blaney Bog particularly in the western section.

All these factors suggest that this system is continuously affected by the dyke and canal as well as possibly other ongoing agricultural drainage practices in nearby areas. Although based on the present dataset on water fluctuations further interpretation of species distribution is difficult, the results suggest that water levels can not be the only underlying environmental factor for plant community distribution. Soil and water chemistry data are going to be used to further investigate plant environment relationships.

Organic matter accumulation

Soil cores collected throughout Blaney Bog show that the soils in the area are a mixture of organic deposits of various depth that are mixed with floodplain deposits. The mix of organic and mineral material resulted in a wide range of organic matter content in the soil samples (12.4 to 76.5%). The Kalmia and Sedge sites had the highest soil organic matter content at 73.8% and 50.1% respectively (Table 4-3). On the other hand, the Spiraea and Phalaris sites had the lowest at 43.0 and 35.1% respectively. Soil carbon levels were significantly higher in the Kalmia sites compared to the rest of the sites (Table 4-4 and 4-5). According to the expected decrease in organic matter content along the bog-fen gradient, the Kalmia sites reflect the poor-fen/bog end of the spectrum with the highest soil organic matter content. The Spiraea and Sedge sites reflect the transitional stages with more soil organic matter content, and the Phalaris sites fit into the rich fen end with mainly mineral content and shallow peat deposits. This responds to the vegetation classification.

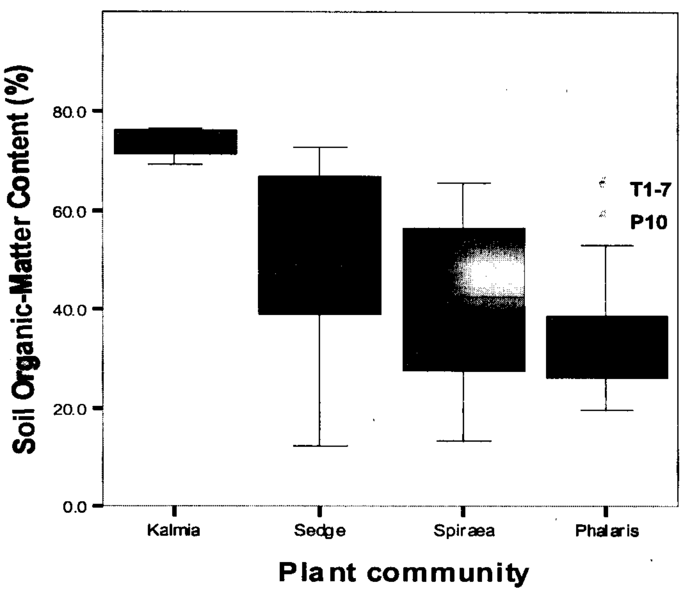
Table 4-3. Minimum, maximum, median and mean carbon (%) and soil organic matter (%) content for the four plant community types. Organic content was calculated by multiplying % carbon by 1.58 (Sprecher, 2001). The Spiraea and Sedge sites are also separated according to location within the enclosed section by the dyke (Dyke) and in the open area (Open).

		%Total C	*Soil organic matter %*
Kalmia	**min**	43.9	69.4
	max	48.4	76.5
	median	47.3	74.7
	mean	46.7	73.8
Spirea	**min**	8.5	13.4
	max	41.4	65.4
	median	28.2	44.6
	mean	27.2	43.0
	Dyke	17.3	27.4
	Open	33.7	53.3
Sedge	**min**	7.8	12.4
	max	46.1	72.8
	median	33.0	52.1
	mean	31.7	50.1
	Dyke	30.1	47.5
	Open	34.5	54.4
Phalaris	**min**	12.5	19.7
	max	41.0	64.8
	median	19.1	30.2
	mean	22.2	35.1

Within the plant community groups there was variation in soil organic matter content (Table 4-3 and Figure 4-5). Sedge and Spiraea sites show the most variation in organic matter content, which may be related to their presence throughout the study site in both the enclosed and open sections. Table 4-3 presents mean organic matter content for the groups with the sites subdivided according to their location in the study area. The sites in the open area have higher organic matter content for both plant community types. The Spiraea sites in the open area have double the soil organic matter content than sites in the enclosed area. In the Phalaris group, sites T1.7 and P10 both have higher soil organic matter content than the rest of the sites in this group. Both sites are located along the eastern edge of the enclosed section close to the canal.

The lower range in carbon content indicates that a number of sites have predominantly a mineral substrate and would fall into the mineral rather than organic soil category (<17% carbon). These sites include the lower range of the Sedge (T2-6), Phalaris (P1 and P12) and Spiraea groups (P5, P11, T1-5). Sites P1, P11 and P12 are all along the northwestern edge of the study area and are located fairly close to the road which may be a factor affecting the soil properties at these sites. Also in the previous section on the water table, fluctuations were recorded to be the highest in the northwest section of the enclosed area for the Phalaris and Spiraea sites, which may be the cause for the low soil organic matter content at P1, P11 and P12. The other three sites are located in various locations throughout the study area in the enclosed and open sections, although a single factor causing lower organic matter content is unclear, the undulating mineral substrate and higher local floodplain deposits may be factors.

Figure 4-5. Boxplot diagram of % carbon content according to each plant community group. The boxes are divided at the median and the upper and lower sides of each box mark 25% and 75% percentiles of distribution. The whiskers mark adjacent values, those data points that come nearest to the inner fences while still being inside or on them. Circles represent outliers.



Soil organic matter content changed with depth as a result of different decomposition rates and where undulating alluvial deposits mixed with organic deposits. Figure 4-6 shows how the soil organic matter content (%) changed with depth in the different plant community types. In the Kalmia sites, the high organic matter content increased slightly with depth reflecting the slower decomposition of organic matter in the subsurface where conditions remain waterlogged throughout the year. Studies have shown that decomposition rates decrease with peat depth; decomposition rates are 5 times higher near the surface where aerobic conditions exist than 20 cm deeper below the surface where anaerobic conditions are more common (Mitsch & Gosselink, 2000). The Sedge sites reflect the same pattern, although the organic matter content is lower overall and the difference between horizons is larger. These patterns are consistent with larger water level fluctuations in the enclosed section where the Sedge sites are located. Also, silts and sands washing over the organic deposits as water levels rise and sites become flooded are likely to cause the lower organic matter content in the upper horizon. The upper horizons in the Sedge and Phalaris also show this alluvial deposition pattern, however it would appear that the organic deposits are shallower at these sites where organic matter content decreases with depth.

Figure 4-6. Clustered boxplot diagram of % carbon content according to each plant community group.

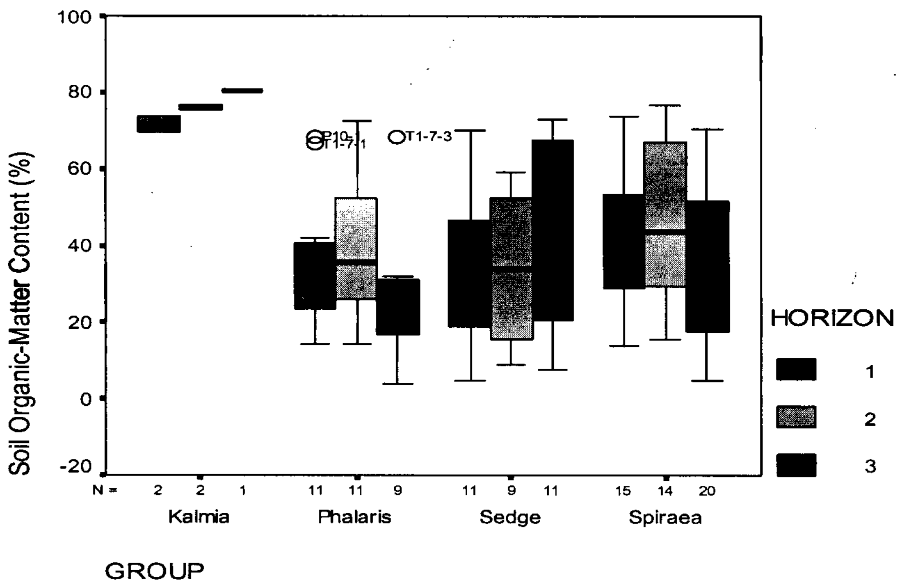


Table 4-4. Kruskal-Wallis test results. The four plant community groups were compared for each variable to test for significant differences between groups. A Chi-Square value higher than 7.815 (DF=3) means that the groups are different at the 0.05 significance level.

Water	PH	EC	Al^{+3}	Ca^{+2}	Fe^{+2}	K^{+}	Mg^{+2}	Na^{+}	SiO_2	NO_3^{-}	NH_4^{+}	PO_4^{3-}	Species richness
Chi-Square	2.07	11.32	10.21	9.24	2.23	2.69	4.39	7.60	14.70	3.15	15.28	6.91	10.96
Df	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00

Soil	PH	AL	CA	CU	FE	K	MG	NA	MN	ZN
Chi-Square	13.51	13.34	9.42	12.96	12.84	14.97	4.93	13.54	9.76	8.20
Df	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00

Soil	%Total C	% Total N	% Total P	N:P ratio	C:N ratio	C:P ratio	Species Richness
Chi-Square	12.68	2.57	15.13	12.25	15.09	14.33	10.95
Df	3.00	3.00	3.00	3.00	3.00	3.00	3.00

Table 4-5. Mann-Whitney U test results. Variables shown to be significantly different between groups in the Kruskal Wallis tests were further tested pairwise between all groups separately. Z values higher than 1.96 were considered to be significant at the 0.05 significance level.

Water components

	EC	Al^{+3}	Ca^{+2}	SiO_2	NH_4^{+}
Phalaris and Spiraea Test Statistics					
Mann- Whitney U	101	72	82	82	80
Z	-0.132	-1.403	-0.965	-0.965	-1.052
Phalaris and Kalmia Test Statistics					
Mann-Whitney U	8	8	25	9	0
Z	**-2.038**	**-2.038**	-0.113	-1.925	**-2.944**
Phalaris ans Sedge Test Statistics					
Mann-Whitney U	11	27	26	17	28
Z	**-2.973**	-1.811	-1.883	**-2.543**	-1.738
Spiraea and Kalmia Test Statistics					
Mann-Whitney U	11	9	24	14	0
Z	**-1.984**	**-2.173**	-0.756	-1.701	**-3.024**
Spiraea and Sedge Test Statistics					
Mann-Whitney U	14.5	27	12	14	28
Z	**-3.038**	**-2.266**	**-3.184**	**-3.069**	**-2.205**
Kalmia and Sedge Test Statistics					
Mann-Whitney U	0	12	9	0	0
Z	**-2.737**	-0.679	-1.189	**-2.766**	**-2.717**

Soil Components	pH	%Total C	%Total P	Al	Ca	Cu	Fe	K	Mn	Na	Zn	C:N ratio	N:P ratio	C:P ratio
Phalaris and Spiraea Test Statistics														
Mann-Whitney U	64	80	93	76	86	52	70	84	69	87	55	62	95	91
Z	-1.754	-1.052	-0.482	-1.228	-0.789	**-2.280**	-1.491	-0.877	-1.535	-0.745	**-2.149**	-1.842	-0.395	-0.570
Phalaris and Kalmia Test Statistics														
Mann-Whitney U	0	0	0	0	2	3	2	0	4	0	4	0	1	0
Z	**-2.944**	**-2.944**	**-2.944**	**-2.944**	**-2.717**	**-2.604**	**-2.717**	**-2.944**	**-2.491**	**-2.944**	**-2.491**	**-2.944**	**-2.831**	**-2.944**
Phalaris and Sedge Test Statistics														
Mann-Whitney U	26	29	25	14	28	28	20	18	30	25	24	22	23	23
Z	-1.883	-1.666	-1.955	**-2.752**	-1.738	-1.738	**-2.317**	**-2.462**	-1.593	-1.955	**-2.028**	**-2.173**	**-2.100**	**-2.100**
Spiraea and Kalmia Test Statistics														
Mann-Whitney U	3	0	0	9	7	3	6	0	6	0	28	2	4	0
Z	**-2.740**	**-3.024**	**-3.024**	**-2.173**	**-2.362**	**-2.740**	**-2.457**	**-3.024**	**-2.457**	**-3.024**	-0.378	**-2.835**	**-2.646**	**-3.024**
Spiraea and Sedge Test Statistics														
Mann-Whitney U	60	48	28	39	46	61	40	41	51	44	59	43	37	37
Z	-0.245	-0.980	**-2.205**	-1.531	-1.102	-0.184	-1.470	-1.408	-0.796	-1.225	-0.306	-1.286	-1.653	-1.653
Kalmia and Sedge Test Statistics														
Mann-Whitney U	0	2	0	5	7	3	4	0	6	0	13	1	3	0
Z	**-2.717**	**-2.378**	**-2.717**	-1.868	-1.529	**-2.208**	**-2.038**	**-2.717**	-1.698	**-2.717**	-0.510	**-2.548**	**-2.208**	**-2.717**

Acidity/base richness

The results for water and soil chemistry analyses are provided in Table 4-6. Results on the statistical difference between means by the non-parametric Kruskal-Wallis test are included in Table 4-4. Mann-Whitney test results are presented in Table 4-5 for components that were found to be significantly different between groups.

pH

The average pH of the soil water had a narrow range from 4.6 to 5.6. This range falls into the intermediate, transitional or poor fen category along the bog-fen gradient (Bridgham et al., 1996) (Moore & Bellamy, 1974) (Nicholson et al., 1996). Gorham (1967) found that non-calcareous fens had a range of 4.8 to 6.0. Recent ecological studies of peatland systems demonstrate a discontinuous pH gradient where pH< 5.0 is associated with bogs/poor fens and appears to represent waters buffered by humic acid, whereas rich fens commonly have a pH>6.0 which are buffered by a bicarbonate system (Wheeler and Proctor, 2000). Along this gradient, the rise in pH is related to the input of cations from a mineral source from either surface runoff or groundwater recharge (Mitsch & Gosselink, 2000). The soil pH had a wider range from 3.9 to 5.4, the lower end is more characteristic of acidic fens or bogs (Moore & Bellamy, 1974).

Seasonal differences in water pH were small at the Kalmia and Spiraea sites. The pH was found to be higher in the summer season at the Phalaris sites. Studies have shown that water pH can increase dramatically in drought years compared to wet years, indicating a relationship between precipitation levels and pH values (Glaser et al., 1997; Siegel et al., 1995). On the other hand, in a study of Alberta bogs/fens Vitt et. al. (1995) found little seasonal variation in pH, and no patterns between pH and precipitation events.

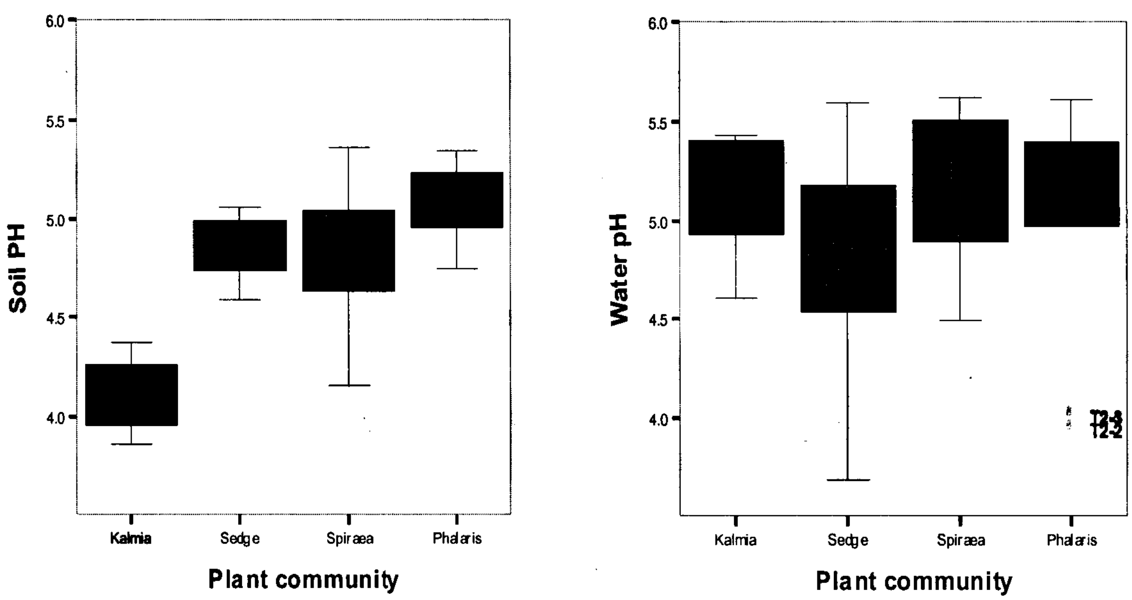
The differences in water pH between plant communities were not statistically significant (Table 4-4). Sedge sites had the lowest pH, followed by the Phalaris, Spiraea and Kalmia sites. This is contradictory with the expected gradient according to species composition where Kalmia sites should have the lowest pH values, Sedge and Spiraea sites intermediate values and Phalaris sites

Table 4-6. Minimum, maximum, median and mean values of water chemistry and soil chemistry components for the four plant communities. Mean values for water chemistry variables for the Kalmia, Spiraea and Phalaris sites are also separated into winter (W= November-March) and summer (S=April-August) means. Seasonal means are absent for the Sedge sites because water was sampled only once.

	Kalmia					Spiraea					Sedge				Phalaris				
	min	Max	median	mean		min	max	median	mean		min	Max	median	mean	min	max	median	mean	
Soil components																			
pH	3.86	4.37	4.10	4.11		4.16	5.36	4.92	4.82		4.59	5.06	4.90	4.86	4.74	5.34	5.00	5.04	
Al	150.02	283.69	207.87	212.36		118.22	4121.55	1163.78	1591.35		153.31	1821.56	764.19	846.45	302.74	3470.88	2209.41	2078.48	
Ca	1126.37	3948.73	1899.46	2218.51		1867.23	6750.40	4578.30	4284.78		2452.22	6980.51	3323.76	3876.43	3029.73	6526.07	4881.57	4719.41	
Cu	0.20	3.01	1.85	1.73		2.33	22.50	8.68	8.44		0.74	29.47	9.65	10.03	0.69	15.98	12.45	11.82	
Fe	105.66	921.07	212.13	362.75		156.39	3387.89	1826.50	1702.22		261.44	1902.80	1202.68	1155.46	170.72	4642.08	2419.76	2501.12	
K	76.83	147.79	120.14	116.22		186.26	1200.09	719.45	734.36		189.05	1199.47	417.12	493.05	375.09	1524.48	791.40	887.39	
Mg	196.27	906.75	462.00	506.76		49.06	1561.05	323.51	500.34		31.31	1394.86	473.89	566.48	60.19	1216.73	838.67	826.81	
Mn	6.85	29.48	16.22	17.19		7.37	273.15	96.60	100.23		5.08	285.88	65.16	90.72	5.07	203.96	166.20	143.40	
Na	97.47	152.83	134.77	129.96		180.59	1497.18	953.62	851.73		178.19	1513.14	616.13	651.23	363.16	1438.04	1152.31	1044.05	
Zn	3.45	7.79	5.64	5.63		0.75	20.79	7.07	7.73		1.02	20.60	7.56	7.88	0.70	27.93	16.55	14.94	
Water components																			
pH	4.61	5.43	5.32	5.12	**W**	4.52	5.62	5.24	5.49	**W**	3.69	5.60	5.02	4.85	3.95	5.61	5.21	5.32	**W**
				5.12	**S**				5.52	**S**								5.47	**S**
EC	37.40	64.30	54.85	52.90	**W**	10.00	124.60	35.10	49.45	**W**	10.00	34.40	11.83	11.92	13.85	82.20	30.90	41.07	**W**
				52.81	**S**				62.08	**S**								69.77	**S**
Al+3	0.012	0.178	0.103	0.084	**W**	0.057	0.853	0.286	0.273	**W**	0.075	0.173	0.140	0.132	0.088	0.353	0.190	0.181	**W**
				0.117	**S**				0.338	**S**								0.291	**S**
Ca+2	0.168	2.475	1.338	1.170	**W**	0.479	12.492	1.715	3.463	**W**	0.403	1.371	0.567	0.701	0.418	10.315	1.177	2.821	**W**
				1.448	**S**				3.279	**S**								2.943	**S**
Fe+2	0.059	1.602	0.506	0.550	**W**	0.031	5.838	0.292	2.537	**W**	0.148	0.636	0.416	0.392	0.038	5.583	0.620	1.547	**W**
				0.793	**S**				4.176	**S**								3.921	**S**
K+	0.233	0.458	0.367	0.269	**W**	0.500	0.553	0.204	0.076	**W**	0.102	0.377	0.177	0.198	0.500	0.649	0.192	0.094	**W**
				0.722	**S**				0.205	**S**								0.569	**S**
Mg+2	0.027	0.789	0.297	0.264	**W**	0.066	0.670	0.225	0.281	**W**	0.070	0.332	0.120	0.157	0.078	0.339	0.182	0.210	**W**
				0.422	**S**				0.328	**S**								0.277	**S**
Na+	1.073	2.574	1.244	2.038	**W**	0.664	6.243	1.869	2.191	**W**	0.703	2.503	1.089	1.228	0.811	3.420	1.626	2.280	**W**
				2.097	**S**				2.023	**S**								2.195	**S**
SiO2	1.984	20.822	10.850	10.141	**W**	0.926	16.824	3.223	5.307	**W**	0.075	1.798	0.663	0.837	0.473	6.908	2.665	3.792	**W**
				10.916	**S**				5.491	**S**								4.246	**S**

the highest. Soil pH however, showed the expected gradient and differences between groups were significant (Table 4-4 and 4-5). The results from the Mann-Whitney comparison show that the Kalmia sites are significantly different from the rest of the sites. However, soil pH at the rest of the sites are not significantly different from each other. Although significant differences in soil pH between plant communities exist, the range in both water and soil pH values were smaller than expected (Figure 4-7). According to species composition, Phalaris sites should fall into the extreme rich fen range and should have pH values >6.0 (Wheeler and Proctor, 2000). The Sedge and Spiraea sites should fall into the moderate-rich fen range and should have pH values close to 6.0 (Mitsch & Gosselink, 2000).

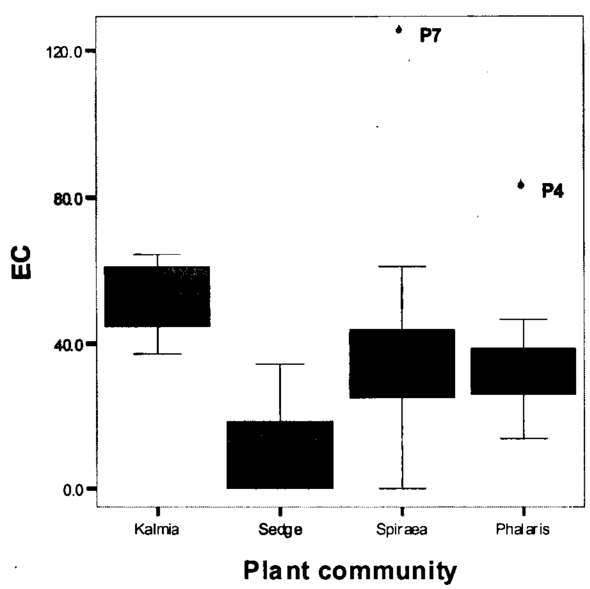
Figure 4-7. Boxplot diagram of soil and water pH according to each plant community group.



Cation concentrations

The concentrations of cations at Blaney Bog for all sites fall within the bog-poor fen range and do not reflect the intermediate and extreme rich fen end of the spectrum reflected by the vegetation at the Spiraea, Sedge and Phalaris sites (Heathwaite & Gottlich, 1993; Nicholson et al., 1996). Within the present range however there was noticeable variability in concentrations of cations in the water among plant community types. Conductivity, a measure of ionic content in water, showed highest median values in the Kalmia sites and lowest in the Sedge sites. Two sites were found to have exceptionally high conductivity values (P4= 84us/cm and 12.50mg/L; P7=125us/cm and 10.35mg/L). These two sites have different plant communities where P4 is a Phalaris site whereas P7 is a Spiraea site (Figure 4-8). The two outliers cause high mean summer conductivity values for the Spiraea and Phalaris sites. The differences between groups were significantly different for all plant communities except between Phalaris and Spiraea (Table 4-4 and 4-5).

Figure 4-8. Boxplot diagram of conductivity (us/cm) according to each plant community group.



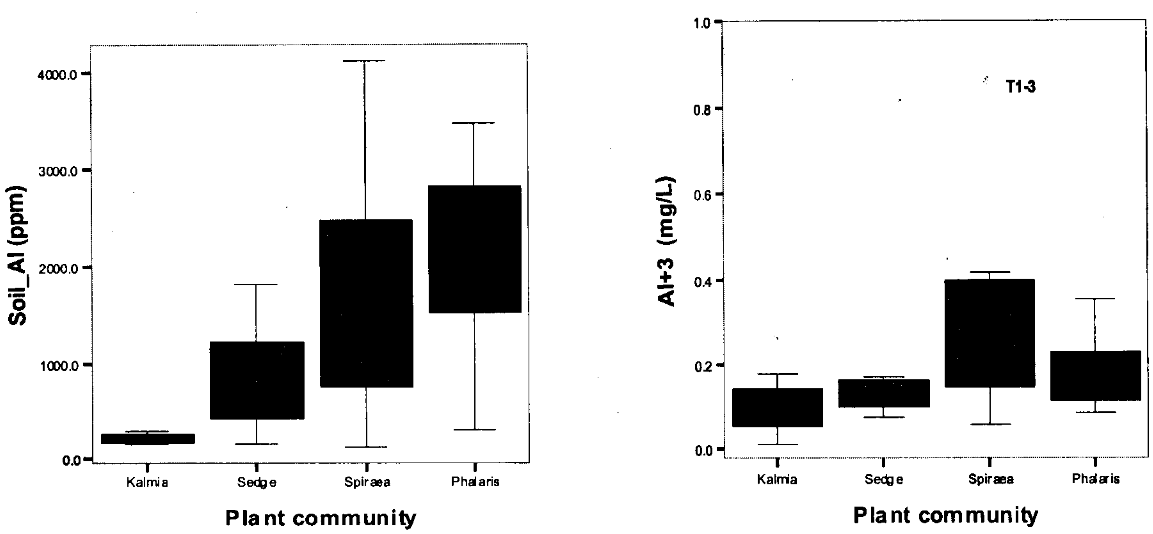
Aluminum, calcium and sodium concentrations were highest in the Spiraea sites. On the other hand, potassium and magnesium showed highest concentrations in the Kalmia sites. Iron concentrations were slightly higher in the Phalaris sites. Magnesium and iron concentrations showed more variability within groups compared to the other water components. The concentrations were significantly different between plant community groups for only aluminum and calcium (Table 4-4). Aluminum concentrations were significantly different between Phalaris and Kalmia sites; Spiraea and Kalmia sites; and Spiraea and Sedge sites (Table 4-5). On the other hand, calcium concentrations were only significantly different between the Spiraea and Sedge sites (Table 4-5). Concentrations of copper, manganese and zinc were found to be below detection limits. In other studies, manganese has been found to be generally below detection limits in bog/fen waters (Burgess et al., 1995). In general, however the results for cation concentrations in Blaney Bog waters contrast other studies where base cation concentrations and conductivity increase along the bog-fen gradient and metal concentrations decrease (Vitt et al., 1990).

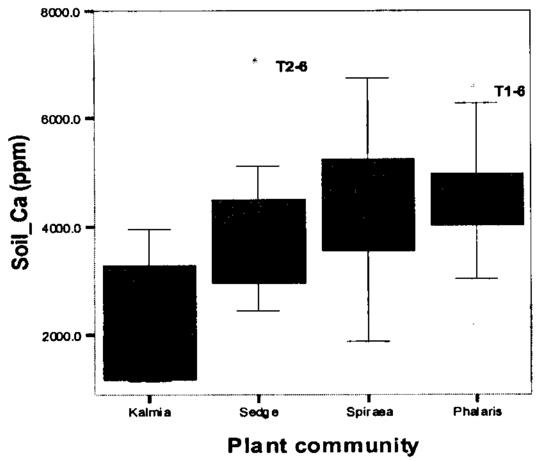
Water chemistry results for cation concentrations also showed seasonality. All cation concentrations were higher in the summer except for calcium, and sodium which showed no seasonal difference. It is predicted that cation concentrations will show seasonality with higher values in the summer (Proctor, 1994). Seasonality is correlated with processes determined by the balance of precipitation and evapotranspiration, or oxidation-reduction processes dependent on water level or temperature (Proctor, 1994). Data from studies in southern regions show more seasonal variability than northern regions caused by early drought and snow-free winters (Wieder 1985). It is surprising that seasonality was not found for calcium, as other studies have shown that calcium concentrations increase during the growing season and a negative correlation has been shown with rainfall (Proctor, 1994; Vitt et al., 1995). On the other hand, the lack of seasonality for sodium concentrations has been shown elsewhere (Vitt et al. 1995).

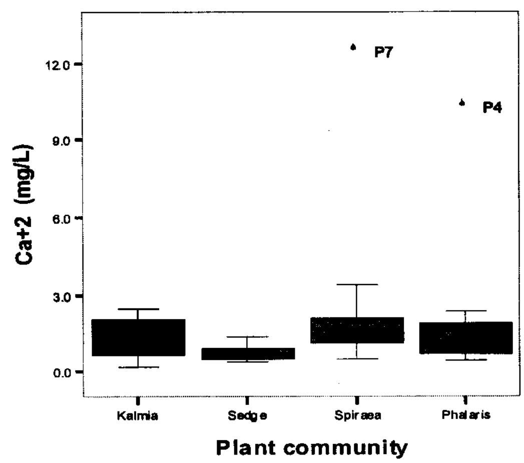
Cation concentrations in the soils were also found to fall within the range expected for bog to poor fen and do not reflect the intermediate and extreme rich fen end of the spectrum reflected by the vegetation at the Spiraea, Sedge and Phalaris sites (Heathwaite & Gottlich, 1993). However, the distribution of cations concentrations among the plant community types, were different from the water component. The Kalmia sites had the lowest concentrations of all cations and Phalaris sites had the highest (Table 4-6). The Sedge and Spiraea sites had intermediate concentrations but generally closer in value to the Phalaris sites. The differences were statistically significant for all variables except magnesium (Table 4-4). The Kalmia sites are significantly different from the rest of the plant community groups (Table 4-5). The Phalaris sites are significantly different from the Sedge sites for aluminum, iron, potassium, and zinc; and from the Spiraea sites for copper and zinc (Table 4-5).

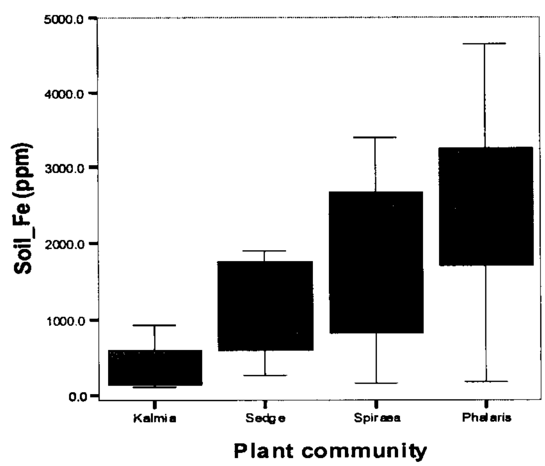
Although not a cation, it is worth mention that silica concentrations in the pore water were found to be high, particularly in the Kalmia sites. Wetlands underlain by siliceous terrains tend to have low pH and low calcium concentrations than calcareous-systems (Bridgham et al. 2001). Also, research on concentrations of silica in bog/fen systems seems to suggest that concentrations are determined by fluxes from a source/sink within the peat where organic acids form complexes with silica (Bennet et al. 1991). It is believed that diatom frustules dissolved in the peat column release silica which is maintained by these silica-organic complexes.

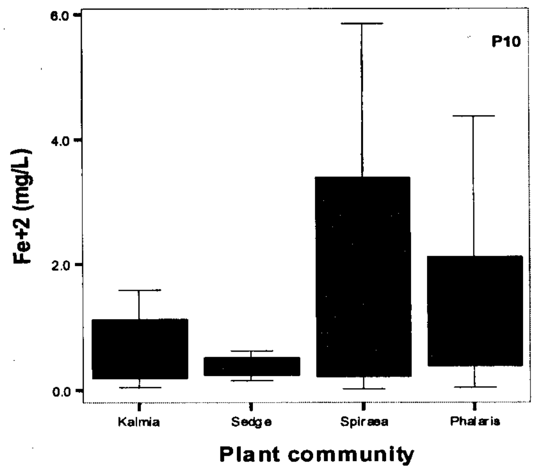
Figure 4-9. Boxplot diagrams of cation concentrations in the soil and water according to each plant community group.

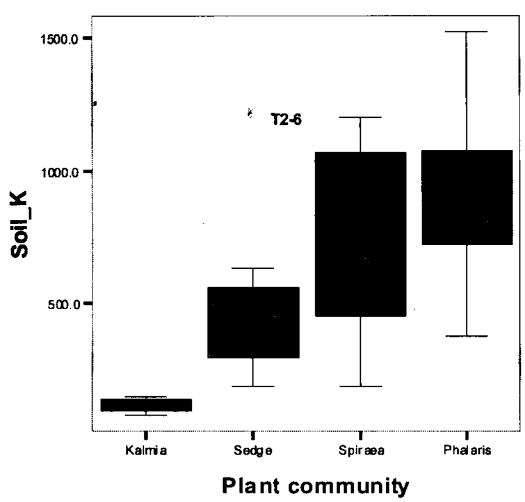


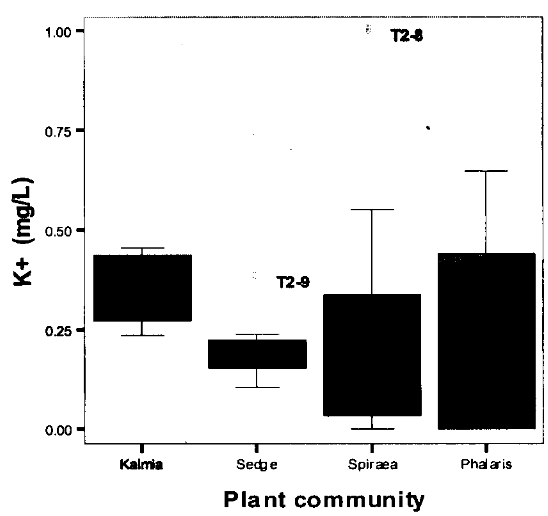

8000.0
6000.0
4000.0
2000.0
Soil_Ca (ppm)
T2-6
T1-6
Kalmia
Sedge
Spiraea
Phalaris
Plant community

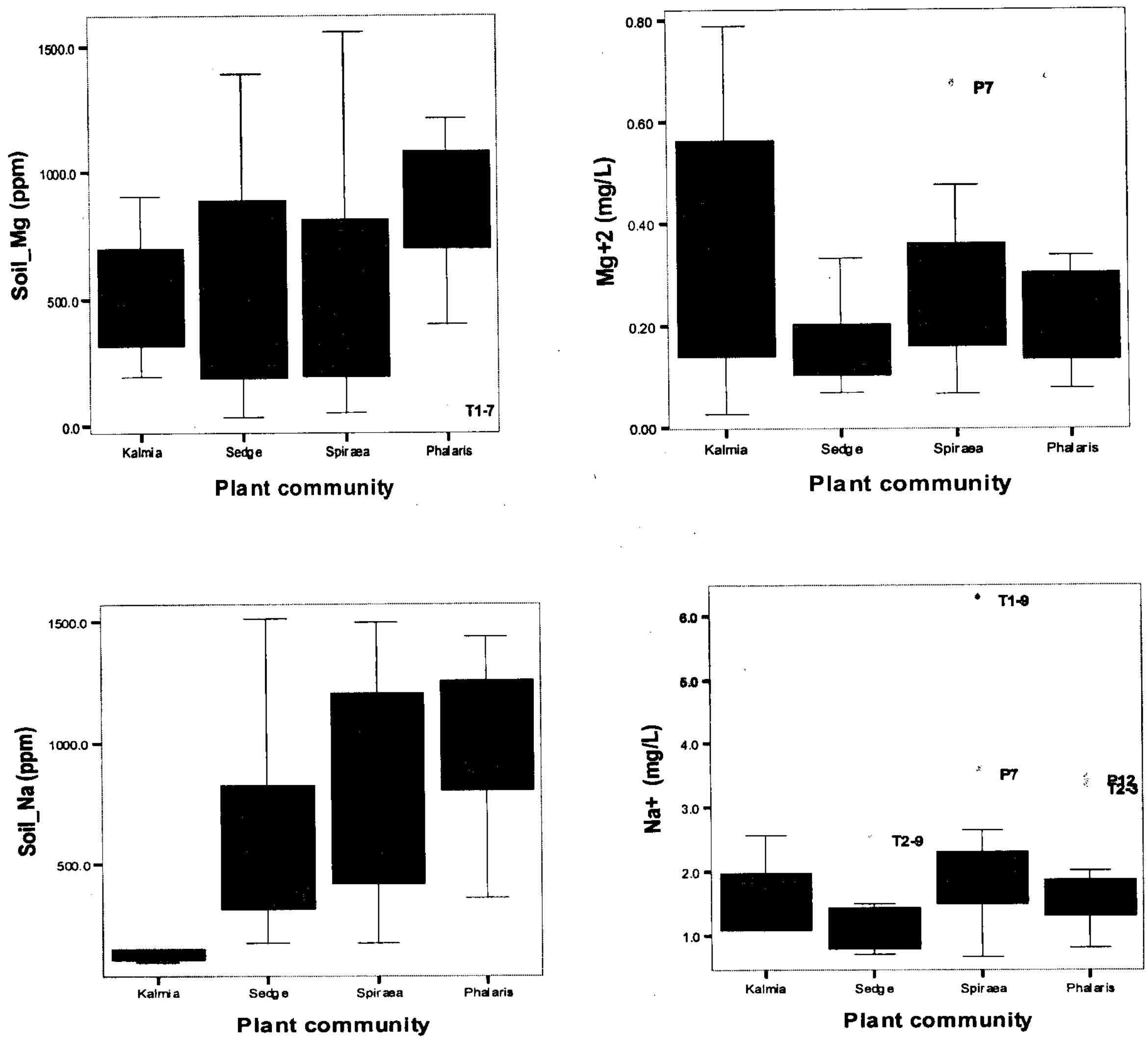

12.0
9.0
6.0
3.0
0.0
Ca+2 (mg/L)
P7
P4
Kalmia
Sedge
Spiraea
Phalaris
Plant community


5000.0
4000.0
3000.0
2000.0
1000.0
0.0
Soil_Fe (ppm)
Kalmia
Sedge
Spiraea
Phalaris
Plant community


6.0
4.0
2.0
0.0
Fe+2 (mg/L)
P10
Kalmia
Sedge
Spiraea
Phalaris
Plant community


1500.0
1000.0
500.0
Soil_K
T2-6
Kalmia
Sedge
Spiraea
Phalaris
Plant community


1.00
0.75
0.50
0.25
0.00
K+ (mg/L)
T2-8
T2-9
Kalmia
Sedge
Spiraea
Phalaris
Plant community



The overall range in pH and cation concentrations in Blaney Bog were smaller than expected in a fen-bog system. The lower pH range may be caused by the hydrological modification of the Blaney Bog system. It has been shown that artificial changes such as a reduction of base-rich water source may cause some base-rich systems to show progressive acidification (Wheeler and Shaw, 1995). The dyke/canal is intended to impede surface water flow which historically would have been a source of base-rich waters. Reduced input of base-rich waters has isolated the system, presently only precipitation is a major source of input and this has caused subsequent acidification and cation concentrations that do not reflect the rich fen sites. Variation in patterns observed between water chemistry and soil chemistry may also be explained by the hydrological modification to the system. Water chemistry is much more dynamic and easily affected by change whereas changes in soil properties take longer. The soil components showed clearer differences between groups for all variables compared to the water variables. Also, a gradient was found with Kalmia sites showing lowest concentrations, Spiraea and Sedge sites intermediate concentrations and Phalaris the highest concentrations. Along this gradient, the Kalmia sites were significantly different from the rest of the sites. This gradient was not visible for the water variables and the Kalmia sites were not as distinct from the rest of the sites with respect to the water component.

Relationships between pH and water/soil cation concentrations

Studies have shown the following relationships between pH and water/soil chemistry variables: (1) positive and highly significant correlation for base cations and EC; and (2) negative and highly significant correlation for metals (Al, Fe, Cu, Mn and Zn) (Vitt et al. 1995).

In Blaney Bog the positive correlation between pH, base cations and conductivity are present (Table 4-7). The correlations are higher in the soil component than the water component. The pH and Ca^{2+} ion concentrations have been shown to be reliably interrelated in mire systems because the input of cations from a mineral source cause the pH to rise (Ross, 1995). Calcium enrichment occurs in fen waters from groundwater, and concentrations are depleted in bog waters where it is taken up by Sphagnum. Other base cation concentrations are also correlated with the base-richness gradient and should show similar patterns to calcium along this gradient.

The concentrations of metals in Blaney bog waters/soils do not show a negative correlation with pH values. Concentrations increase with pH, and similar to the base cations, the correlations are higher in the soil component than the water component. Aluminum concentrations have been shown to decrease with pH and calcium in other studies of bog-fen systems (Wheeler and Shaw, 1995). Concentration profiles are considered to be related to the enhanced dissolution of alumino-silicates embedded within the peat at low pH, and to decreasing solubility of aluminum at higher pH of pore waters (Glaser et al. 1997). Both aluminum and iron should be abundant as pH decreases, a function of organic-acid-metal binding that occurs at low pH (Vitt et al. 1995). Although pH is lowest in the Kalmia sites, the aluminum and iron concentrations are higher in sites of the other three plant community types because of higher mineral content in the soil. The results suggest that the difference in mineral content of the substrate is large enough that the expected negative correlations between aluminum and iron concentrations and pH are absent.

Table 4-7. Spearman's correlation coefficients for pH and cations in the water and soils at Blaney Bog. All values are significant at the 0.05 level. A dash means that correlation coefficients were not calculated for that variable.

	Water pH	*Soil pH*
EC	0.52	-
Al+3	0.40	0.55
Ca+2	0.55	0.78
Cu	-	0.61
Fe+2	0.41	0.44
K+		0.65
Mg+2	0.41	0.45
Mn	-	0.65
Na+		0.70
SIO2	0.53	-
Zn+2	-	

Nutrient status

Nitrogen and phosphorus were examined to investigate the relationship between plant community and nutrient status in Blaney Bog. Nutrient levels for each community type are presented in Table 4-8.

Table 4-8. Minimum, maximum, median and mean values of water nutrient and soil nutrient components. Values of water variables are separated into winter (W= November-March) and summer (S=April-August) means.

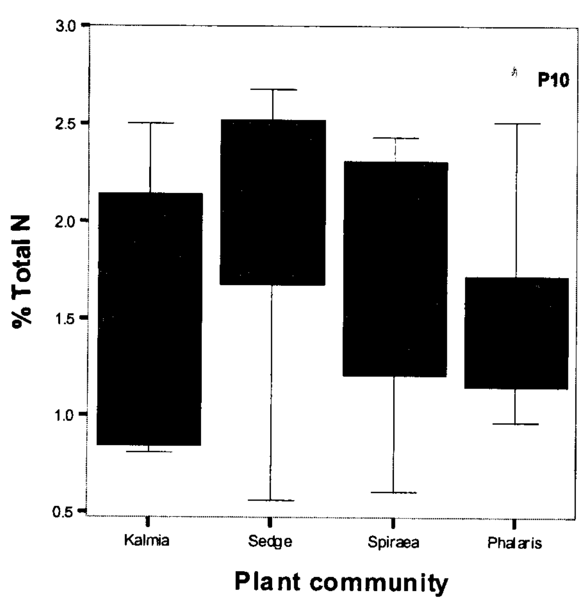
		NO3-	*NH4+*	*PO43-*
Kalmia	**min**	0.038	2.101	0.115
	max	0.179	4.534	0.364
	median	0.063	2.886	0.286
	mean (W)	0.119	2.860	0.287
	mean (S)	0.046	3.406	0.199
Spiraea	**min**	0.017	0.045	0.010
	max	1.340	1.097	0.348
	median	0.089	0.255	0.094
	mean (W)	0.166	0.511	0.097
	mean (S)	0.046	1.026	0.128
Sedge	**min**	0.023	0.047	0.014
	max	0.619	0.513	0.348
	median	0.031	0.099	0.053
	mean (W)	0.170	0.151	0.111
Phalaris	**min**	0.010	0.050	0.020
	max	1.698	1.130	0.432
	median	0.033	0.219	0.068
	mean (W)	0.065	0.320	0.070
	mean (S)	0.050	1.340	0.118

		% Total N	% Total P	C:N ratio	N:P ratio	C:P ratio
Kalmia	**min**	0.81	0.02	17.51	38.10	1486.70
	max	2.51	0.03	59.73	90.98	2742.11
	median	1.33	0.03	39.86	50.60	1803.00
	mean	1.50	0.03	39.24	57.57	1958.70
Spiraea	**min**	0.61	0.04	13.85	7.18	99.42
	max	2.43	0.14	18.65	50.40	939.82
	median	2.01	0.11	14.43	15.48	222.49
	mean	1.79	0.10	15.01	20.88	328.98
Sedge	**min**	0.56	0.04	13.97	8.11	113.22
	max	2.68	0.12	17.67	59.10	1043.99
	median	2.12	0.07	15.46	29.52	470.21
	mean	1.98	0.07	15.63	29.59	477.23
Phalaris	**min**	0.97	0.06	12.77	9.66	128.18
	max	2.75	0.14	16.75	42.21	564.12
	median	1.32	0.10	14.06	15.50	198.03
	mean	1.54	0.10	14.30	16.99	242.57

Nitrogen

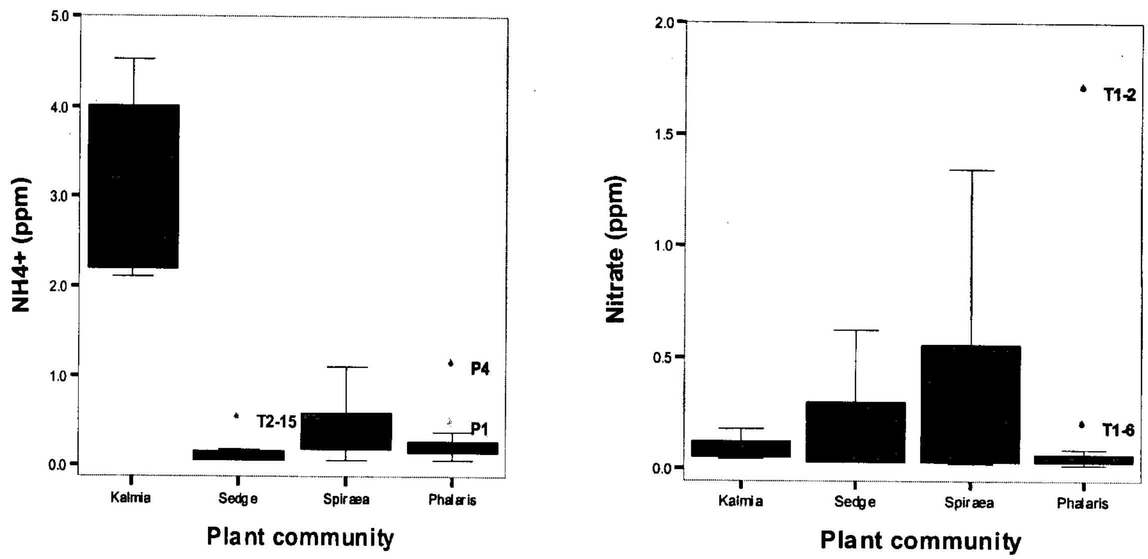
Nitrogen is an essential nutrient for plant growth and is taken up by plants in large amounts with small concentrations remaining in the soil. Brady (1990) lists N as a critical soil constituent because of the tendency of N to be easily lost by decomposition of organic compounds. Generally, N concentrations in soils increase with increased organic matter contents, because soil N is mostly organic in nature (Collins & Kuehl, 2001). However within pealtands it has been found that the N content in peat may amount to 2.5% whereas in fens the N content is approximately 4%, the differences in soil N concentrations are caused by differences in species composition and the ability of each species to store N (Bridgham et al., 1998). Sphagnum moss increase in bogs has been found to contribute to the drop in nitrogen levels because generally Sphagnum spp. have a nitrogen content smaller than 1% (Gorham & Janssens, 1992). Nitrogen is traditionally considered to be a limiting nutrient in freshwater wetlands (Damman, 1988). The soils sampled in Blaney Bog had a mean of 1.61 total % N, ranging from 0.56 to 2.75. These N concentrations are closer to bogs rather than fens but within the normal range observed in organic wetlands (0.48-3.00) (Bedford et al., 1999). The differences between plant community groups were not significant (Table 4-4). Average N concentrations have been found to be significantly higher in moderate-rich fens than in other wetland types (Bedford et al., 1999).

Figure 4-10. Boxplot diagram of total soil N (%) according each plant community group.



Ammonium ion is the primary form of mineralized nitrogen in most flooded wetland soils. Nitrogen mineralization involves the conversion of organically bound nitrogen to ammonium nitrogen through biological transformations as organic matter decomposes. This process of ammonification occurs in aerobic and anaerobic conditions. The average ammonia readings throughout the study period ranged from 0.143 to 4.53 ppm. The Kalmia sites had the highest concentrations, and the differences between groups were significant (Table 4-4). Only Phalaris sites were not significantly different from either the Spiraea or the Sedge sites (Table 4-5). Other studies have also found concentrations of ammonium to be greater in bogs compared to fens (Waughman, 1980; Proctor, 1994). Summer ammonium levels were higher than winter levels due to higher temperatures and consequently increased microbial activity. Nitrate is not immobilized by negatively charged soil particles, instead it is much more mobile in solution and thus if it is not taken up by plants it is rapidly lost with groundwater flow. Nitrate levels were lower than ammonium concentrations and ranged from 0.022-0.313 mg/L. The Spiraea sites had the highest nitrate concentrations in the winter. The differences between groups were not significant (Table 4-4). Vitt et al. (1995) also found that ammonia levels were higher than nitrate in all peatland types with the higher ammonia levels in bogs compared to fens. While seasonal variation was observed in both forms of nitrogen, nitrate levels showed more fluctuations indicating that variation in concentrations was associated with rain where higher precipitation resulted in higher nitrate concentrations.

Figure 4-11. Boxplot diagrams of ammonium and nitrate according to each plant community group.



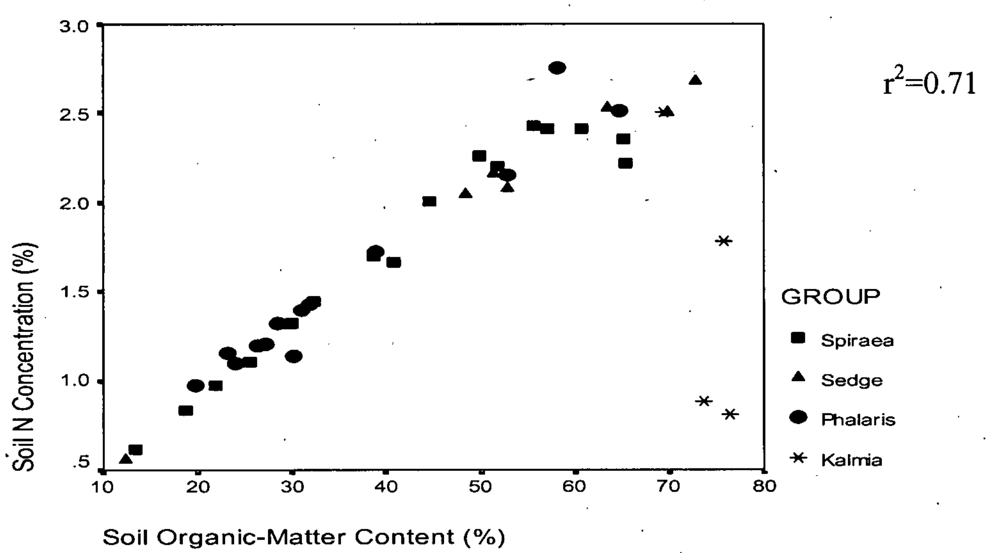
C:N ratio

Total nitrogen is a function of organic matter. Studies show a linear relationship between carbon and nitrogen content. Organic matter provides energy for microorganisms that are essential in biochemical reactions involving nitrogen in soils. C:N ratio is used as an index of humification or decomposition and humus quality. State of decomposition is also an indicator of soil chemical properties where nutrients are released into the soils as the organic matter decomposes. C:N ratio greater than 20-30:1 are characterized by immobilization where inorganic nitrogen is converted to organic nitrogen and microorganisms use it as energy. C:N ratio narrower than 20:1 are characterized by mineralization, where organic matter is decomposed and inorganic ions released.

In Blaney Bog, the Kalmia sites had an average C:N of 39:1 ratio, whereas the range in the C:N ratio in all the other sites was 12-18:1 (Table 4-8). The differences between groups were not found to be significant (Table 4-4). The lower C:N ratios of the non-Kalmia sites reflect the higher decomposition rates due to greater water fluctuations that result in periodic aeration and consequent lower organic matter content at these sites. Decomposition rates are slower in the

Kalmia sites which is evident by the on average higher organic matter content and higher water table. The rate of decomposition in peat bogs is generally low because of waterlogged conditions. Also, slower decomposition rates in bogs are partly attributed to the presence of a Sphagnum carpet, which has been shown to severely inhibit microbial decomposition. The C:N quotient in the Kalmia sites is however lower than what is expected in bogs where C:N values have been recorded between 60-100:1 (Damman, 1988). Although water level fluctuations in the Kalmia sites are small compared to the other sites, the water levels fluctuate more than expected for a bog-poor fen and this might explain the lower C:N ratio. Figure 4-12 demonstrates the strong positive correlation between carbon content and nitrogen concentrations in soils of the sites surveyed at Blaney Bog. Although the correlation is present, a clear subdivision according to plant community types is not. Sites vary in their nitrogen content within the groups. The Kalmia sites show particular spread in nitrogen levels with three of the four sites appearing as clear outliers in the scatterplot.

Figure 4-10. Soil nitrogen (N) concentrations in relation to soil organic-matter content.



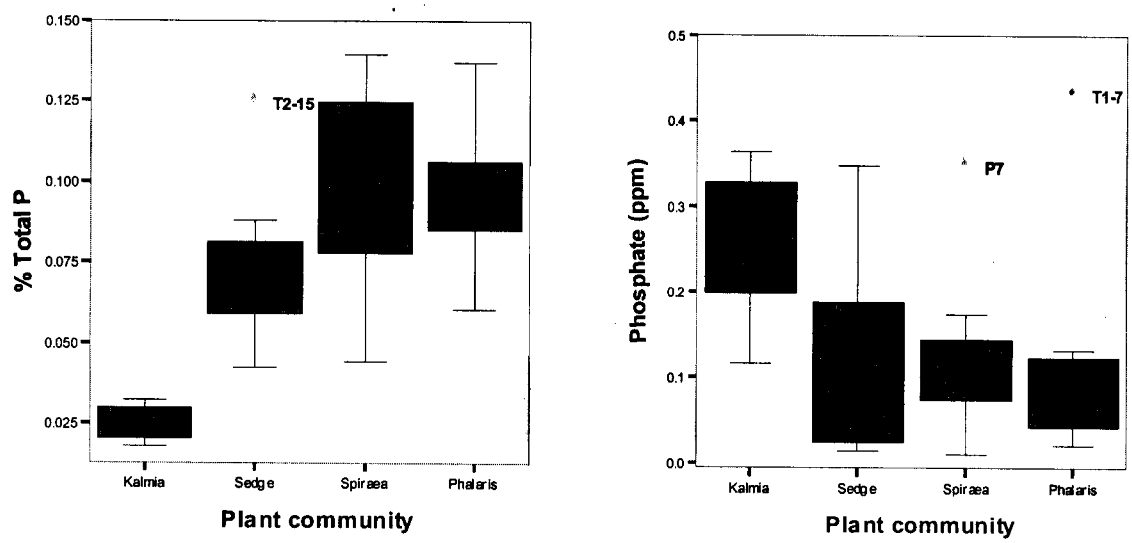
Phosphorus

Phosphorus is an essential plant nutrient and is taken up by plants in the form of $H_2PO_4^-$ and HPO_4^{2-} inorganic ions. Phosphorus occurs in soils in organic and inorganic form but the amount of it available to plants depends on: dissolution into ionic forms, soil pH, decomposition of organic matter and microbial activity. For example, calcium phosphates are less soluble as soil pH climbs, and iron and aluminum phosphates are less soluble as the pH drops. Phosphorus adsorption dynamics are dependent on iron, aluminum and manganese hydroxyl-oxide sesquioxide contents. Mineral soils are likely to have higher phosphorus adsorption capacity than peats because they have more iron. Maximum availability of phosphate ions for plant growth occurs within pH 6.5-7.5. Organic-phosphorus and fixed mineral phosphorus comprise approximately 90% of total phosphorus in a wetland; very small concentrations of phosphorus are found in the water column.

Soil samples from the bog show a mean of 0.087% total of phosphorus, ranging between 0.018 and 0.140 falling well within the range observed for P concentrations in organic wetlands (Bedford et al., 1999). Among the groups, Spiraea has the highest mean concentration level of phosphorus, whereas the Kalmia group has the lowest. The differences were found to be significant (Table 4-4). The Kalmia sites show lower phosphorus concentrations compared all the other sites (Table 4-5). Only the Phalaris sites are not significantly different from the Spiraea and Sedge sites (Table 4-5). Studies have shown that average P concentrations were significantly lower in bogs and poor fens than in other wetland systems (Bedford et al., 1999).

In the water, the average values of orthophosphate were found to range from a minimum of 0.025 to 0.364 ppm. The highest values were in the Kalmia sites and did not show seasonal differences between summer and winter concentrations. The differences between groups were not found to be significant (Table 4-4). Vitt et al. (1995) found highest phosphate concentrations in poor fens and lowest in bogs. They also found that phosphate concentrations showed little seasonality.

Figure 4-13. Boxplot diagrams of phosphorus and phosphate levels according to each plant community group.

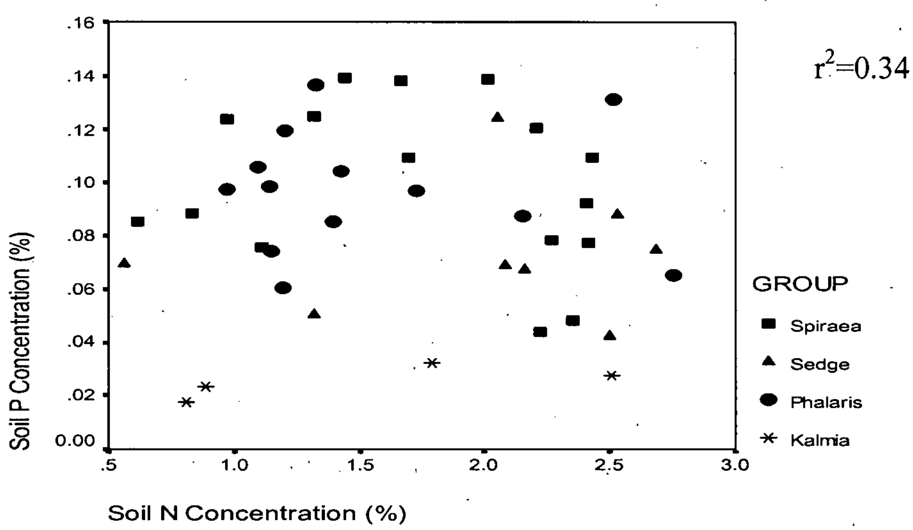


N:P ratio

Fertilization studies are the most appropriate method for investigating nutrient limitation in plant communities, however nutrient limitation can also be inferred from element ratios in soil or water (Bridgham et al., 1998). Experiments have shown that N:P ratios in plant tissues and soil are highly correlated with each other and reflect abundance/scarcity of these nutrients in the system (Aerts et al., 1999; Verhoeven et al., 1990). Verhoeven et al. (1996) suggest that N:P ratio > 16 suggests P limitation, N:P ratio<14 suggests N limitation, and 14<N:P<16 suggests co-limitation. Soil N:P ratios range from 2 to 60 in bogs fens (Bedford et al., 1999). The N:P ratios in Blaney Bog ranged from 16 to 58, supporting that the plant communities surveyed in Blaney Bog are phosphorus limited. The differences between groups were significant (Table 4-4).

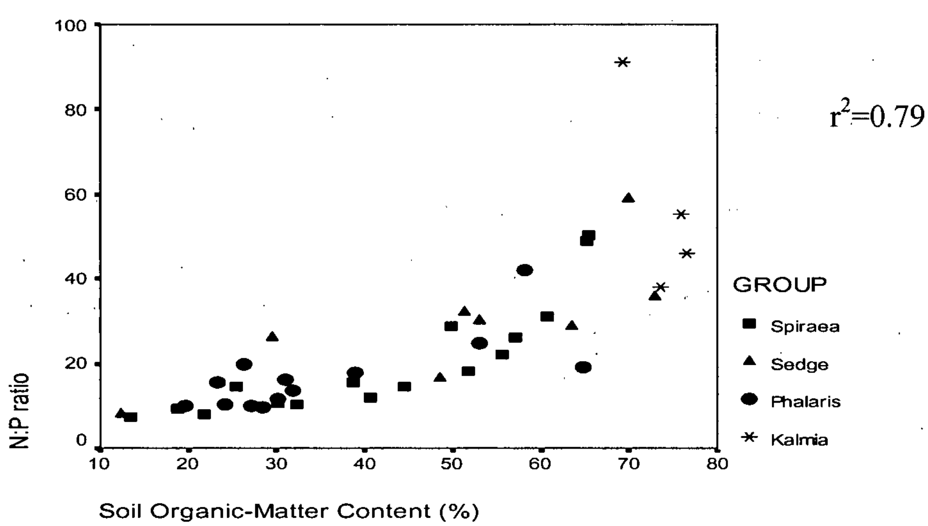
Relationships between nutrient concentrations and N:P ratios were examined by plotting phosphorus concentrations against nitrogen concentrations (Figure 4-14). Although mean N:P ratio values for the plant community types are different, the graph shows that the sites are not distributed in any linear fashion, as expected, but spread out. The graph does reflect low phosphorus levels in the Kalmia sites compared to the other plant community types. However diverse nitrogen concentrations blur any linear relationship between N and P.

Figure 4-14. Phosphorus (P) and nitrogen (N) concentrations in soil samples from Blaney Bog.



As expected there is a positive correlation between organic matter and N:P ratio (Figure 4-15). The variation in soil organic-matter content within plant community types blurs the separation between plant communities along this gradient. However the Kalmia sites are clustered towards the higher end of the gradient.

Figure 4-15. Soil N:P ratios in relation to soil organic-matter content.

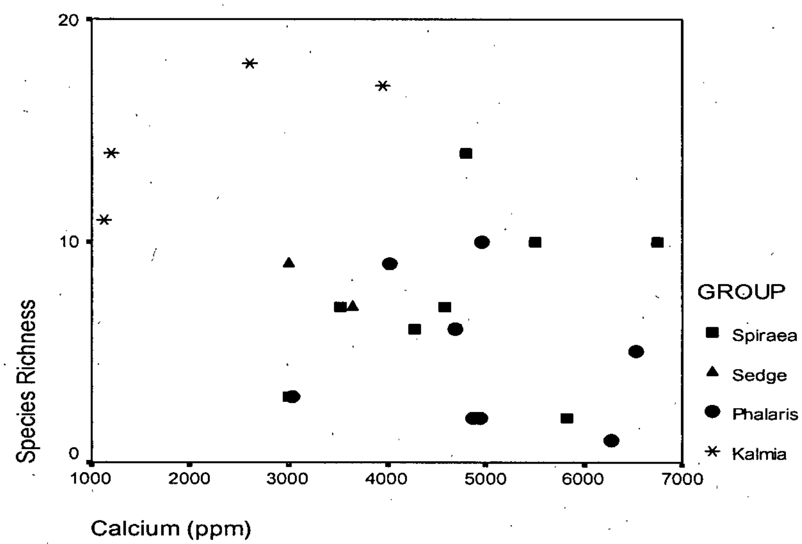


Species richness

Community response to nutrient status is of great interest in wetland ecology as nutrient enrichment is an increasing threat to these systems. Eutrophication has been shown to have a decreasing effect on species richness in wetland plant communities. In general, species richness increases as inflow of mineral rich water into a wetland increases, thereby reducing anaerobic conditions and stimulating diversity (Bedford et al., 1999). On the other hand too many nutrients can create relatively uniform, mono-species stands. Keddy and associates have done extensive research on relating species richness and biomass in wetlands (Keddy, 2000). Their results conform to the hump-shaped model proposed by Tilman (1986) where richness is highest at an intermediate level of biomass and lower at the low and high ends of the biomass gradient. Glaser et al. (1990), in studies of Minnesota wetlands, found that vascular plant and bryophyte species richness generally rises with increasing pH and calcium, reaching a peak within a chemical range associated with rich fens, and then decreasing in extremely rich fens. Vitt et al. (1990) also found this pattern and thought it was because moderate rich fen sites had a mixture of species characteristic of moderate rich fen sites as well as poor and rich fen species due to the higher variability in chemistry and nutrient status at these transitional sites. Other studies have found no relationship between species richness and biomass, nor strong relationships between species richness and indicators of nutrient status in soils or water (Bedford et al., 1999).

In order to examine relationship between species richness and the rich fen-bog gradient in Blaney Bog, species richness was graphed as a function of pH, Ca, C:N ratio, C:P ratio and N:P ratio. The scatterplots of pH and Ca show a negative trend, with species richness decreasing as pH values and Ca concentrations increase. The Kalmia sites have the highest species richness and lowest pH and Ca concentrations whereas the other sites generally have lower species richness and higher pH and Ca concentrations. The scatterplots of nutrient ratios show that sites cluster towards low nutrient ratios and low species richness values. The exceptions are the Kalmia sites which generally exhibit high species diversity and high nutrient ratio values. The low r2 values and lack of linear patterns indicates no clear relationships between nutrient ratios and species richness. The pronounced difference between the Kalmia sites and the rest of the sites is clear however with respect to higher nutrient ratios and species richness.

Figure 4-16. The relationship between species richness and pH and Ca concentrations in the soil. Spearman's correlation coefficients not significant.



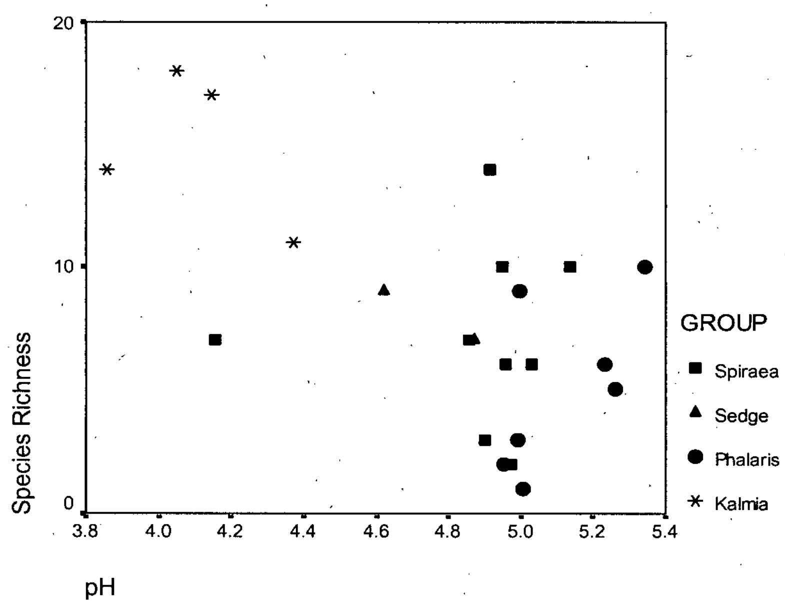
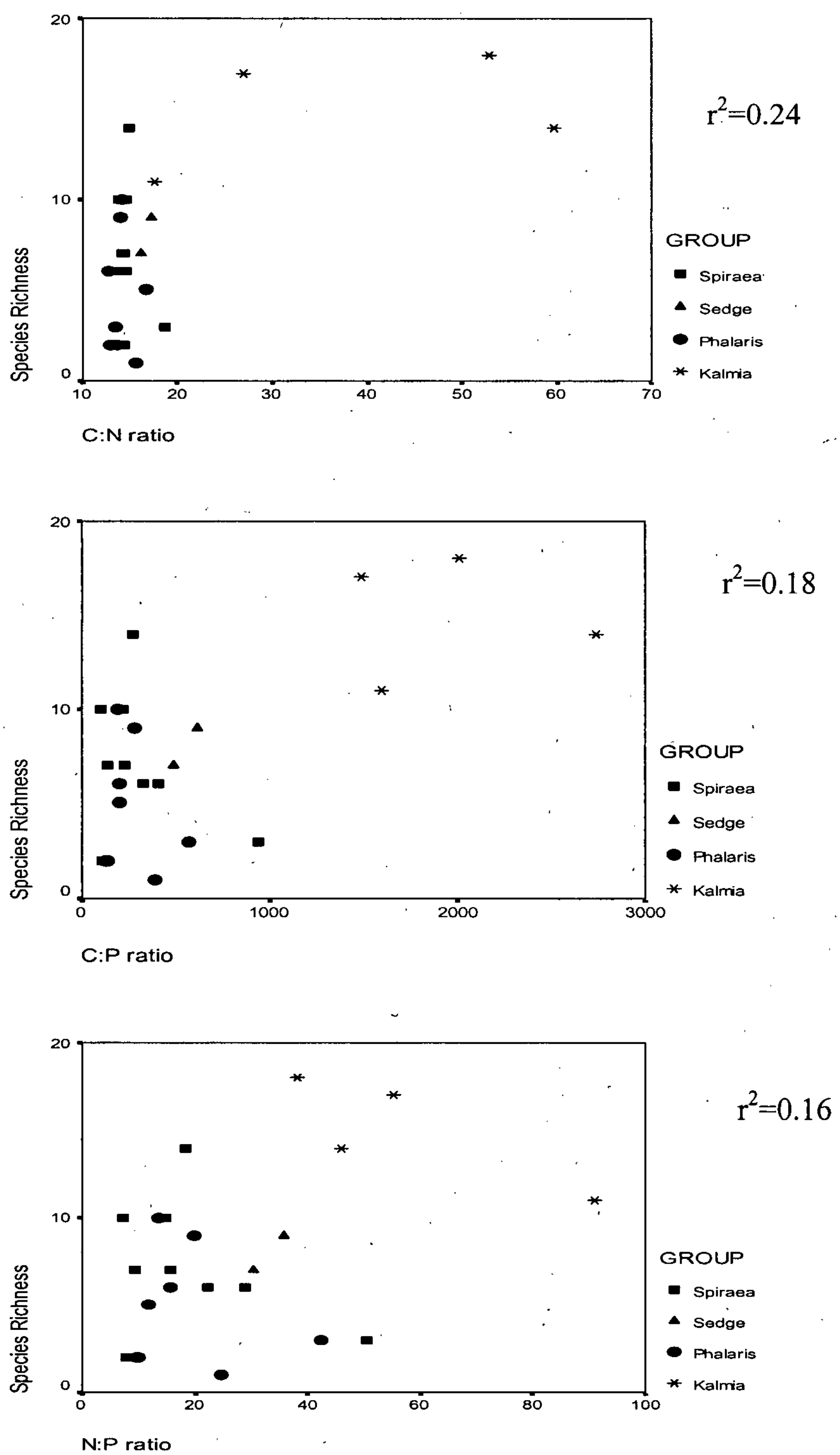


Figure 4-17. The relationship between species richness and soil nutrients within Blaney Bog. Species richness is the mean number of species (vascular plants and bryophytes) per 2m^2 for three 2m^2 plots. Richness is plotted as a function of (a) the carbon-to-nitrogen ratio (C:N); (b) the carbon-to-phosphorus ratio (C:P); and (c) the nitrogen-to-phosphorus (N:P) ratio. Soil ratios are all based on total C,N, and P concentrations.



Multivariate approach

Due to the complexity of environmental factors underlying vegetation distribution in wetlands, a multivariate approach can be used to analyze the multitude of gradients simultaneously. Nonmetric Multidimensional Scaling (NMS) was used to ordinate the vegetation data and the resulting solution was correlated with the water and soil data. The final solution had low stress (5.421) indicating that the difference was small between the original data and the final solution. McCune and Grace (2002) suggest that a stress value between 5 and 10 is a "good ordination with no real risk of drawing false inferences".

The results of the ordination show that there is a clear separation along Axis 3 between Kalmia associated species and sites and the rest of the species/sites (Figure 4-18). Soil components are strongly correlated with this axis (Table 4-9). Total carbon, soil nutrient ratios show strong negative correlation whereas soil cation concentrations and pH are positively correlated. In addition, there is also a separation along Axis 3 among the Sedge sites and the Spiraea sites. The Sedge sites are slightly closer to the Kalmia sites reflecting slightly higher total carbon concentrations and nutrient ratios. Zinc concentrations in the soil show correlation with Axis 2, separating the Phalaris species/sites from the Sedge and Spiraea sites and associated species.

Axis 3 further demonstrates the pattern observed in Blaney bog and in the literature on wetlands: an increase in soil organic matter content was found to be associated with a decrease in pH and soil cation concentrations (Glaser et al., 1997). In addition, total soil nutrient concentrations are not highly correlated with the same axis as the base richness/acidity variables. Soil phosphorus concentrations only show a highly significant correlation with Axis 1 and nitrogen concentrations are not highly correlated with any axis. On the other hand, nutrient ratios are highly correlated with Axis 3 reflecting decreased nutrient availability as soil organic matter content increases. Ordination analyses have shown that more than 50% variance in wetland sites was explained by nutrient ratios, organic matter content, and pH (Bridgham & Richardson, 1993). At Blaney Bog, Axis 3 from the NMS explained 57% of the total variation in plant species composition among sites and was strongly correlated with several of the soil and water variables measured. The correlations were higher for the soil variables.

Figure 4-18. Nonmetric Multidimensional Scaling (NMS) ordination graph of the 23 sites and 51 species in Blaney Bog. The final solution stress was 5.421 and instability 0.00008. The variance explained was: Axis 1 r^2=0.138; Axis 2 r^2=0.253; and Axis 3 r^2=0.573 (cumulative r^2=0.964). Vectors representing environmental variables are included. The four plant community types are presented by the ellipses.

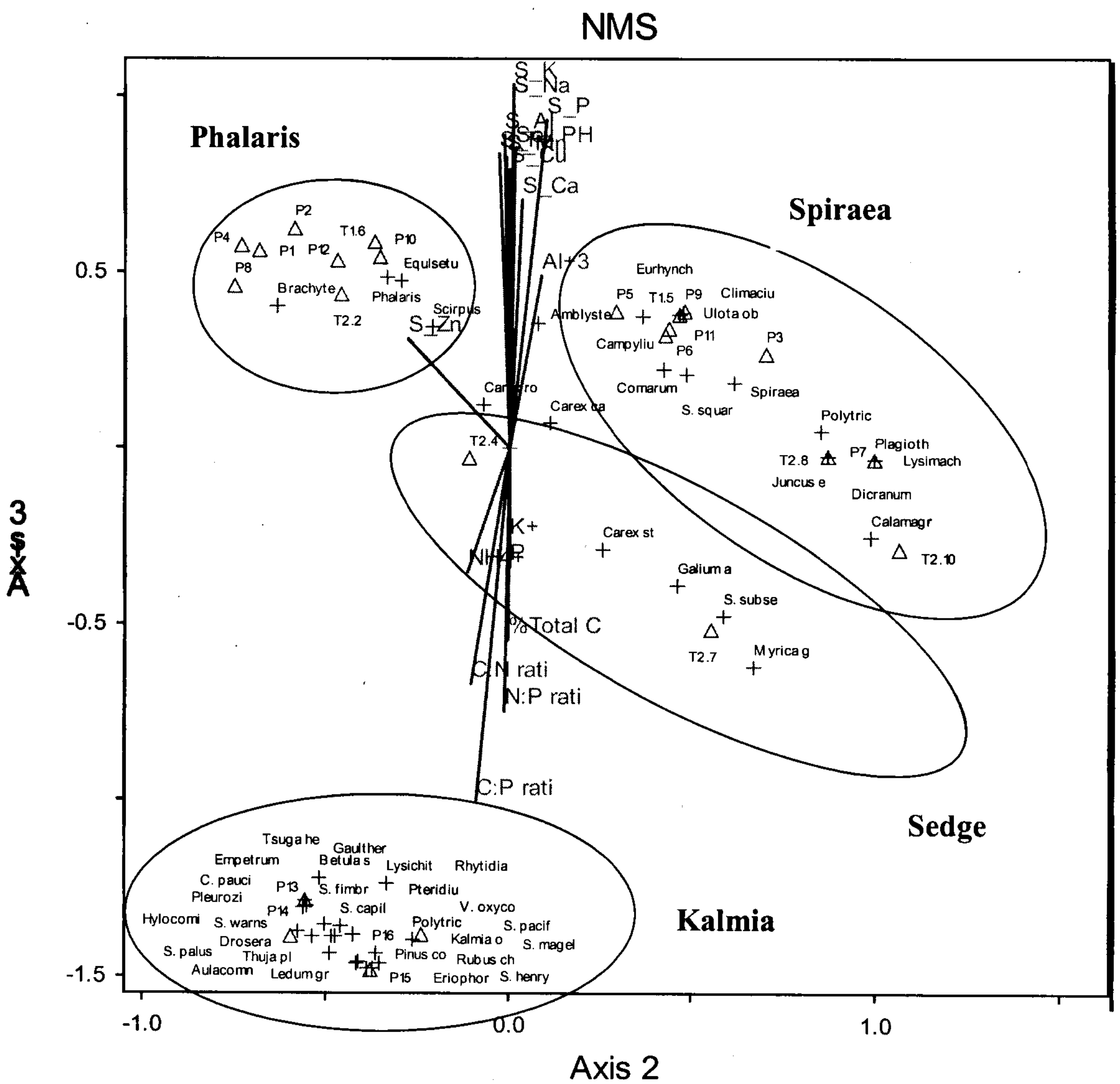


Table 4-9. Pearson and Kendall Correlations with NMS Ordination Axes

Axis:	1			2			3		
	r	r-sq	tau	r	r-sq	tau	r	r-sq	tau
Soil components									
PH	-.313	.098	-.170	.106	.011	-.059	.826	.682	.581
%Total C	.083	.007	.146	-.052	.003	-.028	-.659	.435	-.462
%Total N	-.234	.055	-.146	.170	.029	.170	-.048	.002	-.075
Al	-.173	.030	-.091	-.111	.012	-.186	.844	.712	.518
Ca	-.229	.052	-.043	.167	.028	.020	.751	.565	.470
Cu	-.193	.037	-.162	-.025	.001	-.178	.797	.635	.510
Fe	-.278	.077	-.209	-.150	.023	-.209	.818	.669	.557
K	-.251	.063	-.099	.093	.009	-.004	.910	.828	.557
Mg	.147	.022	-.115	-.370	.137	-.241	.378	.143	.273
Mn	-.077	.006	-.146	-.081	.006	-.020	.814	.663	.462
Na	-.307	.094	-.170	.089	.008	.083	.891	.793	.439
P	-.384	.147	-.194	.284	.081	.154	.864	.746	.368
Zn	.036	.001	-.083	-.471	.222	-.241	.501	.251	.478
C:N ratio	.361	.131	.233	-.288	.083	.075	-.732	.535	-.613
N:P ratio	.297	.088	.123	-.108	.012	-.051	-.771	.595	-.423
C:P ratio	.403	.162	.138	-.269	.072	-.051	-.896	.803	-.455
Water components									
NO3-	.343	.118	.289	.287	.083	.083	-.126	.016	-.178
NH4+	.544	.295	.360	-.303	.092	-.146	-.529	.280	-.249
P	.647	.419	.388	.030	.001	-.008	-.518	.269	-.277
Al+3	-.132	.017	-.059	.263	.069	.115	.625	.391	.344
Ca+2	.299	.090	.154	.170	.029	.075	.282	.079	.146
Fe+2	-.083	.007	-.099	-.035	.001	-.004	.333	.111	.178
K+	.057	.003	.096	.029	.001	.038	-.458	.210	-.281
Mg+2	.252	.064	.206	.224	.050	.103	-.017	.000	-.063
Na+	.368	.135	.107	.219	.048	.107	.190	.036	.099
SiO2	.738	.544	.293	-.096	.009	-.087	-.154	.024	-.087
Water_pH	.519	.269	.207	.053	.003	-.016	.057	.003	.080
EC	.339	.115	.289	.072	.005	-.123	-.171	.029	-.067

The correlation between ordination axes and the water variables are generally not as high. Ammonia and potassium ions in the water show a fairly strong positive correlation and aluminum ions a negative correlation with Axis 3. The rest of the variables show weak correlation with any of the three axes. In contrast, ordination results in other studies have shown that water pH and cation concentrations were highly correlated with axes explaining species distribution in wetlands (Glaser et al., 1997; Vitt & Chee, 1990). These results indicate that the soil components are more important in explaining the spread of the sites at Blaney bog with respect to species composition.

Chapter 5: Summary and Conclusions

The primary aim of this thesis was to investigate the reasons for the pattern and species composition of the various plant community-types in a disturbed stream fen/mound bog complex and examine which environmental gradients were important in the distribution of these wetland species. Species distribution was linked with water table fluctuations, organic matter accumulation, acidity/base richness and nutrient status in water and soil components. Four major plant community types were surveyed for all components: Kalmia, Phalaris, Spiraea and Sedge. In all but the Sedge group, water table fluctuations were measured.

Plant Community Summary

Kalmia sites

The species composition of the Kalmia sites is most consistent with bog/poor fen plant communities described in the literature on peatland systems. Indicator species of bog/poor-fen communities include *Sphagnum* spp.; ericaceous shrubs such as *Kalmia occidentalis*, *Ledum groenlandicum* and *Vaccinium oxycoccos*; coniferous tree species such as *Pinus contorta* and *Tsuga heterophylla*; and other acidophillic species such as *Eriophorum chamissonis* and *Drosera rotundifolia*. Mean species richness (n=28) and species diversity (H'=2.60) were the highest at the Kalmia sites compared to the other plant communities surveyed at Blaney Bog. The high species richness and diversity were higher than expected for bog/poor fen communities which are generally considered to be species poor because of the limiting conditions of these sites (low pH and nutrient poor). The high species diversity may be because the Kalmia sites are on the eastern edge where little disturbance of the wetland system is visible.

Water level fluctuations were small at the Kalmia sites with summer minimum levels not exceeding 18cm below the peat surface. The small fluctuations correspond to flow-through fen systems which are little affected by low precipitation levels due to groundwater seepage and surface water flow and bogs where the water table is kept high through capilarity. A high water table throughout the year is conducive to organic matter accumulation exceeding decomposition, as a result the substrate was high in soil organic matter content with a mean of 74%. Verhoeven et al. (1994) found substantially lower decay rates in bogs compared to other peatlands and mineral soil wetlands. Peat chemistry corresponded to expected range for bog/poor-fen sites with a pH slightly above 4.0, and low concentrations of all cations. Although aluminum and iron are expected to be high at the Kalmia sites because of low soil pH, the differences in mineral content of the substrate between the different plant communities surpassed differences in soil pH and as a result the peat at the Kalmia sites exhibited low concentrations of these metals.

Water chemistry of the Kalmia sites was inconsistent with soil chemistry results. The pH was slightly above 5.0, which was much higher than expected for bog/poor-fen sites. A pH of 5.0 is indicative of conditions where the water is in equilibrium with partial pressure of CO_2: a static system that is saturated with CO_2. The static state of the water at these sites indicates that the water chemistry is controlled by the vegetation and internal bio-cycling of nutrients in situ. Concentrations of magnesium, an important element in bio-cycling, were also found to be higher at these sites. Frequent reducing conditions and consequently little aeration, favored high ammonia levels and low nitrate levels in the water. Flooded conditions also resulted in higher phosphate levels in the Kalmia sites.

Soil nitrogen levels were lowest at the Kalmia sites compared to the rest of the sites, as expected from oligotrophic-mesotrophic sites. Soil nitrogen levels were much lower than expected for three out of the four sites (Figure 4-10). Low soil N levels may be a product of local species composition where ericaceous shrubs, in particular *Myrica gale*, have higher N fixation rates because of symbiotic associations. Site P16 had high cover of ericaceous shrubs compared to the other three sites and correspondingly high soil N levels. The other three sites had higher percent cover of Sphagnum spp. and corresponding lower soil N concentrations.

Phosphorus levels in the soil were also low at the Kalmia sites as expected from the oliogrotrophic-mesotrophic sites. As a result the N:P ratio was highest for these sites compared to all the other sites in Blaney Bog indicating these were phosphorus limited. Both the C:N and

C:P ratios were very wide, the result of the high soil organic matter content and low nutrient levels at these sites reflecting nutrient poor conditions.

The differences between the Kalmia sites compared to the rest of the sites at Blaney Bog were significant for most soil variables measured and some water variables.

Sedge sites

In species composition, the Sedge (Carex spp.) sites corresponded to small sedge fen communities. Small sedge fen communities are characterized by Carex spp. such as *Carex rostrata, Carex sitchensis, Carex canescens*; as well as *Scirpus cyperinus*; and a mix of *Sphagnum* spp. and brown mosses for bryophytes. Small sedge fen communities are transitional between eutrophic fens and poor fens. These moderate-rich fen communities are generally species rich and the Sedge sites at Blaney Bog had intermediate values for both species richness (n=16) and diversity (H'=2.18) compared to the other sites. Moderate-rich fen communities should exhibit high species richness and diversity because of favorable conditions with intermediate pH levels and intermediate nutrient levels. The lower recorded diversity may be a result of human impact on the study area.

Water levels were not monitored at these sites, however the substrate was high in soil organic matter with a mean of 50% suggesting that the sites are predominantly flooded. The organic matter content of Sedge sites in the enclosed section was slightly lower (47.5%) compared to the sites in the open section (54.4%) suggesting that water levels and subsequent decomposition may be more prominent in the enclosed section. However it is also important to note that the slight difference may be caused by more alluvial deposits in the western end of the study area. SOM content may also be a factor of species composition. Szumigalski and Bayley (1996) found higher decomposition rates to be associated with plant material with higher N content such as Carex spp. compared to mosses. Soil chemistry variables showed intermediate values between the Kalmia sites and the Spiraea and Phalaris sites reflecting the relatively high organic matter content mixed with mineral content and transitional status along the fen-bog gradient.

Results for cation concentrations in the water chemistry were unexpected. The values for all variables were the lowest for all the four groups, especially surprising was the low pH at 4.8.

Silica concentrations were considerably lower in the Sedge sites compared to the other groups. The unexpected results for water chemistry for these sites may be caused by differences in sampling methodology. As described in the methods, at these sites water was only sampled once by scooping surface water or digging to the water level, whereas the other sites had installed dipwells that were sampled monthly for 10 months. Interestingly, ammonia levels were found to be slightly higher than nitrate concentrations suggesting predominantly flooded conditions at these sites with some water level fluctuation. Phosphate levels were intermediate, also suggesting a similar pattern in water levels.

Soil N levels were the highest at the Sedge sites reflecting the high N content of Carex spp. characteristic of these sites. Soil P concentrations were intermediate. Intermediate organic matter content resulted in the C:N, N:P and C:P ratios showing intermediate nutrient levels as expected from the moderate-rich fen sites.

Spiraea sites

The species composition of the Spiraea sites, with the dominant shrub *Spiraea douglasii*, corresponds to shrub fen or moderate-rich fen sites which are transitional between reed fens and poor fens. Species composition of the understorey reflected this transition with a mix of the species common at the Sedge sites and species common at the Phalaris sites. Specifically common understorey species included *Phalaris arundinacea, Scirpus cyperinus and Carex canescens*. Bryophyte cover was also a mix of Sphagnum spp. and brown mosses. The mix of species may also be because the Spiraea sites are widely distributed throughout the study area. Species richness (n=16) and diversity (H'=2.25) were intermediate compared to the other sites. The mix of vascular and bryophyte species at these sites and moderate-rich fen pH and nutrient conditions should favor higher species richness and diversity.

Water level fluctuations were substantial at the Spiraea sites with summer minima exceeding 1.0m below the surface. The drops in the water level are much higher in the enclosed section compared to the open area of Blaney Bog. Such minimum levels exceed levels seen in flow-through fen systems. Greater water fluctuations in the enclosed section suggest the dyke/canal is blocking water inflow from the original east to west gradient of surface water and groundwater.

The substrate was moderately high in soil organic matter with a mean of 42%, however the SOM content was double in the Spiraea sites in the open section (53.3%) compared to the SOM content in the Spiraea sites in the enclosed section (27.4%). Higher water level fluctuations and lower organic matter in the enclosed section suggest higher decomposition rates and frequent aeration in the Spiraea sites. Bridgham (1991) also found that decay rates were much faster in disturbed sites compared to undisturbed sites. Factors explaining faster decomposition rates were removal of waterlogging conditions and subsequent aeration of the sites.

Peat chemistry was characteristic of moderate-rich fen communities with intermediate concentrations of all cations. The pH value was somewhat low and would have been expected to be above 6.0 for moderate-rich fen sites. Water chemistry results diverged from the peat chemistry results with higher pH at 5.5 for both summer and winter. Calcium, aluminum and iron concentrations in the water were higher than for all the other sites. All other cation concentrations were intermediate. The lower pH values and cation concentrations may be a result of acidification of the sites from the dyke/canal blocking off base-rich water inflow. When pH values are compared, soil pH at the Spiraea were 4.7 and 4.4 in the open and enclosed sections respectively. Water pH shows even greater difference with 4.3 in the enclosed section and 5.3 in the open. The sites in the enclosed section receive less water compared to those located along Blaney Creek and Anderson Creek. The inflow and periodic flooding throughout the year serve as sources of minerals for these sites, thereby increasing the pH.

Nitrate concentrations were high in the Spiraea sites compared to the other sites reflecting the low water levels and aerated conditions at these sites. However, the nitrate levels were higher in the winter compared to summer levels, when water table levels were higher. Soil nutrient levels were high compared to the other sites.

Phalaris sites

The species present at the Phalaris sites correspond most to reed fen communities which are considered extreme-rich fens along the fen-bog gradient (Damman 1995; Wheeler and Proctor 2000). These sites were the most species poor with a mean of 13 species. Some sites were dominated by Phalaris and showed very little diversity in vascular plant species composition and very low bryophyte cover. Low species richness and diversity has been shown in other rich fen systems where mono-species dominated and in sites affected by eutrophication causing species loss (Wheeler and Shaw, 1995). On the other hand, some studies have found the opposite where rich fen communities have high species richness.

The patterns in water level fluctuations at the Phalaris sites were similar to the observations at the Spiraea sites. Summer minima were somewhat smaller at the Phalaris sites (85cm below the surface) which may be because reed canary grass does not require as much water intake as woody Spiraea shrubs. A comparison of conditions in the enclosed/open sections is not possible because there were no Phalaris sites present in the open section.

The substrate was a mix of floodplain deposits and organic matter, resulting in the lowest SOM content (mean of 33%), half of the mean SOM content for the Kalmia sites. Higher mineral content is reflective of sites in the early stages of wetland ecosystem development where organic deposits are still slightly above the underlying mineral substrate. Correspondingly, all soil cation concentrations were high and pH was higher than at the other sites. However, compared to the literature the pH of 5.0 was much lower than expected where most extreme-rich fens have pH values 6.0-6.5. The pH of the water was somewhat higher (5.3) however this is still lower than expected. The conductivity at these sites was high, however most cation concentrations were intermediate. Similar to the Spiraea sites, low pH values and base cation concentrations may reflect the decreasing inflow of mineral enriching water because of the dyke/canal.

Contrary to the expected high nutrient availability in rich fen communities, all nutrient components showed intermediate levels at the Phalaris sites with values between those found at the Spiraea and Sedge sites. C:N, C:P ratios reveal that these sites have the lowest ratios and are therefore least limited by low organic matter content.

Environmental components summary

The water components studied at Blaney Bog are much more dynamic than the soil components. Soil variables showed a clear gradient between low cation concentrations at the Kalmia sites, intermediate concentrations at the Sedge and Spiraea sites and highest at the Phalaris sites. A different picture was painted from results of the water data. The Kalmia sites were higher in magnesium than all the other sites. Phalaris sites had lower concentrations than Spiraea for most of the cations. The Sedge sites also had very low levels compared to all the other sites. The unclear patterns in the water variables suggest that the water chemistry variables are more prone to be affected by seasonality and human induced changes such as hydrological modification than soil chemistry variables at Blaney Bog. Multivariate analyses, which included all components, also revealed that the distinction between sites according to species distribution is strongly correlated to soil components and less so with respect to water components.

Soil nutrient levels did not completely coincide with the bog-fen gradient. There were deviations from the expected pattern because of species specific interactions. This was most evident in the Kalmia sites with nitrogen levels and differences in ericaceous shrub cover compared to Sphagnum cover. P levels did however show an increase along the gradient from nutrient poor to nutrient rich. Nutrient ratios revealed the expected patterns where an increase in organic matter content is associated with decreased nutrient availability. These findings point out that total soil nutrient concentrations may not be appropriate indicators of nutrient status and availability in wetlands and should be interpreted with care. If only total concentrations are available, then ratios may be better indicators of nutrient conditions.

Summary

The study shows that Blaney Bog is not one wetland system but if fact the separation caused by the dyke/canal has had a significant effect and partitions the site into two different sections. The open section on the eastern side is dominated by Kalmia sites and this area is most representative of poor fen/bog systems. The fact that this area has not been affected by the hydrological modification done to the system and that vegetation patterns closely represent underlying environmental conditions, are evidence that it is the most representative of baseline conditions of Blaney Bog. On the other hand, the enclosed area has been affected by water management at the site and possibly ongoing disturbances from neighboring agricultural activities. The enclosed area is dominated by Phalaris, Spiraea and Sedge communities, which are characteristic of moderate-extremely rich fen sites. These were not reflected in the underlying chemical conditions, which were found to be more acidic and nutrient poor than expected.

In conclusion, this study found that the soil chemistry is more static or in steady state than the water levels and chemistry at Blaney Bog. The soil variables studied were more reflective of site conditions according to the dominant vegetation than the water variables. The disconnect between water chemistry and vegetation were greater for the Phalaris, Spiraea and Sedge sites than the Kalmia sites. This is further evidence that the disturbance of wetland hydrology at this site has affected most of the study area and that the Kalmia sites are closest to baseline conditions. Of the four community types, the Kalmia sites were the most representative of poor fen sites, whereas the water chemistry of sites in the other three plant community groups were inconsistent with theoretically expected values from studies in undisturbed fens.

Future monitoring of this disturbed system should focus on the soil. Indicators associated with soil organic matter content and soil chemistry would better indicate change in system condition than water chemistry. In a monitoring program, the Kalmia sites should serve as the baseline for any comparisons and predictions of change. In addition, water table fluctuations should be monitored more extensively than covered in this project to further investigate the relationships between the water table and plant distribution and the influence of the water table on site characteristics. Factors that might have significant effect on the site that were not included in this study and should be monitored include: neighbor activities (specifically the cranberry operation across 224th street) and local precipitation chemistry.

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APPENDIX I: Mean plant species composition at each site

Species	*P1*	*P2*	*P3*	*P4*	*P5*	*P6*	*P7*	*P8*	*P9*	*P10*	*P11*	*P12*	*P13*	*P14*	*P15*	*P16*
Athyrium filix-femina (L.) Roth	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Betula sp.	0	0	0	0	0	0	0	0	0	0	0	0	2.5	0	0	0
Calamagrostis canadensis (Michx.) Beauv. ?	0	0	0	0	0	0	0.5	0.5	0	0	0	0	0	0	0	0
Carex canescens	0	0	0	0	0.1	0	7.5	7.5	0	0	0.1	0	0	0	0	0
C. pauciflora Lightf.	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0	0	0
Carex rostrata	0	0	0	0	0	0	0	0.1	0	0	0	0	0	0	0	0
Carex sitchensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Comarum palustre L.	0	0	0	0	0	0.5	0.1	0	0	0	0.1	0	0	0	0	0
Drosera rotundifolia L.	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5	2.5	0
Empetrum nigrum	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0	0	0
Equisetum sp.	0	0.1	0	0	0	0	0	0.1	0	0	0	0	0	0	0	0
Eriophorum chamissonis C.A. Mey.	0	0	0	0	0	0	0	0	0	0	0	0	2.5	7.5	2.5	0
Galium aparine L.	0	0	0	0	0	0	0	0	0	0	0	0.1	0	0	0	0
Gaultheria shallon Pursh	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0	0	0
Juncus effusus L.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Kalmia occidentalis Small	0	0	0	0	0	0	0	0	0	0	0	0	17.5	17.5	17.5	7.5
Ledum groenlandicum Oeder	0	0	0	0	0	0	0	0	0	0	0	0	29	17.5	29	29
Lysichiton americanum Hult. & St. John	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0
Lysimachia thyrsiflora L.	0	0	0	0	0	0	0.1	0	0	0	0	0	0	0	0	0
Myrica gale L.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5	17.5
Phalaris arundinacea L.	87	62.5	17.5	100	29	29	0	87	29	41.5	29	41.5	0	0	0	0
Pinus contorta var. contorta Dougl. ex Loud.	0	0	0	0	0	0	0	0	0	0	0	0	0	2.5	2.5	0
Polystichum munitum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pteridium aquilinum (L.) Kuhn	0	0	0	0	0	0	0	0	0	0	0	0	29	0	0	0
Rosa spp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rubus chamaemorus L.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.5	0.1
R. spectabilis Pursh	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Scirpus cyperinus (L.) Kunth	0.5	0	0	0	2.5	2.5	7.5	17.5	0	7.5	0	29	0	0	0	0
Spiraea douglasii Hook.	0	0	62.5	0	29	41.5	41.5	0.1	62.5	0.5	41.5	0.1	0	0	0	0
Thuja plicata Donn ex D. Don	0	0	0	0	0	0	0	0	0	0	0	0	7.5	0	0	0
Tsuga heterophylla (Raf.) Sarg.	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0.1	0	0
Typha latifolia L.	0	0	0	0	0	0	0	0	0	0	0	0	2.5	17.5	2.5	7.5
Vaccinium oxycoccos L.	0	0	0	0	0	0	0.1	0	0	0	0	0	0	7.5	0	0
Aulacomnium palustre (Hedw.) Schwaegr.	0	0	0	0	0.1	0.1	0.5	0	0	0	0	0.1	0	0	0	0
Amblystegium spp.	0	0	0	0	0	0	0	7.5	0.1	0	0	0	0	0	0.1	0
Brachythecium frigidum (C. Muell) Besch Mem. Soc. Sci. Nat. Cherbourg	0	0	0	0	0.1	0.1	0.5	0	7.5	0	7.5	0.1	0	0	0	0
Campylium spp.	0	0	0	0	0	0	0	0	0	0	0.1	0	0	0	0	0
Climacium dendroides	0	0	0	0	0	0	0.1	0	0	0	0	0	0	0	0	0
Dicranum scoparium Hedw.	0	0	0	0	0	0	0	0	7.5	0	7.5	0	0	0	0	0
Eurhynchium spp.	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0	0	0
Hylocomium splendens (Hedw.) Schimp. in B.S.G.	0	0	0	0	0	0	0.1	0	0	0	0	0	0	0	0	0
Plagiothecium undulatum (Hedw.) B.S.G. Bryol. Eur. Fasc.	0	0	0	0	0	0	0	0	0	0	0	0	2.5	0.1	0.1	0
Pleurozium schreberi (Brid.) Mitt.	0	0	0	0	0	0	2.5	0.1	0	0	0.5	0	0	0	0	0
Polytrichum commune Brid.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0.5
Polytrichum juniperinum Hedw. Spec. Musc.	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0	0	0
Rhytidiadelphus triquetrus (Hedw.) Warnst.	0	0	0	0	0	0	0	0	0	0	0	0	17.5	17.5	2.5	17.5
Sphagnum capillifolium (Ehrh.) Hedw.	0	0	0	0	0	0	0	0	0	0	0	0	2.5	0	0	0
S. fimbriatum Wils. ex Wils. & Hook. in Hook.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0.1
S. henryense Warnst.	0	0	0	0	0	0	0	0	0	0	0	0	0.5	7.5	29	17.5
S. magellanicum Brid.	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0.5	2.5	0.1
S. pacificum Flatb.	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1	2.5	0
S. palustre L.	0	0	0	0	0	2.5	5	0	0	0	2.5	0	0	0	0	0
S. squarossum	0	0	0	0	0	0	0.5	0	0	0	0	0	0	0	0	0
S. subsecundum	0	0	0	0	0	0	0	0	0.1	0	7.5	0	0	0.5	0	0.1

Species	***T1.5***	***T1.6***	***T2.2***	***T2.4***	***T2.7***	***T2.8***	***T2.10***
Athyrium filix-femina (L.) Roth	0	0	0	0	0	0	0
Betula sp.	0.1	0	0	0	0	0	0
Calamagrostis canadensis (Michx.) Beauv. ?	0	0	0	0.5	0	0	17.5
Carex canescens	0	0	0.1	7.5	2.5	0.5	0
Carex pauciflora Lightf.	0	0	0	0	0	0	0
Carex rostrata	0	0	17.5	2.5	7.5	2.5	0
Carex sitchensis	0.1	0	2.5	29	41.5	0	0
Comarum palustre L.	0	0.1	0	0	0.1	0	0
Drosera rotundifolia L.	0	0	0	0	0	0	0
Empetrum nigrum	0	0	0	0	0	0	0
Equisetum sp.	0.1	0	0	0	0	0	0
Eriophorum chamissonis C.A. Mey.	0	0	0	0	0.5	0	0
Galium aparine L.	0	0.1	0.1	0	2.5	0.1	0
Gaultheria shallon Pursh	0	0	0	0	0	0	0
Juncus effusus L.	0	0	0	0	0	0.1	0
Kalmia occidentalis Small	0	0	0	0	0	0	0
Ledum groenlandicum Oeder	0	0	0	0	0	0	0
Lysichiton americanum Hult. & St. John	0	0	0	0.1	0	0	0
Lysimachia thyrsiflora L.	0	0	0	0	0	0	0
Myrica gale L.	0	0	0	0	0	0	41.5
Phalaris arundinacea L.	29	62.5	41.5	17.5	0	2.5	0
Pinus contorta var. contorta Dougl. ex Loud.	0	0	0	0	0	0	0
Polystichum munitum	0	0	0	0	0	0	0
Pteridium aquilinum (L.) Kuhn	0	0	0	0	0	0	0
Rosa spp.	0	0	0	0	0	0	0
Rubus chamaemorus L.	0	0	0	0	0	0	0
R. spectabilis Pursh	0	0	0	0	0	0	0
Scirpus cyperinus (L.) Kunth	0	0.1	17.5	7.5	2.5	7.5	0
Spiraea douglasii Hook.	41.5	7.5	0.1	0	17.5	29	41.5
Thuja plicata Donn ex D. Don	0	0	0	0	0	0	0
Tsuga heterophylla (Raf.) Sarg.	0	0	0	0	0	0	0

Typha latifolia L.	0	0	0	0	0	0	0
Vaccinium oxycoccos L.	0	0	0	0	0	0	0
Aulacomnium palustre (Hedw.) Schwaegr.	2.5	0	2.5	0	0	0	0
Amblystegium spp.	0	0	0	0	0	0.5	0
Brachythecium frigidum (C. Muell) Besch Mem. Soc. Sci. Nat. Cherbourg	2.5	0	2.5	0	0	0	0
Campylium spp.	0	0	0	0	0	0	0
Climacium dendroides	0	0	0	0	0	0	0
Dicranum scoparium Hedw.	0	0	0	0	0	0	0
Eurhynchium spp.	0	0	0	0	0	0	0
Hylocomium splendens (Hedw.) Schimp. in B.S.G.	0	0	0	0	0	0	0
Plagiothecium undulatum (Hedw.) B.S.G. Bryol. Eur. Fasc.	0	0	0	0	0	0	0
Pleurozium schreberi (Brid.) Mitt.	0	0	0	0	0	0	0
Polytrichum commune Brid.	0	0	0	0	0	0	0
Polytrichum juniperinum Hedw. Spec. Musc.	0	0	0	0	0	0	0
Rhytidiadelphus triquetrus (Hedw.) Warnst.	0	0	0	0	0	0	0
Sphagnum capillifolium (Ehrh.) Hedw.	0	0	0	0	0	0	0
S. fimbriatum Wils. ex Wils. & Hook. in Hook.	0	0	0	0	0	0	0
S. henryense Warnst.	0	0	0	0	0	0	0
S. magellanicum Brid.	0	0	0	0	0	0	0
S. pacificum Flatb.	0	0	0	0	0	0	0
S. palustre L.	0	0	2.5	0	0	0.1	0
S. squarossum	0	0	0	0	7.5	0.1	0
S. subsecundum	0	0	0	0	0	0	0
S. warnstorfii	0	0	0	0	0	0	0
Ulota obtusiuscula (C. Muell and Kindb. in Mac. Cat. Can. Pl.)	0	0	0	0	0	0	0

APPENDIX II: Mean values of water variables for 10 month study period at each site

Site	pH	EC	NO^{3-}	NH_4^+	PO_4^{3-}	Al^{+3}	Ca^{+2}	Fe^{+2}	K^+	Mg^{+2}	Na^+	SiO_3^{2-}
P1	5.34	38.90	0.06	0.45	0.07	0.19	1.81	1.04	0.44	0.28	1.65	4.25
P2	4.97	26.50	0.03	0.14	0.04	0.12	1.18	0.47	0.00	0.09	1.41	3.15
P3	5.28	25.20	0.31	0.24	0.04	0.14	1.33	0.24	0.00	0.12	1.44	3.37
P4	5.57	82.20	0.03	1.13	0.13	0.35	10.32	4.37	0.00	0.30	1.87	6.91
P5	5.62	44.70	0.02	0.59	0.08	0.41	2.39	4.93	0.00	0.19	1.87	4.57
P6	5.54	43.00	0.04	1.06	0.17	0.33	1.72	3.15	0.08	0.12	1.89	5.08
P7	5.53	124.60	0.03	1.10	0.35	0.26	12.49	5.84	0.00	0.67	3.53	16.82
P8	5.48	26.30	0.03	0.24	0.10	0.21	1.13	2.12	0.00	0.15	1.30	2.51
P9	5.53	54.20	0.03	0.58	0.07	0.40	3.41	5.67	0.00	0.42	2.47	3.23
P10	5.34	37.80	0.02	0.38	0.03	0.33	1.91	5.58	0.05	0.27	2.03	2.76
P11	5.48	30.70	0.04	0.26	0.05	0.32	1.12	3.61	0.26	0.25	1.27	3.14
P12	5.40	44.00	0.05	0.19	0.06	0.17	2.28	2.74	0.00	0.32	3.42	4.00
P13	5.25	64.30	0.07	4.53	0.28	0.10	1.60	0.32	0.31	0.34	2.57	6.44
P14	4.61	37.40	0.06	2.10	0.12	0.01	0.17	0.06	0.23	0.03	1.07	1.98
P15	5.38	57.80	0.18	3.50	0.29	0.11	2.48	1.60	0.42	0.79	1.10	15.26
P16	5.43	51.90	0.04	2.27	0.36	0.18	1.07	0.69	0.46	0.25	1.39	20.82
T1-1	5.61	13.85	0.01	0.09	0.06	0.20	0.45	0.42	0.55	0.14	0.81	0.53
T1-2	5.21	36.10	1.70	0.08	0.13	0.09	2.34	0.04	0.52	0.33	1.59	3.32
T1-3	4.82	28.70	0.59	0.22	-0.02	0.85	1.12	0.24	0.20	0.23	1.47	3.22
T1-4	4.64	17.32	0.02	0.07	0.09	0.17	0.48	0.24	0.07	0.07	0.66	1.60
T1-5	4.52	35.10	1.34	0.28	0.14	0.29	2.10	0.03	0.32	0.30	1.70	4.36
T1-6	5.16	21.30	0.19	0.22	0.12	0.24	0.94	0.39	0.30	0.12	0.98	0.71
T1-7	5.17	27.20	0.08	0.22	0.43	0.23	0.69	0.71	0.19	0.08	1.03	1.75
T1-8	5.16	35.90	0.09	0.26	0.17	0.42	1.66	1.46	0.55	0.20	1.63	2.93
T1-9	4.97	30.00	0.86	1.00	0.14	0.06	1.72	0.44	0.06	0.15	6.24	2.24
T2-1	4.01	20.20	0.00	0.05	0.02	0.11	0.42	0.62	0.21	0.14	1.87	0.47
T2-2	3.95	30.90	0.03	0.26	0.03	0.14	0.52	0.30	0.65	0.18	1.63	1.28
T2-3	4.02	46.70	0.03	0.18	0.11	0.11	1.35	0.35	0.12	0.34	3.30	2.66
T2-4	3.69	22.70	0.04	0.10	0.03	0.14	0.47	0.59	0.10	0.11	0.72	-0.41

T2-5	4.34	11.64	0.00	0.06	0.01	0.14	0.47	0.38	0.15	0.10	0.70	-0.77
T2-6	5.01	12.02	0.03	0.05	0.03	0.17	0.56	0.46	0.18	0.12	0.86	-0.74
T2-7	5.06	14.56	0.02	0.05	0.02	0.17	0.57	0.46	0.17	0.12	0.89	-0.82
T2-8	4.49	24.60	0.05	0.40	0.09	0.19	0.61	0.42	0.99	0.17	1.52	1.05
T2-9	5.30	34.40	0.62	0.10	0.08	0.09	1.37	0.15	0.38	0.33	2.50	1.80
T2-10	5.24	35.50	0.67	0.05	0.13	0.10	2.05	0.15	0.39	0.48	2.66	2.02
T2-11	5.22	25.50	0.52	0.07	0.08	0.15	2.04	0.29	0.33	0.44	2.14	0.93
T2-12	5.16		0.29	0.15	0.07	0.12	0.96	0.22	0.31	0.22	1.99	1.19
T2-13	5.02		0.29	0.16	0.12	0.16	0.85	0.29	0.24	0.19	1.49	1.77
T2-14	5.60		0.31	0.17	0.35	0.11	0.91	0.18	0.16	0.21	1.36	1.58
T2-15	4.74		-0.01	0.51	0.26	0.07	0.40	0.64	0.21	0.07	1.29	1.25

APPENDIX III: Weighted averages of soil variables at each site

Site	*pH*	*%Total C*	*% Organic Matter*	*% Total N*	*C:N ratio*	*N:P ratio*	*C:P ratio*	*Al (ppm)*	*Ca (ppm)*	*Cu (ppm)*	*Fe (ppm)*	*K (ppm)*	*Mg (ppm)*	*Mn (ppm)*	*Na (ppm)*	*P (ppm)*
P1	4.95	12.48	19.71	0.97	12.89	9.94	128.18	3470.88	4947.37	15.36	3112.04	1524.48	1084.50	203.96	1402.69	973.29
P2	4.95	17.95	28.36	1.32	13.57	9.66	131.13	2386.56	4881.57	11.96	1795.53	1387.36	767.22	166.20	1405.16	1368.91
P3	4.97	13.82	21.84	0.97	14.28	7.80	111.39	4121.55	5824.14	10.39	2779.31	1100.21	903.24	173.15	1451.44	1240.97
P4	5.01	33.51	52.94	2.15	15.57	24.69	384.45	2979.48	6270.52	12.45	4022.50	777.59	700.09	146.46	699.38	871.58
P5	4.96	35.23	55.66	2.43	14.50	22.15	321.26	1163.78	4283.23	10.40	2239.19	586.55	302.62	96.60	564.51	1096.65
P6	4.16	24.43	38.61	1.70	14.38	15.48	222.49	1086.13	3530.52	4.20	1426.36	629.67	290.27	65.57	716.82	1098.22
P7	4.92	32.73	51.72	2.20	14.86	18.22	270.85	811.74	4808.14	2.47	626.54	719.45	220.09	34.69	953.62	1208.56
P8	5.00	16.68	26.35	1.20	13.93	19.89	277.02	2209.41	4028.91	15.98	4642.08	791.40	1216.73	151.47	1163.74	602.12
P9	5.03	31.52	49.80	2.27	13.90	28.87	401.32	973.33	4694.12	14.35	2133.35	639.17	619.71	113.57	768.00	785.35
P10	4.99	36.79	58.13	2.75	13.36	42.21	564.12	1130.01	3029.73	13.68	3951.83	430.07	402.30	63.46	552.89	652.18
P11	5.14	8.48	13.40	0.61	13.85	7.18	99.42	2680.85	6750.40	22.50	2833.93	1200.09	1561.05	273.15	1497.18	853.01
P12	5.23	14.69	23.21	1.15	12.77	15.50	198.03	2817.82	4696.12	11.36	3262.15	813.04	1124.15	169.04	1108.09	741.74
P13	4.05	46.60	73.63	0.88	52.83	38.10	2012.93	283.69	2597.54	0.20	275.73	124.49	906.75	29.48	151.00	231.50
P14	3.86	48.40	76.47	0.81	59.73	45.91	2742.11	187.73	1201.38	1.26	148.54	76.83	492.64	6.85	97.47	176.51
P15	4.15	48.00	75.83	1.78	26.89	55.29	1486.70	228.01	3948.73	3.01	921.07	147.79	431.37	20.82	152.83	322.84
P16	4.37	43.90	69.36	2.51	17.51	90.98	1593.06	150.02	1126.37	2.44	105.66	115.79	196.27	11.62	118.53	275.57
T1-1	5.26	15.24	24.08	1.09	13.92	10.31	143.54	2554.80	4907.98	13.33	2259.73	1076.77	948.90	183.97	1152.31	1061.66
T1-2	4.74	17.17	27.13	1.20	14.31	10.01	143.28	3137.68	5045.71	13.58	2784.89	1280.29	1040.34	189.69	1254.63	1198.49
T1-3	5.05	19.01	30.03	1.32	14.43	10.56	152.31	2279.45	4980.93	12.56	1826.50	1166.53	724.05	158.91	1188.30	1247.81
T1-4	5.14	20.44	32.30	1.44	14.18	10.33	146.46	2859.64	4605.12	9.05	2045.77	1021.18	607.37	122.67	1177.55	1395.87
T1-5	4.86	11.85	18.72	0.83	14.20	9.43	133.88	3066.82	4578.30	8.68	2956.66	1041.89	907.93	168.91	1222.97	884.85
T1-6	5.26	19.12	30.21	1.14	16.75	11.61	194.43	1766.28	6526.07	10.99	1405.05	945.31	838.67	168.32	1205.95	983.45
T1-7	5.03	41.01	64.80	2.51	16.32	19.16	312.57	302.74	4715.58	0.69	170.72	375.09	60.19	5.07	363.16	1312.17
T1-8	4.22	36.15	57.12	2.41	15.01	26.18	393.01	681.85	4223.04	7.62	1648.61	317.33	113.74	55.94	282.39	919.92
T1-9	4.57	25.75	40.68	1.67	15.44	12.06	186.16	2210.19	3577.73	8.80	3387.89	1096.80	616.24	121.99	1173.99	1383.10
T1-10	5.36	28.21	44.57	2.01	14.04	14.49	203.46	1455.99	5561.82	5.15	1006.60	885.26	323.51	69.17	1116.53	1386.42

T2-1	4.98	19.65	31.04	1.40	14.06	16.39	230.36	671.12	3974.38	10.04	983.80	726.83	702.49	132.38	1023.91	852.82
T2-2	5.34	20.15	31.84	1.42	14.16	13.65	193.23	2077.48	4970.77	13.86	2419.76	777.03	1207.09	179.53	1438.04	1042.86
T2-3	4.80	24.56	38.80	1.73	14.22	17.80	253.10	1516.03	3357.66	10.41	1704.49	630.77	655.92	104.70	802.76	970.21
T2-4	4.87	33.51	52.95	2.08	16.12	30.23	487.33	651.07	3648.10	11.13	1165.28	442.74	793.04	92.12	716.25	687.64
T2-5	5.06	18.66	29.48	1.32	14.19	26.15	370.99	877.32	5102.58	11.22	1240.08	635.60	987.68	169.44	894.64	502.97
T2-6	5.04	7.83	12.38	0.56	13.97	8.11	113.22	1821.56	6980.51	29.47	1902.80	1199.47	1394.86	285.88	1513.14	691.92
T2-7	4.62	46.10	72.84	2.68	17.20	35.78	615.32	217.74	2999.43	0.74	288.29	260.90	31.31	5.08	223.90	749.20
T2-8	4.95	16.14	25.51	1.11	14.57	14.59	212.55	2070.20	5496.23	12.99	2552.43	842.99	1297.94	208.03	1307.65	759.49
T2-9	4.85	44.20	69.84	2.50	17.67	59.10	1043.99	153.31	3882.31	4.96	261.44	189.05	202.05	13.30	178.19	423.38
T2-10	4.90	41.40	65.41	2.22	18.65	50.40	939.82	128.17	2999.66	4.45	156.39	193.78	171.45	21.72	198.86	440.51
T2-11	4.69	41.23	65.14	2.35	17.52	48.93	857.25	118.22	1987.34	3.71	162.93	186.26	94.84	20.02	180.59	480.95
T2-12	4.31	38.43	60.71	2.41	15.94	31.09	495.59	232.51	1867.23	2.33	303.21	231.19	49.06	7.37	283.12	775.37
T2-13	4.59	40.22	63.54	2.53	15.88	28.82	457.58	627.23	2452.22	3.43	882.17	332.50	175.10	29.65	411.29	878.93
T2-14	4.93	32.50	51.35	2.16	15.04	32.09	482.84	1086.43	2964.70	8.79	1774.65	391.49	421.78	67.09	516.01	673.10
T2-15	4.94	30.67	48.47	2.05	14.98	16.46	246.56	1336.94	2981.58	10.51	1728.98	492.65	526.01	63.23	756.42	1244.09