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Nitrogen Dynamics and Ecological Characteristics in Marshes and Fens in Boreal Alberta, Canada

by

Randi L. Mewhort

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of Master of Science

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Dr. Suzanne E. Bayley

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April 14, 2000

Abstract

Ecological and environmental characteristics were examined to classify and contrast five peatlands in the southern boreal region of Alberta, Canada. Species assemblages, production, decomposition, plant phosphorus tissue concentrations, peat nutrient concentrations, and surface water chemical concentrations differed between marshes and fens, supporting the hypothesis of two wetland classes with distinct functional differences. Nutrient cycling parameters of monthly net nitrogen and phosphorous mineralization rates (1995-1996), potential methane production (1996), and denitrification (1996) were compared between marshes and fens. Mean monthly net nitrogen mineralization rates were higher in marshes, while yearly sums were not different between wetland classes. Phosphorus showed low mineralization or immobilization, and like potential methane production and denitrification did not differ between marshes and fens. The internal nitrogen budget of the wetlands suggested that the difference in surface water nitrogen pools between fens and marshes is the most likely cause of the observed differences between the wetland classes.

"Learn. That is the only thing that never fails."
--Merlyn the wizard
in T.H. White's "The Sword in the Stone"

Dedication

This work is respectfully dedicated to the myriad of people who encouraged, supported and listened to me throughout this degree-

Most especially to my family, Sharon, Hugh, Craig and David Marple, who all believed in me, and ultimately to my husband Doug and daughters Miranda and Clarissa, who were the reason I continued and eventually persevered.

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A special thanks to my supervisory committee, whose comments over the years made this thesis what it is at this point. Suzanne, thank you for your time, patience, and belief that I had what it took to do this degree. You taught me more than I will probably realize for years. Dr. Vitt, thank you for your time and energy in defining the first chapter of this work, it took a collection of data and turned it into a meaningful (I hope) discussion on wetland classification and characteristics. Dr. Pluth, you kept me on track for a masters degree and provided key assistance with nitrogen cycling chats at critical times.

Further thanks to Dr. Sybil Seitzinger, who made time and space in her lab to teach me her denitrification technique, and lent me her chambers to make chapter four a reality. Dr. Sue Watts provided technical support in the interpretation of the denitrification data and in the difficult task of mathematically modeling diffusive flux, as well as a wonderful pep talk.

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To my husband, Doug, I'd like to say that this truly was a joint venture that would not have been possible without your determination, confidence, late night talks and remarkable technical skills. I think the most amazing thing was the totality of your love for me throughout both the highs and lows. Thank you. Finally, my daughters Miranda and Clarissa gave me something to work for and a reason, above all others, to continue.

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1. Introduction

Wetland terminology has a long history of being regionally specific and ambiguous (Mitsch and Gosselink, 1993). Common wetland terms are often assumed to denote specific surface water chemistry characteristics, nutrient status and hydrological conditions (Bridgham *et al.*, 1996). Marsh and fen are two wetland terms that are used to identify particular wetland classes. Both marshes and fens are wetlands that have vascular emergent macrophyte vegetation, can accumulate peat, and have standing water through much of the ice free season (National Wetlands Working Group, 1997).

The Canadian wetland classification system differentiates between marshes and fens on the basis of peat accumulation, water table characteristics, pH and dominant vegetation. Marshes are defined as having less than 40 cm of peat, being periodically inundated by standing or slowly moving water, having a circumneutral to basic pH and supporting reeds, rushes, or sedges (National Wetlands Working Group, 1997). Fens have greater than 40cm of peat, have a high water table with slow internal drainage down low gradient slopes, have slightly acidic to basic pH and support graminoid vegetation (National Wetlands Working Group, 1997).

Marshes and fens represent wetlands at the high end of a gradient of total nutrient availability, wetland production, and litter decomposition (Vitt, 1994). Several studies have examined the relationships between production and decomposition at the bog-fen end of this presumed gradient (summarized in Thormann and Bayley, 1997a and b) and currently no studies could be found that directly compares the biogeochemistry between marshes and fens.

Nutrient availability may be related to the relative size of the nutrient pools within the wetland and the turnover of these pools. Decomposition is the primary source of recycling nutrients, but decomposition studies have not shown conclusive differences between wetland types (Thormann and Bayley, 1997a; Aerts and DeCaluwe, 1997; others see chapter two). The nutrient pools are partitioned between the water, the plant tissues and the peat/soil. Water has different levels of nutrients depending on the source and flow pattern (groundwater, groundwater upwelling, surface flow) and marshes generally have higher levels of nitrogen and phosphorus in the water relative to fens (Thormann and Bayley, 1997c; Mitsch and Gosselik, 1993). Plant tissues (predominantly *Carex* in this region) generally respond to higher nutrients by allocating more nutrients into leaves (luxury consumption) (Bernard *et al.*, 1988), and wetlands with higher productivity, such as marshes, show increased nutrient concentrations with increased stem density due to less structural material (Auclaire, 1977). Peat nutrient concentrations are highly dependent on the plant litter nutrient concentrations, and peat nutrients have been observed to be higher with higher external nutrient supply (Bernard *et al.*, 1988). Recent work in the region indicated the tissue concentrations of nitrogen and phosphorus were most strongly affected by stand densities and the nutrient status of the wetland, but no analysis was made of the peat (Thormann and Bayley, 1997c).

Chapter two looks in detail at the species and environmental differences between the five wetlands of this study, attempting to discover if the five wetlands comprise a gradient of fens or if there are distinct classes of wetlands present. I hypothesized that two distinct wetland classes, fens and marshes, existed in this geographical area and both were capable of accumulating significant peat deposits. Additionally, multivariate analysis was used to look for the major environmental factors separating the species and sites (Kent and Coker, 1994). These differences were then examined in relation to the biogeochemical factors of Vitt (1994) and functional parameters of Mitsch and Gosselink (1993). Due to the large number of measurements required to achieve this objective, it was not feasible to sample a greater number of wetlands. My hypotheses were that the marshes would have higher nutrient availability, production and decomposition than fens.

Chapter three looks in greater detail at the gradient of nutrient availability. Wetland systems such as marshes and fens are more "open" than many terrestrial ecosystems, in that water flows can import materials/nutrients, and at the same time export materials/nutrients (Mitsch and Gosselink, 1993). In general, wetlands are nutrient deficient systems (Bowden, 1987), and northern wetlands show greater deficiencies than temperate or tropical systems (Jonasson *et al.*, 1993). Wetlands with known differences in surface water chemistry nutrients (Thormann and Bayley, 1997c) were compared using traditional methods of estimating net nutrient mineralization as an index of nutrient availability (Brown, 1982). Environmental factors were used in regression and correlation analysis to look for possible predictors of nutrient availability.

Flooded environments often result in high fluxes of methane, or high activity of anaerobic bacteria producing methane and low oxidation of that methane at the peat/ water interface (Harriss and Frolking, 1991). Methane is a greenhouse gas of concern due to rising levels in the atmosphere, and wetlands release globally significant levels of methane (Schlesinger, 1991). Few studies have looked at carbon and nutrient relationships in boreal peatlands (Thormann and Bayley, 1997a; Humphrey and Pluth, 1996), despite the central role nutrients play in ecosystem structure and function (Bridgham *et al.*, 1996). Chapter three estimated potential methane production to provide some estimate of carbon turnover in relation to the nutrient availability.

I hypothesized that marshes, with a higher pH and higher external nutrient availability, wuold have higher net mineralization rates than fens, with lower pH and lower external nutrient availability (following Vitt (1994)). Nitrogen mineralization is the sum of two processes, ammonification (the production of ammonia) and nitrification (the production of nitrate). Nitrate is generally not present in significant amounts in wetlands, due to the flooded anoxic conditions (Gambrell and Patrick, 1978). I expected that net nitrogen mineralization rates would be dominated by net ammonification in these boreal sites. Summer (June, July and August) was expected to have higher mineralization rates than winter (September, October, and September-June), likely related to temperature differences (Stanford *et al.*, 1973).

Methane evolution under uniform conditions should indicate relative levels of anoxic microbial degradation of organic matter, which could then be compared with nutrient mineralization rates. Methane emissions in this study were investigated in laboratory incubations to enhance the understanding of the relative turnover rates of organic matter between marshes and fens, given uniform flooding in the cores of all sites. Methane emissions are known to be low in northern peatlands (Gorham, 1991; Mitsch and Gosselink, 1993), but I proposed that I would see higher potential methane production in marshes relative to fens, as there were increased nutrients in these marshes to support higher decomposer populations.

The primary mechanism of nitrogen loss from wetlands is biological denitrification (Kadlec and Knight, 1996). Biological denitrification is the production of gaseous nitrogen by microbial and fungal reduction of nitrogenous oxides, with the principal products being dinitrogen (N_2) and nitrous oxide (N_2O) (Tiedje *et al.*, 1989). The relative importance of denitrification in prairie or boreal wetlands is unknown (Crumpton and Goldsborough, 1998; Seitzinger, 1994). Despite the lack of direct measurements, the capabilities of these wetlands for nitrogen removal are presumed high due to nitrogen disappearance over distance and through the year (White, 1997).

Chapter four estimated the loss of nitrogen from these wetlands as previous analysis of the peak biomass tissue (Thormann, 1995) had indicated nitrogen limitation (Verhoeven *et al.*, 1996). Denitrification was estimated using the N_2 flux technique, which was thought to best relate to field rates of denitrification. Comparisons were made with the acetylene block technique, which is the most common method for estimating denitrification. I expected differences in denitrification estimates between fens and marshes; I hypothesized that the marshes, having higher pH and higher external nutrient availability, would have higher denitrification estimates than the fens (with lower pH and external nutrient availability). I further hypothesized that summer (July and August) would have higher denitrification estimates than fall (September and October), since high temperatures enhance denitrification (Kadlec and Knight, 1996). Acetylene block measurements were compared with N_2 flux data to compare methods within this study, to compare with results of other studies, and to examine the relative contribution of coupled nitrification/denitrification in these systems, as nitrification is blocked with greater efficiency than denitrification by acetylene (Knowles, 1990).

Chapter four also summarizes nitrogen pathways measured in this study. A nitrogen budget highlights discrepancies between inputs and outputs (relative to the plants) from the wetlands. The contributions from the various nitrogen pools within the wetlands were then assessed.

Chapter five summarized the major conclusions of this study and related the major factors measured to each other.

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2. Ecological and functional differences between marshes and fens in the southern boreal region of Alberta, Canada.

Introduction:

Wetland terminology has a long history of being regionally specific and ambiguous (Mitsch and Gosselink, 1993). Common wetland terms are often assumed to denote specific surface water chemistry characteristics, nutrient status and hydrological conditions (Bridgham *et al.*, 1996). Marsh and fen are two wetland terms that are used to identify particular wetland classes. Both marshes and fens are wetlands that have vascular emergent macrophyte vegetation, can accumulate peat, and have standing water through much of the ice free season (National Wetlands Working Group, 1997).

The Canadian wetland classification system differentiates between marshes and fens on the basis of peat accumulation, water table characteristics, pH and dominant vegetation. Marshes are defined as having less than 40 cm of peat, being periodically inundated by standing or slowly moving water, having a circumneutral to basic pH and supporting reeds, rushes, or sedges (National Wetlands Working Group, 1997). Fens have greater than 40cm of peat, have a high water table with slow internal drainage down low gradient slopes, have slightly acidic to basic pH and support graminoid vegetation (National Wetlands Working Group, 1997). In the United States, marsh and fen are defined as in Canada, but there is no limitation on marsh peat accumulation. The US system further differentiates between the two classes on the basis of marshes having periods of drawdown, higher nutrient loading, higher productivity and higher decomposition than fens (Hansen *et al.*, 1995), as do other researchers in Canada (Vitt, 1994; Vitt and Zoltai, 1995).

In the western boreal region of Canada it is not always visually clear whether a wetland is a marsh or a fen, which can cause difficulties in describing study sites. Most wetlands in this area have substantial peat deposits, and many wetlands support sedge, reed and rush growth without clear indicators of wetland class. Another influence in the boreal region confounding the problems of wetland classification is beavers. Many wetlands are strongly influenced by beaver activity, which can influence hydrological conditions a long distance from the site of active dams and lodges. Beaver-induced hydrologic changes can in turn induce changes to the vegetative composition of the wetland and may influence the biogeochemistry of wetland soils (Naiman *et al.*, 1994). Thus many wetlands are in succession, either recovering from beaver influences that have ceased or adapting to current flooding, further complicating the process of wetland description in the boreal region. Current mapping and classification activities in the western boreal region in Alberta reported that wetlands occupy 28.8% of the landscape of this region, of which 30.9% of the wetlands are bogs, 61.1% are fens, and 8.0% are marshes (Vitt *et al.*, 1998).

The Canadian wetland classification system classifies all peat-accumulating wetlands in this region as bogs or fens, and is ideologically opposed to the existence of marshes which are accumulating peat in this geographical area (National Wetlands Working Group, 1997). Based on earlier work (Thormann and Bayley, 1997c&d), I hypothesize that the two distinct wetland classes, fens and marshes, exist in this geographical area and both are capable of accumulating significant peat deposits. I hypothesize that they differ in terms of surface water chemistry, plant species composition, and environmental conditions as well as functional processes.

Class differences between wetlands have in the past been equated with functional differences between wetlands (Bridgeham *et al.*, 1996; Heinselman, 1970), where wetland functions refer to decomposition, primary productivity, and nutrient dynamics, consumption, organic export, and energy flow (Vitt, 1994; Mitch and Gosselink, 1993). Bridgeham *et al.* (1996) argue that the literature does not support such assumptions, and that few studies have looked concurrently at the classification and functioning of wetlands. This study attempted to look in detail at the classification of five wetlands in the boreal region of Alberta, Canada and relate observable differences in classification to functional differences in primary productivity, decomposition, and nutrient partitioning between the surface water, plant tissue, and peat. Due to the large number of measurements required to achieve this objective, it was not feasible to sample a greater number of wetlands.

Plant biomass, an estimate of net primary productivity, is an important ecosystem function hypothesized to differ in marshes and fens. Marshes and fens have overlapping NPP values in many studies (Mitsch and Gosselink, 1986), however marshes have demonstrated higher NPP values in this region in a previous study (Thormann and Bayley, 1997b). This difference in marsh and fen NPP is further supported by a recent synthesis of NPP in wetlands across continental western Canada, which showed no overlap in NPP values between the combined wetland classes of bogs and fens, and combined wetland classes of marshes and swamps (Campbell *et al.*, 1999). Concurrent measures of NPP with the other parameters were made to be sure that all measures of functional differences were made in the same sites during the same year as the other measures. It is expected that marshes will have higher NPP (as estimated by peak biomass) than fens, as previously reported by Thormann and Bayley (1997b) and Campbell *et al.* (1999).

Despite the faster decomposition rates of marshes being cited as one of the key functional differences between marshes and fens (Hansen *et al.*, 1995; Zoltai and Vitt, 1995; and Vitt, 1994), actual mass losses reported in the literature are inconclusive (Thormann and Bayley, 1997a; Aerts and DeCaluwe, 1997; Szumigalski and Bayley, 1996a; Verhoeven and Arts, 1992; Ohlson, 1987; Morris and Lajatha, 1986; Bartsch and Moore, 1985; Davis and Van der Valk, 1978). The long-term incubations (one year or greater) used in previous studies in this area may miss rate differences on a shorter time scale. I measured mass loss using 30 day incubations replicated through the growing season in addition to long-term incubations in an attempt to demonstrate that while marshes and fens may not show strong differences in mass losses after one year, marshes decompose fresh litter faster in the shorter term than fens. Fen microbes are postulated to have a slower short-term decomposition rate because nutrients are more limited in the surface water (Thormann and Bayley, 1997c).

The nutrient pools in wetlands are partitioned between the water, the plant tissues and the peat/soil. Water has different levels of nutrients depending on the source and flow pattern (groundwater, groundwater upwelling, surface flow) and marshes generally have higher levels of nitrogen and phosphorus in the water relative to fens (Thormann and Bayley, 1997c; Mitsch and Gosselik, 1993). Plant tissues (predominantly *Carex* in this region) generally respond to higher nutrients by allocating more nutrients into leaves (luxury consumption) (Bernard *et al.*, 1988), and wetlands with higher productivity, such as marshes, show increased nutrient concentrations with increased stem density due to less structural material (Auclaire, 1977). Peat nutrient concentrations are highly dependent on the plant litter nutrient concentrations, and peat nutrients have been observed to be higher with higher external nutrient supply (Bernard *et al.*, 1988). Recent work in the region indicated the tissue concentrations of nitrogen and phosphorus were most strongly affected by stand densities and the nutrient status of the wetland, but no analysis was made of the peat (Thormann and Bayley, 1997c). I measured all three nutrient pools over the same time period; my hypothesis being that the marshes will have higher surface water nutrients than fens (as has been demonstrated), and that there will also be higher levels of nitrogen and phosphorus in the plant tissues and the peat of marshes than in fens.

Study Sites:

This study focussed on 2 fens and 3 marshes, all located in central Alberta, Canada in the boreal ecozone (Rowe, 1972), at the edge of the current southern limit for peatlands (Halsey *et al.*, 1998). The 2 fens are located near the town of Perryvale, with the Floating Sedge Fen (FSF) located at 54° 28' N, 113° 19' W and the Sedge Fen (SF) located at 54° 28' N, 113° 18' W. The marshes are between the towns of Clyde and Nestow. The Lakeside Marsh One (LM1) is located north of the town of Clyde at 54° 10' N, 113° 34' W. The Riverine Marsh (RM) is located east of the town of Nestow, along a portion of the river called Helliwell Lake, at 54° 15' N 133° 37' W. The Lakeside Marsh Two (LM2) is located on the south tip of Duggan's Lake, at 54° 12.5' N 133° 25' W. This area is characterized by mild summers and cold, snowy winters, with a long term mean annual temperature of 1.7°C (Thormann and Bayley, 1997a).

Four of the sites were initially chosen in spring 1995, 2 marshes (the LM1 and the RM) and 2 fens (FSF and SF). Analysis of the water chemistry data following the 1995 field season indicated that the RM was more similar to the fens in water nutrient concentrations than to the LM1. In an attempt to improve marsh replication, a third marsh was chosen in 1996, the LM2. The LM1 and both fens were previously studied and classified by Thormann and Bayley (1997a), where additional site and climate descriptions can be found.

Lacustrine Marsh One

The Lacustrine Marsh One is a sedge dominated wetland on the north end of Wakomao Lake (360 ha), and is the lacustrine marsh of Thormann and Bayley (1997a). Water drains from the north to the south of the lake into the Redwater river. Periodic flooding of the marsh occurs due to heavy spring run off and occasional beaver (*Castor canadensis*) activity at the south end outflow. The marsh is highly productive and may receive secondarily treated wastewater from the town of Clyde (population <1000) in addition to agricultural run off. Average surface water pH over the two years was 7.1, and the peat depth was 1.5- 1.75 m. The dominant vegetation is *Carex utriculata* Boott. and *Typha latifolia* L., with an abundant surface layer of *Lemna minor* L. No moss species were observed at this site.

Lacustrine Marsh Two

Located on the south tip of Duggan's Lake, this marsh is not adjacent to an inflow or outflow. There was considerable evidence of beaver activity through the 1996 field season, as willow and trees upland of the marsh were cut down by late August. The average pH of the surface water over the 1996 field season was 7.6, and the peat depth was approximately 80 cm. The vascular vegetation is dominated by *Typha latifolia* L., *Carex utriculata* Boott, and *Carex aquatilis* Wahlenb.. *Lemna minor* L. is also present. No moss species were observed.

Riverine Marsh

This marsh is similar to the riverine marsh of Thormann and Bayley (1997a) both in vegetation and in water chemistry. The site was chosen in an attempt to decrease extreme water fluctuations caused by beaver activity. The marsh is on the edge of Helliwell Lake, at the headwaters of the Tawatinaw River where it is quite wide (400 m) but with definite flow. Beavers were present nearby, as evidenced by a well-established lodge. In 1995, the water levels in the marsh were quite low, approximately 5 cm above the peat. In 1996, the area was inundated for the entire season at an average of 50 cm above the peat (possibly due to beaver activity downstream). The average pH of the surface water over the two field seasons was 7.8 and the peat depth was approximately 90 cm. The vascular vegetation is dominated by *Typha latifolia* L., *Carex utriculata* Boott, *Carex aquatilis* Wahlenb., with *Polygonum amphibium* L. common. A single moss species (*Drepanocladus aduncus* (Hedw.) Warnst.) was observed in 1995, but not in 1996.

Sedge Fen

The Sedge Fen is part of an extensive wetland complex adjacent to a large lake, and is the same Riverine Sedge Fen described in Thormann and Bayley (1997a). This wetland substrate has a distinct oxidized layer at the surface that is orange-red, while the peat below is brown-black. Analysis of recent water chemistry has demonstrated iron rich ground waters surfacing in this fen (Thormann, unpub.). The average pH of the surface water over the two field seasons was 6.8, and the peat depth was greater than one meter. The vegetation is dominated by *Carex aquatilis* Wahlenb., *Carex utriculata* Boott, and *Carex lasiocarpa* Ehrh., while the moss species (Table 1) are sparsely distributed.

Floating Sedge Fen

The Floating Sedge Fen surrounds a small pond and is a floating peat mat (about 1–1.5m thick) that fluctuates with the water level of the pond. The pond substrate is also composed of peat approximately 1-1.5m in depth. This wetland was previously described by Thormann and Bayley (1997a), Szumigalski and Bayley (1996a) and Vitt *et al.* (1995). The average pH of the surface water over the two field seasons was 6.1. This site is very species diverse (Table 1), and has a moss strata dominated by *Sphagnum warnstorfii* Russ. and *Aulacomnium palustre* (Hedw.) Loeske, a herbaceous strata dominated by *Carex lasiocarpa* Ehrh., and a shrub strata of *Salix pedicellaris* Pursh, *Andromeda polifolia* L. and *Oxycoccos quadripetalus* Gilib..

Methods:

Plant species assemblages data

Plant collections were made at the end of August during both field seasons and keyed to species. Field identification during both field seasons supplemented the plant collection data. The resulting species data lists were compared to Thormann (1995) for the LM1, the FSF, and the RSF, and any additional species present in Thormann (1995) were included in the species data list. Vascular plants were identified following Packer (1983), with the exception of *Carex utriculata* Boott, for which Griffiths (1989) was used. The single moss species (*Drepanacladus aduncus*) in the RM was described following Anderson *et al.* (1990).

Plant species were assigned a relative abundance based on the proportion of the peak biomass each species contributed. A category of 0 indicated the species was not present at that site, a 1 indicated at least one plant was present, a 2 was 0.5 to 10 % of the biomass, a 3 was 10 to 50% of the biomass, and a 4 was 50 to 100% of the biomass for each strata (using combined data of this study and Thormann (1995)). Herbaceous plants and shrubs were all treated as separate strata and relative abundancies were assigned to each stratum separately. Mosses were grouped into one category, as the presence/ absence of bryophytes is considered one of the key vegetational differences between the wetland classes (Vitt, 1994), but species varied between the fens which obscured this relationship.

Water chemistry data

Water chemistry samples were taken every two weeks from May until October of each year. Samples were taken from the same point each time, except for two samples in May at the LM1, where extreme water levels prevented entry to the wetland. Collection was made in acid washed 1 L Nalgene and 75 mL polypropylene bottles, and stored on ice. Field measurements of pH were made using a Fisher Accumet 925 pH meter.

Laboratory analysis estimated the water chemistry parameters nitrate (NO_3^- and NO_2^-), ammonium (NH_4^+), total dissolved nitrogen (TDN), soluble reactive phosphorus (SRP), total phosphorus (TP), chloride (Cl^-), sulfate (SO_4^-), sodium (Na^+), potassium (K^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), alkalinity (total), bicarbonate (HCO_3^-), and conductivity. Nitrate samples were filtered using a 0.45 μm HAWP millipore filter, while ammonium samples were not filtered. Both nitrate and ammonium were analyzed on a Technicon Auto Analyser II. TDN was also analyzed on the Technicon Auto Analyser II following digestion with 4N H_2SO_4 and H_2O_2. SRP was analyzed using the methods of Menzel and Corwin (1965). TP was analyzed using the Bierhuizen and Prepas (1985) persulfate method following digestion and measured spectrophotometrically *as per* APHA (1992). Water samples analyzed for anions (Cl^- and SO_4^-) were initially filtered with a GFC filter and then analyzed on a Dionex Series 2000 i/sp with a conductivity detector and a AS4A-SC ion pac 4mm column. Water samples analyzed for base cations (Na^+, K^+, Ca^{2+}, and Mg^{2+}) were initially filtered with GFC filters, fixed with 0.5 mL concentrated $H\ NO_3$ and then analyzed with a Perkin-Elmer Atomic Absorption Spectrometer. Conductivity was measured with a CDM 83 Bach-Simpson radiometer within 24 hours and corrected for temperature. Analysis of alkalinity and bicarbonate were conducted using a Mettler DL21 Titrator with a Mettler ST20 sample changer following APHA (1992).

Physical data

Measurements of water levels relative to the peat surface were recorded using a Steven's Type F water level recorder during the ice-free season. Water level fluctuations were cross-referenced against an independently set meter stick, read every two weeks. The water level data were recorded in two forms, a single reading at the same sampling time as the water chemistry measurements, and as an average value from the week preceding the water chemistry measurements.

The position of the anaerobic/aerobic interface depth was measured in monthly intervals from May to November for both field seasons. Three steel welding rods (one meter long) were placed in each site at the beginning of each month. After approximately 30 days, the distance from the peat surface to the lowest extent of rust on each rod was measured and that distance assumed to be the initiation of anoxic conditions (following Bridgham *et al.*, 1991). Each month, therefore, had an estimate of the anoxic depth.

Sediment pore water temperatures were measured at the same time as anoxic measurements using a Fisherbrand field thermometer (range –10 to 100°C) inserted into the peat to a depth of 13 cm. Thaw depth was measured from the beginning of May to November using a 1.5 m aluminum rod inserted into the peat.

Bulk density measurements were made on cores taken in August and September 1995, and June, July, August, September and October 1996. Twelve cores were taken in

August 1995, while 15 cores were taken in September 1995. These cores were 5.0 cm in diameter and approximately 10 cm in length. During the 1996 field season, 7.5 cm diameter cores, approximately 12 cm in length were sampled, two for each site in June, July and August, while September and October four and six cores were taken, respectively. The cores were dried at 48 °C until a constant weight was reached; upon which time the cores were immediately weighed. The dry mass (g) was divided by the volume of the core (cm^3) to arrive at the estimate of bulk density (D_b), following Hausenbuiller (1985).

Decomposition

Decomposition was estimated by plant litter mass loss using 3x6 cm nylon mesh bags, 1-mm mesh gauge (Thormann and Bayley, 1997a). To compare with mineralization, dominant plant litter from each site was collected in early June 1995, dried at 60°C and 1-2 grams of intact leaf material was placed in each bag. Bags were put out in early June 1995 and were retrieved after 30, 56, 86, 360, and 506 days in the field. Bags were also put out at the beginning of June, July, August 1995, and June, July, August, September, and October 1996. These bags were retrieved after an average of 30 days (ranging from 28-31 days). Thus there are both monthly and annual rates. The LM2 was added as a site in 1996 and no spring plant material was collected for decomposition bags. The RM plant litter was then used in the LM2 as it has similar dominant vegetation. Dried sub-samples were then ground to a fine powder and analyzed for total carbon and total nitrogen using Control Equipment Corporation 440 Element Analyzer.

Leaching was done as a separate experiment in May 1996 following Thormann and Bayley (1997a). Ten samples of weighed, dried plant litter were placed in 250 mL beakers with 160 mL of distilled, deionized water and sealed with Parafilm "M" laboratory film. Following a two-week incubation in the dark, the plant material was removed, dried and weighed. The percent mass loss was determined as the dried amount remaining divided by the initial dried amount.

Production

Vascular plant growth was estimated following Thormann and Bayley (1997b). Peak biomass was obtained from plots harvested in late August as this month showed the highest biomass in earlier work (Thormann and Bayley, 1997b). The RM may have been underestimated slightly (50 g/m²/year), since the RM in Thormann and Bayley's (1997b) study showed peak biomass in late July. At each site one 5m x 25m (125 m²) plot was established in late August 1995. Five randomly placed quadrats in each plot were clipped at that time and again in late August 1996.

Two different sized quadrats were used depending on the stem density of the vegetation. LM1, LM2, and SF had high stem densities, so $^1/_{16}$ m² (25 cm x 25 cm) quadrat was used in these sites. The FSF and RM had low stem densities, so a ¼ m² (50 cm x 50 cm) was used in these two sites. Plant material within the quadrat was clipped, dried at 48°C, and sorted into live and dead material. The dead material was discarded (as it was assumed to be from previous years), and live material divided into individual taxa and weighed. Peak biomass was the sum of the individual taxa in each quadrat and the moss growth for the year for the FSF, and was assumed to be an estimate of the net primary productivity (NPP).

Moss growth was only estimated in the FSF, as it was the only site studied with significant bryophyte biomass. Clymo's (1970) cranked wire method was employed using the same wires and transects as Thormann and Bayley (1997b). Measurements were made on one plot 5m x 25m (125 m²) originally established in 1993. Five circular transects were used, three for *Sphagnum warnstorfii* and two for *Aulacomnium palustre*. Growth in length was measured at the end of May, June, July, August, September, and October. These values resulted in a length estimate of the growing season growth. The conversions of Thormann and Bayley (1997b) were used to convert the linear growth increments (cm/year) to net production values for the year (g/m²/year). This conversion factor took into account weight per unit length and corrected for surface area, as the surface of the peat was not perfectly flat.

Shrub peak biomass was determined following Thormann and Bayley (1997b). The new terminal growth (leaves, flowers and new twigs) were weighed and used as a measure of the peak biomass, as the radial growth is believed to be minimal in dwarf shrubs (Thormann and Bayley, 1997b; Vasander, 1982). *Salix sp.* were not significant contributors to peak biomass (<10%), so their radial growth was not measured in this study.

Surface water nutrient quotients

Water chemistry results (analyzed as previously described) were used to calculate the quotient of nitrogen to phosphorus in the surface waters of the wetlands. Ammonium (NH_4^+) and nitrate (NO_3^- and NO_2^-) concentrations were converted to molar amounts, summed, and this value was divided by the molar amount of soluble reactive phosphorus (SRP) to obtain the N:P quotient for each sample.

Plant nutrient content

Carex plants from the peak biomass harvest of 1996 and spring harvest of 1995 were analyzed for total nitrogen, total carbon. Peak biomass was additionally analyzed for total phosphorus. Spring biomass was combined from each site, and three random *Carex* leaf samples drawn per site. In the sampling of peak biomass, three of the five harvest plots were subsampled and analyzed for each site, using the *Carex* leaf tissue. The dried plants were ground using a Wiley mill and analyzed for total nitrogen (TN) and total carbon (TC) using a Control Equipment Corporation 440 element analyzer. Total phosphorus (TP) was analyzed using a persulfate oxidation digestion following Menzel and Corwin (1965), with modifications as outlined in Prepas and Rigler (1982). The nutrients were expressed as % carbon (%C) and % nitrogen (%N) of total dry weight. TP was expressed as μg/g dry weight and converted to % phosphorus (%P).

Peat nutrient content

Peat samples were collected June, July, August, and September 1995, and June, July, August, September, and October 1996 using a sheet metal corer 15 cm in diameter. Five sampling points along a 5 m x 25 m (125 m^2) plot were sampled at each time, frozen at - 10°C. At the time of analysis the top 4 cm of the core was homogenized by hand, subsampled, dried at 48°C and ground. This ground sample was then analyzed for %N, %C. Analysis for TP was conducted on three dried and ground samples from the August

1996 set of cores. All nutrient analysis procedures were the same as outlined for plant nutrients.

Statistical Procedures:

Statistical packages were used with the physical, water chemistry and relative abundance data (see methods for details of parameters measured) to determine if the 5 sites in the study represented 2 distinct wetland types (marsh or fen) or if a gradient of wetland types existed. Environmental variables (physical parameter values and water chemistry parameter values) and relative abundance data were used in multivariate analyses to look for evidence of clustering or gradients. Species relative abundance data were used in TWINSPAN analysis, a divisive hierarchical method yielding a two-way classification of species and sites, to determine if marshes and fens were two distinct groups or a gradient of wetlands (Hill, 1979; ter Braak, 1987). Underlying gradients can be determined from indirect ordination (Jongman *et al.*, 1987), and the environmental data of this study were evaluated using a form of indirect ordination, specifically principle components analysis in PC-ORD (version 3.17; McCune and Mefford, 1997). Direct ordination to analyze the possible relationships between species and environmental data was done using a detrended canonical correspondence analysis (DCCA) in CANOCO (version 4.0; ter Braak and Smilauer, 1998). Direct ordination constrains the sites and species to lie along measured environmental gradients, and generates a biplot where sites and species lie along measured environmental gradients (displayed as trajectories). Environmental data were transformed before multivariate analysis (x-mean/s.d.).

Functional differences were generally tested using a t-test assuming unequal variances on SPSS 7.5 for Windows (1996). Interactions were suspected between wetland type and season for the decomposition data, so a GLM (general linear model) was utilized in SAS (SAS Institute Inc., 1989). A GLM is a modified ANOVA procedure that was dictated by unequal sample sizes. A post-hoc test (Tukey's HSD) was conducted to determine which factors were significantly different. Single factor ANOVA's and T-tests were conducted on SPSS 7.5 for Windows (1996). Significant non-normality was detected in some parameters and analysis of the data revealed leptokurtic distributions.

The non-normal data sets did not respond to transformation, but use of parametric tests on these data sets was considered appropriate as the result is a higher powered test (Zar, 1984).

Results:

Differentiation between wetland classes

Multivariate analysis (TWINSPAN, PCA and DCCA) of the 5 wetlands indicated that the marshes and fens differ from each other in species composition and environmental variables. Species composition differences emerged from TWINSPAN, where marshes and fens emerged as two groups from the first TWINSPAN division (Figure 2-1). The second division divided the marshes into the LM1 sites (and one RM site) and the combined LM2 and remaining RM sites. The third division divided the fens in the SF sites and the FSF sites. The division of the species resulted in two distinct assemblages (Figure 2-1). A detailed species list is presented in Table 2-1.

Water chemistry variables in the wetlands, examined with a PCA (principal component analysis), indicated that the fens were very closely grouped, while the marshes were more variable (Figure 2-2a). Physical parameters were also examined with PCA, however the groupings were not as distinct (Figure 2-2b; Table 2-3). Examination of environmental variables revealed strong colinearity between many variables, and exploratory CCA (canonical correspondence analysis) indicated that the environmental variables could be restrained to water level above the peat surface, surface water alkalinity, chloride, ammonium, and potassium and still explain a high proportion of the variation ($R^2 = 0.90$).

A DCCA of species with these environmental variables showed a strong separation between the marsh and fen sites identified by TWINSPAN along the first axis, primarily related to water level above the peat surface and surface water concentrations of alkalinity, chloride, ammonium, and potassium (Figure 2-3). Nitrate primarily separated the sites along the second axis. *Carex lasiocarpa* and mosses were dominant or common species in the fens, while *Carex utriculata*, *Lemna*, *Typha*, and *Carex atheroides* were dominant in the marshes. *Carex aquatilis* appears ubiquitous across the marshes and the sedge fen. The DCCA also demonstrated out that while the fens are distinct from the marshes, considerable differences exist between the fens, primarily related to vegetation.

Production

Peak biomass (as an estimate of net primary productivity) was significantly different between the marshes and the fens (t_{stat}=2.01, $P_{T\leq t}$=0.015, d.f.=26.8). Differences were more pronounced when only the vascular strata was tested (t_{stat}=3.65, $P_{T\leq t}$=0.0011, d.f.=27.6). As can be seen on Figure 2-4, it is specifically the lacustrine marshes that had greater peak biomass than the fens, while the RM was quite different from the two lacustrine marshes and had the lowest vascular production overall.

Decomposition in marshes and fens

Decomposition rates were significantly greater in the summer months than in the winter months (Tukey's HSD). During the summer, marshes had significantly greater monthly mass losses than fens (GLM= 4.68, Pr>F= 0.0005). Winter decomposition rates were not significantly different between marshes and fens, and were not different from weight loss attributed to leaching, except for LM2 (which is likely due to the small sample size of 6)(Figure 2-5). Decomposition over the longer term (506 days) demonstrated the same trend with marshes having significantly greater weight loss than fens at all time periods (GLM=15.67, Pr>F=0.0001) (Figure 2-6).

Overall the marsh mean decomposition rate was 48 ± 1.2 % wt loss/30 days and fen mean decomposition rate was 37.2 ± 1.5 % wt loss/30 days. During the summer the marsh mean decomposition rate was 53.4 ± 0.8 % wt loss/30 days and fen mean decomposition rate was 43.3 ± 1.2 % wt loss/30 days. The winter mean decomposition rate for the marshes was 27.5 ± 3.2 % wt loss/30 days, and for the fens was 16.2 ± 2.3 % wt loss/30 days. Leaching over 7 days is similar between the marshes (23-24 %), but is slightly less in the FSF (20%), and even less in the SF (14 %) (Figure 2-5).

Physical parameters

Water level and anoxic depth relative to the peat surface were significantly higher in marshes than in fens in 1995 and 1996 (Table 2-3), although differences in 1995 were driven by the LM1, as the RM was similar in both parameters to the FSF (Tukey's HSD test). Soil temperature did not differ between sites in either year, while bulk density was strongly different between marshes and fens (Table 2-3). Bulk density demonstrated differences within marshes and fens during post-hoc tests (Tukey's HSD test).

Surface water chemical concentrations

Bioavailable nutrients in the surface water (measured as ammonium, nitrate, total dissolved nitrogen, soluble reactive phosphorus, and total phosphorus) were all significantly greater in marshes than in fens (Table 2-2). The N:P quotient (on a molar basis) was also significantly greater in marshes (38.9±8.6) than in fens (12.4±1.9) (Table 2-2).

Surface water chemical concentrations in general were always lower in fens as a group than marshes (Table 2-2). Examination of the surface water chemical concentrations by site revealed that for all parameters but SRP, both fens had lower concentrations than the marshes (as ordered by Tukey's HSD test). Significant differences did occur between the two fens for alkalinity, calcium, bicarbonate, magnesium, and pH. Significant differences also occurred between the three marshes for alkalinity, calcium, chloride, bicarbonate, magnesium, sodium, pH, sulfate, and total phosphorus. T-test differences in SRP were dominated by the LM1, as the other marshes were not statistically different from the fens (Tukey's HSD).

Carex tissue nutrient concentrations and quotients

Plant tissue from marshes had consistently higher concentrations of nitrogen than were found in fen plant tissue (Table 2-3), however, in the late August sampling these differences only approach statistical significance (t_{stat} =4.400, $Pr_{t \leq T}$=0.056, d.f.=13). A decrease in nitrogen concentrations in the plant tissue was observed in both wetland classes between spring and late August (Figure 2-7), where concentrations decreased by 0.88% for marshes and 0.69% for fens. Carbon concentrations, in contrast, were similar at both sampling periods (Table 2-3). The phosphorus content of the peak plant tissue was higher in marshes than in fens (t_{stat} =6.99, $Pr_{t\leq T}$=0.02, d.f.=13), while the N:P quotient was lower in marshes than in fens, indicating that in marshes less nitrogen was utilized for each unit of phosphorus relative to fens.

Peat nutrient concentrations and quotients

Peat nutrient content analysis from the August sampling showed higher nitrogen levels in the marsh peat than in the fen peat (t_{stat} =14.02, $Pr_{t\leq T}$=0.002, d.f.=13). In the case of marsh peat, the nitrogen content of the August peat was similar to the spring plant tissue concentrations (Figure 2-7). In the fens, the peat from August had a nitrogen content that was intermediate between spring and peak plant tissue concentrations (Figure 2-7). Carbon content and C:N quotients of the peat in marshes and fens in August were not significantly different between wetland classes (Table 2-3). Phosphorus concentrations for this period were significantly different between marshes and fens, with fens having approximately twice the amount of phosphorus in the peat as marshes (Figure 2-7, Table 2-3). The nitrogen: phosphorus quotients for August peat samples were likewise significantly different between marshes and fens (t_{stat} =3.85, $Pr_{t\leq T}$=0.009, d.f.=13), with marshes having a higher N:P quotient than fens.

Peat samples taken monthly from June to September 1995 and June to October 1996 showed similar trends in carbon and nitrogen percentages and in C:N quotients when pooled and analyzed to the peat samples from late August 1996. With the larger sample sizes, significant differences were detected for overall carbon content (t_{stat} =4.44, $Pr_{t\leq T}$=0.001, d.f.=199), overall nitrogen content (t_{stat} =10.06, $Pr_{t\leq T}$<0.001, d.f.=199), and overall C:N quotients (t_{stat} =10.4, $Pr_{t\leq T}$<0.001, d.f.=110.3). Marshes had, overall, a lower percent carbon, higher percent nitrogen and a lower C:N quotient than fens in the top 4 cm of the peat.

Discussion:

Differentiation between wetland classes

Two distinct classes of wetlands were revealed during multivariate analysis of the five wetlands in the southern boreal Alberta, both supporting sedges and with one metre or more of peat. Strong differences in plant species assemblages and environmental parameters between wetland groups supported the hypothesis of two distinct wetland classes (Figure 2-1 and 2-2a). Of the physical parameters, only the water level above the peat surface was strongly different between wetland classes (Figure 2-3). The differences were illustrated by high eigenvalues in TWINSPAN and along DCCA axis 1 (Figure 2-1 and 2-3).

Plant species assemblages were strongly different ($\lambda = 0.9385$) between wetland classes. The wetlands described as marshes were distinct by having a combination of *Carex atheroides*, *Typha latifolia*, *Lemna minor*, and *C. utriculata*. This domination by sedges, rushes and aquatic vegetation agrees with the list of wetland vegetation common to Canadian marshes (National Wetlands Working Group, 1997; Vitt, 1994). The two wetlands described as fens were similar to each other in the presence of *Carex lasiocarpa* and abundance of mosses, but distinct from each other as exhibited by different *Carex* species and the presence of shrubs in only the FSF (Figure 2-3). The presence of mosses and sedges defines these sites as fens according to Canadian wetland definition (National Wetlands Working Group, 1997) and other researchers (Vitt, 1994; Zoltai and Vitt, 1995).

The different species assemblages at each site are most likely caused by differences in the physical settings of the wetlands (elevation, basin morphology, and hydrology) which results in differences in water chemistry (Hill and Devito, 1997), and in turn promotes different vegetation (Nicholson and Vitt, 1994). Following the conclusion that there were two wetland classes represented by these sites, contrasts between the classes formed the basis of the analysis of the functional parameters. T-tests were considered appropriate as the classification of the wetlands demonstrated two groups.

Environmental parameters

Water chemistry values were clearly different between marshes and fens (Figure 2-2a); with marshes having higher conductivity and pH, in addition to higher concentrations of alkalinity, calcium, total dissolved nitrogen, potassium, total phosphorus, chloride, and magnesium (Table 2-2). Hydrological differences between the wetlands may be responsible for the differences in water chemistry values; both wetland classes are influenced by ground water and surface water, however the marshes receive greater fluxes of water and hence greater concentrations of cations, anions and nutrients (Vitt, 1994; Zoltai and Vitt, 1995). While the fens did not show large variation in water chemistry values, in general the FSF had lower values than the SF, which may reflect the lesser influence of ground and surface water on this floating mat fen adjacent to a pond. The surface water chemistry ranges for fens agree with corresponding parameters measured by Vitt *et al.* (1995) for boreal fens and Nicholson and Vitt (1994) for fens in central Alberta. The surface water chemistry ranges for marshes follow those measured by Thormann and Bayley (1997c) for boreal marshes and Nicholson and Vitt (1994) for marshes in central Alberta.

The physical parameters alone in a PCA did not differentiate between marshes and fens (Figure 2-2b), but when included in the DCCA, the physical factors did exhibit an influence (Figure 2-3). Specifically, the marshes had higher water levels above the peat surface relative to the fens. Sediment anoxic depth was strongly correlated to water depth, which would decrease the sediment anoxic depth. Both sediment anoxic depth and bulk density were significantly different between marshes and fens (Table 2-3), while peat temperature did not differ between wetland classes.

Surface water nutrient concentrations

In addition to the surface water parameters discussed above, surface nutrient values differed between wetland classes. As has been reported by others (Thormann and Bayley, 1997c; Zoltai and Vitt, 1995), the marshes had significantly higher surface water nutrient concentrations than the fens. In contrast with the results of Thormann and Bayley (1997c), this study found all measured surface water nutrients to be higher in the marshes than in the fens. In general the ranges of various surface water nutrient parameters agree with ranges for similar sites reported earlier (Thormann and Bayley, 1997c; Vitt *et al.*, 1995; Nicholson and Vitt, 1994), although the fens in this study appear to have lower surface water nutrient concentrations than the prairie parkland fens (Nicholson and Vitt, 1994). The lower nitrate values reported in these boreal sites and those of Vitt *et al.* (1995) could relate to geological factors e.g. latitudinal gradient compared to the prairie parkland sites of Nicholson and Vitt (1994). Bayley and Devito (unpub.) have found extremely low nitrate levels in a large number (150+) of boreal wetlands in central Alberta, which would indicate that nitrate rarely accumulates in the surface waters of boreal wetlands.

The ratio of available N to available P is sometimes used to infer the limiting nutrient in fresh waters (Lockaby and Conner, 1999). The Redfield ratio is a molar N:P quotient of the requirements of autotrophic activity (Redfield, 1958), where a quotient above 16 suggests phosphorus limitation, while below suggests nitrogen limitation (Valiela, 1991). The surface water molar N:P quotient was quite variable in the marshes, as can be seen by the high standard error (38.9 ± 8.6). LM1 had the lowest N:P quotient and lowest variation (5.5 ± 1.3), indicating that the LM1 is nitrogen limited (Figure 2-8). The RM (62.5) and the LM2 (67.3) both appear to be limited in phosphorus relative to this ratio (Figure 2-8). The fens do not have such a large variation in N:P quotients, the FSF has relatively balanced surface water nutrients (17.8N:1P), while the RSF appears nitrogen limited in the surface water (7.6N:1P) (Figure 2-8). In conclusion, my study indicated that wetland classes (marshes and fens) were not differentiated on the basis of nitrogen or phosphorus limitation inferred from the surface water chemistry.

Plant nutrient concentrations

Nitrogen concentrations for the mixed *Carex* species in our wetlands agree with *Carex* tissue concentrations reported by Thormann and Bayley (1997c), Verhoeven and Schmitz (1991), Koerselman *et al.* (1990), and Richardson *et al.* (1978), and fall in the range quoted in Bernard *et al.* (1988). These values are low relative to European values of Konings *et al.* (1989), but the plants in their study were grown under optimum nutrient conditions in the laboratory. In agreement with Richardson et al. (1978) and Thormann and Bayley (1997c), it was observed that the nitrogen concentrations declined between spring and August plant tissue samples (Figure 2-7).

Phosphorus concentrations in the leaves at peak biomass agree with values of August biomass in Thormann and Bayley (1997c), Koerselman *et al.* (1990), Richardson *et al.* (1989), Bernard *et al.* (1988), and Auclair (1977). My values for phosphorus were again lower than reported in laboratory studies by Konings *et al.* (1989) and by

Veerkamp *et al.* (1980). In general, the plant nitrogen and phosphorus concentrations were, as expected, higher in marshes than in fens, however, only for plant tissue phosphorus were these differences statistically significant. The high cost of tissue nutrient sampling limited the sample size of these parameters, which is the most likely cause for the lack of significance for plant tissue nitrogen between the wetland classes. The N:P quotient was significantly lower in marshes than in fens, agreeing with the findings of Bedford *et al.* (1999) that marshes have lower N:P ratios (quotients) than fens.

The plant tissue N:P quotient has been demonstrated as a useful predictor of nutrient limitation in wetlands, where a molar quotient of 31 N:P or lower indicates N-limitation, and a quotient greater than 35 indicates phosphorus limitation (Verhoeven *et al.*, 1996). All wetlands in this study had a plant tissue N:P quotient below 31, suggesting both fens and marshes are N-limited (Table 2-3; Figure 2-8). This agrees with the findings of Lockaby and Conner (1999) for wetland forests, and Koerselman and Meuleman (1996) for a variety of wetland classes. This contrasts with the surface water chemistry limitations inferred from the Redfield ratio, which would have suggested only the LM1 and SF were N-limited (Figure 2-8).

Peat nutrients

Values obtained for nitrogen and phosphorus do fall within ranges reported in the literature, in particular my peat concentrations are similar to those reported by Waugham and Bellamy (1980) and Verhoeven and Arts (1987) for fens, and Kadlec and Knight (1996) for cattail/sedges on peat. In the fens, the N:P quotient of the peat agreed with the N:P quotient of the plant tissue, indicating N-limitation (Figure 2-8). In marshes, the N:P quotient would suggest a balanced system or possible P-limitation, which is contrary the plant tissue results (Figure 2-8). These results contrast with the results of Bedford *et al.* (1999), who found that only marshes consistently showed N limitation in the plant vegetation and the peat or soil, while fens had variable N,P and co-limitation by N and P. My results indicate that peat nutrients do not consistently provide accurate information on the availability of nutrients to plants, particularly in the marshes (Figure 2-8).

In comparison to peak tissue concentrations, nitrogen values are lower in the plant tissue than in the peat, while phosphorus concentrations are similar or higher. Thus the decomposition process accumulates N in the peat of both wetland classes (presumably through microbial colonization/ immobilization), while in most cases conserving P at similar levels to the plant tissue at peak biomass. The SF is the one wetland that has much higher peat concentrations of phosphorus than is found in the plant tissue (three times higher, data not shown). Hydrologic inputs undoubtedly affect the chemistry of this fen's peat and at this site iron rich groundwater is believed to bind P in an unavailable form (Thormann, unpub.).

Production

While marshes had higher NPP (estimated as peak biomass) overall, the NPP differences were strongest between vascular plant productivity of the lakeside marshes and the fens. This reflects the increased dominance of herbs in marshes, often the only vegetation strata present. Campbell *et al.* (1999) report no other contribution to the NPP of marshes other than the herb strata (the lacustrine marsh biomass estimates from this study fall within their range, 853±429 g/ m^2), while open fens have ca. 30% contribution from the bryophyte strata. The FSF had a much stronger contribution from the moss strata than the average from Campbell *et al.* (1999); moss NPP more than doubled the total NPP values relative to the herb strata NPP. The values reported in this study (352 and 398 g/m^2) agree with the findings of Thormann and Bayley (1997b) and Szumigalski and Bayley (1996b) for this site (356 and 360 g/m^2/yr, respectively). As the bryophyte biomass was not measured for the SF, NPP values were slightly underestimated. SF peak biomass values reported (195 and 283 g/m^2) fall in the range of NPP values reported for western Canadian open fens, 190-356 g/m^2/yr (Campbell *et al.*, 1999). My values for the SF are lower than found in 1993-94 by Thormann and Bayley (1997b) (409 g/m^2/yr), which could be due to higher water levels at this site during 1995 and 1996 inhibiting the *Carex* species.

Decomposition in marshes and fens

Short-term (30 day) decomposition results support the hypothesis that plant material in marshes is decomposing at a faster rate than in the fens. Specifically, the summer months of June, July, August and September showed higher decomposition rates in marshes than in fens. In general, winter rates were not different from initial (14 day) leaching rates observed in the laboratory, indicating that winter decomposition rates were the result of chemical, not microbial, actions. Leaching values reported here are somewhat higher than those measured by Ohlson (1987) and Thormann and Bayley (1997a), which likely related to different collection conditions and timing as well as the species mixture used.

A longer term (506 day) decomposition experiment agreed with the 30 day short term results, where marshes had less mass remaining than fens at all time periods. Agreement with previously reported mass remaining values of Thormann and Bayley (1997a) for the same/similar sites was very close (once adjusted for differences in leaching); the differences range between 6 – 9% for the SF, FSF and RM. The LM1 does have a large difference in mass remaining (40% in this study, 64% in Thormann and Bayley (1997a). This may be related to differences in the water table height between 1993 (Thormann and Bayley, 1997a) where water was below the peat surface, and 1995 (this study) where the water was always at least 20 cm above the peat surface. Support for this explanation comes from van der Valk *et al.* (1991), who found mass remaining of new *Typha* litter to be 43- 49% in flooded areas and 64% in non-flooded areas. Thus it appears that high water levels promote decomposition in northern marshes, and differences in the decomposition rates between marshes and fens may be ultimately controlled by hydrologic conditions, not surface water nutrient dynamics.

Differences between Marsh types

While marshes emerged from the TWINSPAN and DCCA as one group, obvious differences between the riverine and lacustrine marshes emerged. DCCA biplot shows the riverine marsh separated from the other marshes by levels of nitrate and distinct species of *Calamagrostis* and *Polygonum* (Figure 2-3). Productivity was dramatically lower in the riverine marsh relative to all sites, but especially relative to the lacustrine marshes. The water chemistry values of the riverine marsh are intermediate between the marsh range of values and the fen range of values both in this study and when compared to the prairie parkland wetlands (Nicholson and Vitt, 1994). The principal components analysis of the physical parameters has the RM overlapping both the lacustrine marsh and fen groups, which are reasonably independent of each other (Figure 2-2b). Summer short term and long term decomposition rates are also intermediate between the lacustrine marshes and the fens.

There are some explanations why the RM may be intermediate in the parameters measured. The water level fluctuated between two extremes, almost dry in 1995 and extremely flooded in 1996, which may have influenced all parameters. This may be common for riverine systems, due to beaver activity along the flowing watercourse. Certainly Thormann and Bayley (1997c) observed large water level fluctuations at their riverine site, and also reported a lower value for NPP (323 g/m^2) than other studies (Thormann and Bayley, 1997b). The riverine marsh of this study had obvious grazing (evidenced by chewed *Carex* stems), which would have contributed to the lower NPP reported in this marsh (approx. 150 g/m^2) than in the marsh of Thormann and Bayley (1997b). Naiman *et al.* (1994) report total live biomass in beaver influenced ponds and meadows that range from 340 to 362 g/m^2, agreeing closely with Thormann and Bayley (199b). While riverine systems appear to have lower biomass and other functional parameters, my riverine marsh does appear to have lower NPP than other similar systems.

Conclusions

In addition to distinct plant species assemblages, the three wetlands described as marshes differed from the wetlands described as fens in several key characteristics described in the Canadian wetland classification system (National Wetlands Working Group, 1997). Water levels were higher in the marshes than in the fens (Table 2-3), vascular production was higher in the marshes than the fens (Figure 2-4), decomposition rates were faster in marshes than in fens (Figure 2-5 & 2-6), and pH was higher in marshes than in fens (Table 2-2). Additionally, bulk density was significantly higher in the marshes than in the fens (Table 2-3).

Water fluctuations were compared between the sites, and while differences between sites were not observed (data not shown); this was attributed to the short time frame of this study. I did observe large water table fluctuations in the riverine marsh of this study, and Thormann (1995) observed large fluctuations at the LM1 and another riverine marsh. The LM2 was only studied for one year, and historical water levels were not available. Water level fluctuations over several years could be another influence on the differences observed. Combined with the distinct species assemblages, the differences between the five wetlands were considered conclusive evidence that these wetlands represented three marshes and two fens, as visually described at the outset of the study.

The existence of two wetland classes, both accumulating peat, is evident from the distinct differences in ecological and functional parameters presented. The significant peat accumulation in these marshes (> one metre) may be unique to this geographical area, on the edge of the current southern limit for peatlands. This peat accumulation in marshes does point out a failing of the Canadian wetland classification system in this region. It is therefore recommended that peat accumulation greater than 40 cm not be used as a criterion to distinguish between marshes and fens, particularly in the boreal region. Species assemblages, particularly the high relative abundance of mosses, water level relative to the peat surface, and surface water chemistry variables did differentiate between the wetland classes and would be better indicators of wetland class than peat depth.

Nutrient limitations in marshes and fens were evaluated based on the plant tissue nutrient quotients calculated from peak biomass plant samples. Evidence from peak biomass tissue nutrient quotients suggests that all wetlands of this study were nitrogen limited, contrasting with work further south. Inferences from plant tissue nutrients did not consistently agree with N or P limitations suggested either by N:P quotients for surface water chemistry or for peat nutrient concentrations. This lack of agreement indicates that neither surface water chemistry or peat nutrient concentrations were a consistent proxy for tissue nutrient quotients calculated from plant peak biomass.

The visible differences seen in species assemblages between marshes and fens were related to environmental gradients measured. Environmental parameters of the gradients (water chemistry, etc.) and functional parameters (production, decomposition, etc.) were closely related and differentiated between marshes and fens in this study. In these five wetlands, class differences between marshes and fens were indeed related to functional differences observed in the wetlands.

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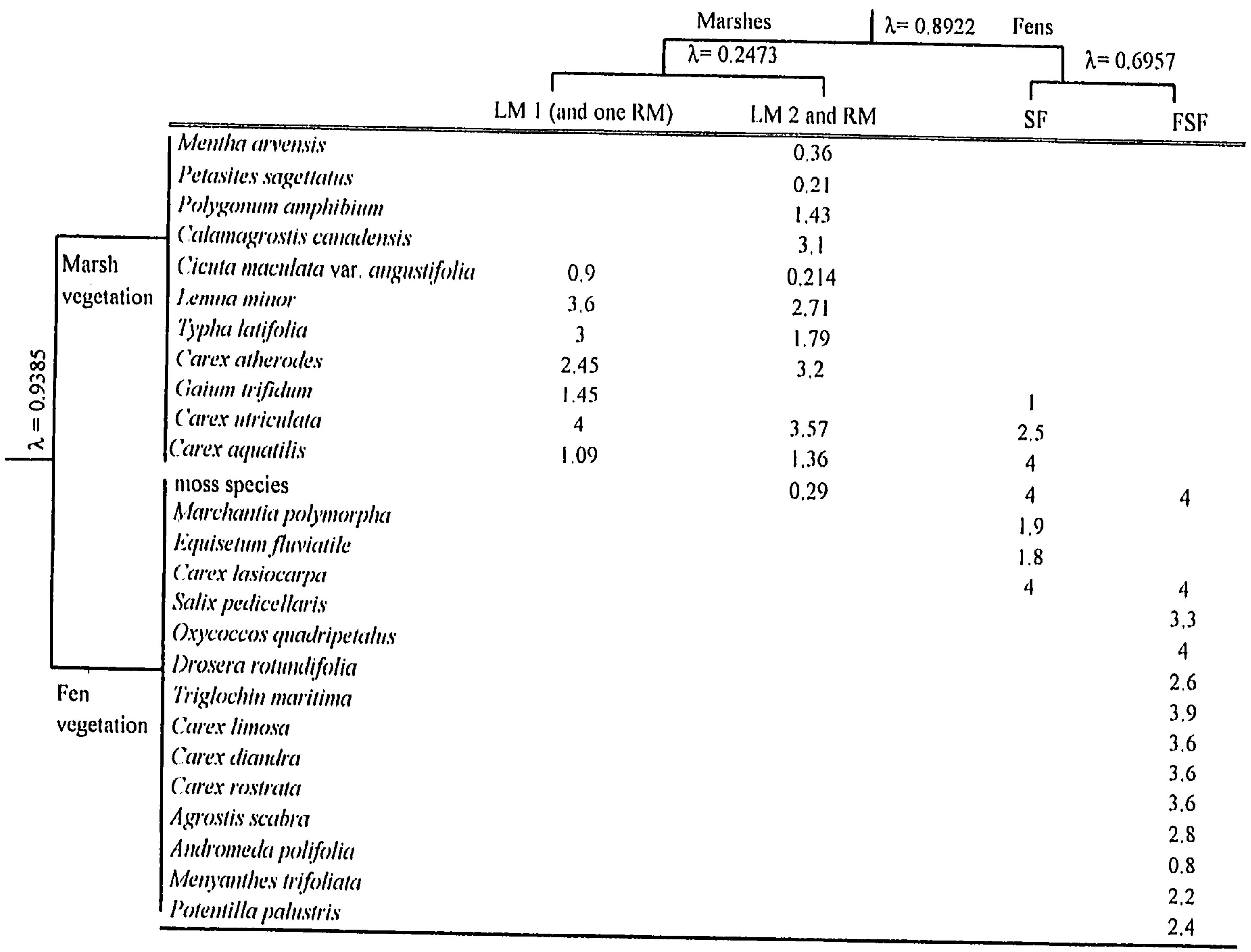

	LM 1 (and one RM)	LM 2 and RM	SF	FSF
Mentha arvensis		0.36		
Petasites sagettatus		0.21		
Polygonum amphibium		1.43		
Calamagrostis canadensis		3.1		
Cicuta maculata var. *angustifolia*	0.9	0.214		
Lemna minor	3.6	2.71		
Typha latifolia	3	1.79		
Carex atherodes	2.45	3.2		
Gaium trifidum	1.45		1	
Carex utriculata	4	3.57	2.5	
Carex aquatilis	1.09	1.36	4	
moss species		0.29	4	4
Marchantia polymorpha			1.9	
Equisetum fluviatile			1.8	
Carex lasiocarpa			4	4
Salix pedicellaris				3.3
Oxycoccos quadripetalus				4
Drosera rotundifolia				2.6
Triglochin maritima				3.9
Carex limosa				3.6
Carex diandra				3.6
Carex rostrata				3.6
Agrostis scabra				2.8
Andromeda polifolia				0.8
Menyanthes trifoliata				2.2
Potentilla palustris				2.4

Figure 2-1: Dendogram of the stand groups and species groups as determined by TWINSPAN. The eigenvalues (λ) are presented at the cut levels. Numbers in the table are the average relative abundance of the species within the stand. Full species names and moss species are presented in Table 1.

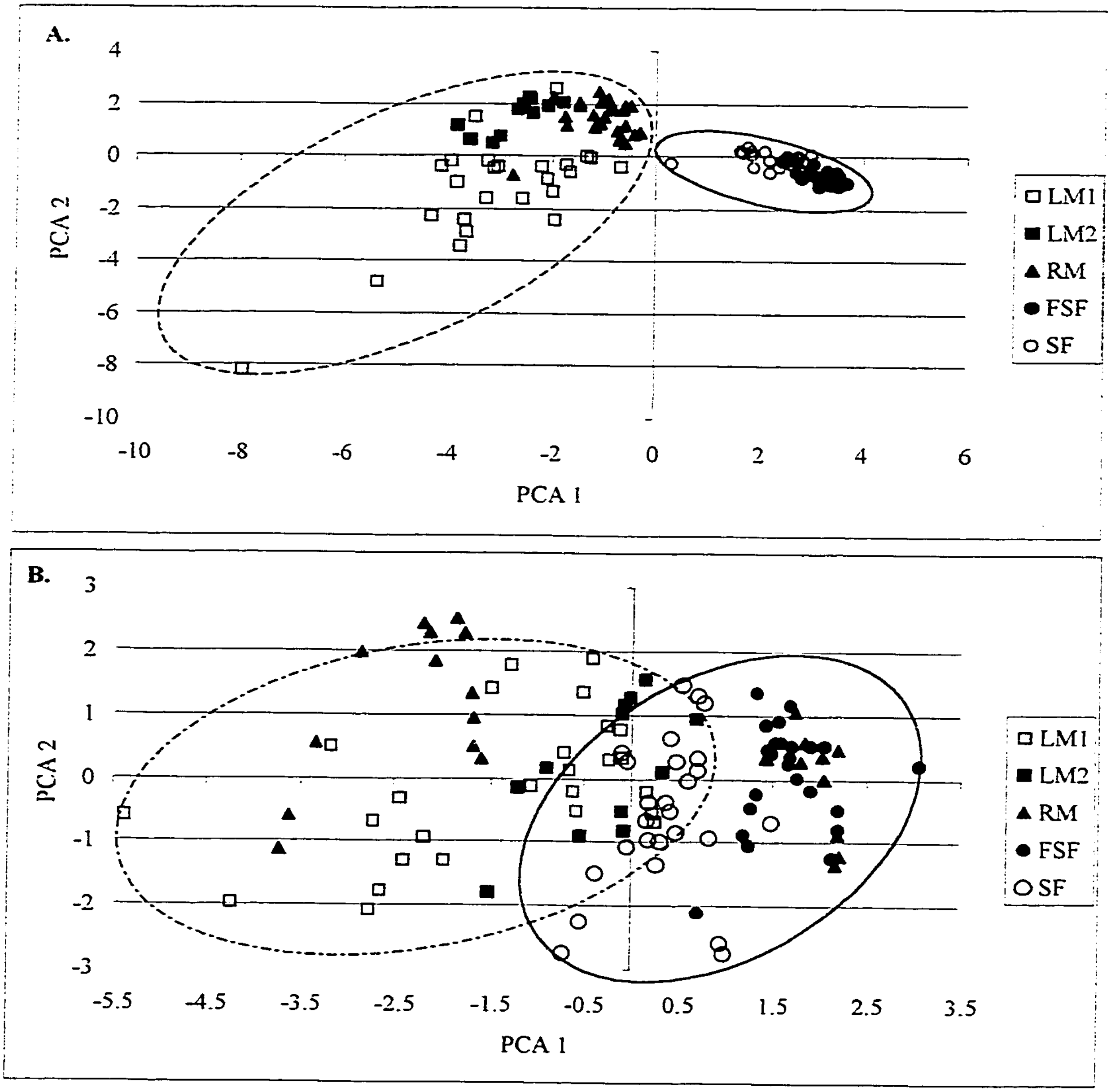

Figure 2-2: PCA ordinations of A. all surface water chemistry data and B. all physical data from the five wetlands. For A. the solid line encircles the sites classified as fens and the dashed line encircles the sites classified as marshes in the first division of TWINSPAN. For B. the solid line again encircles the fens, while the dashed line encircles the lacustrine marshes.

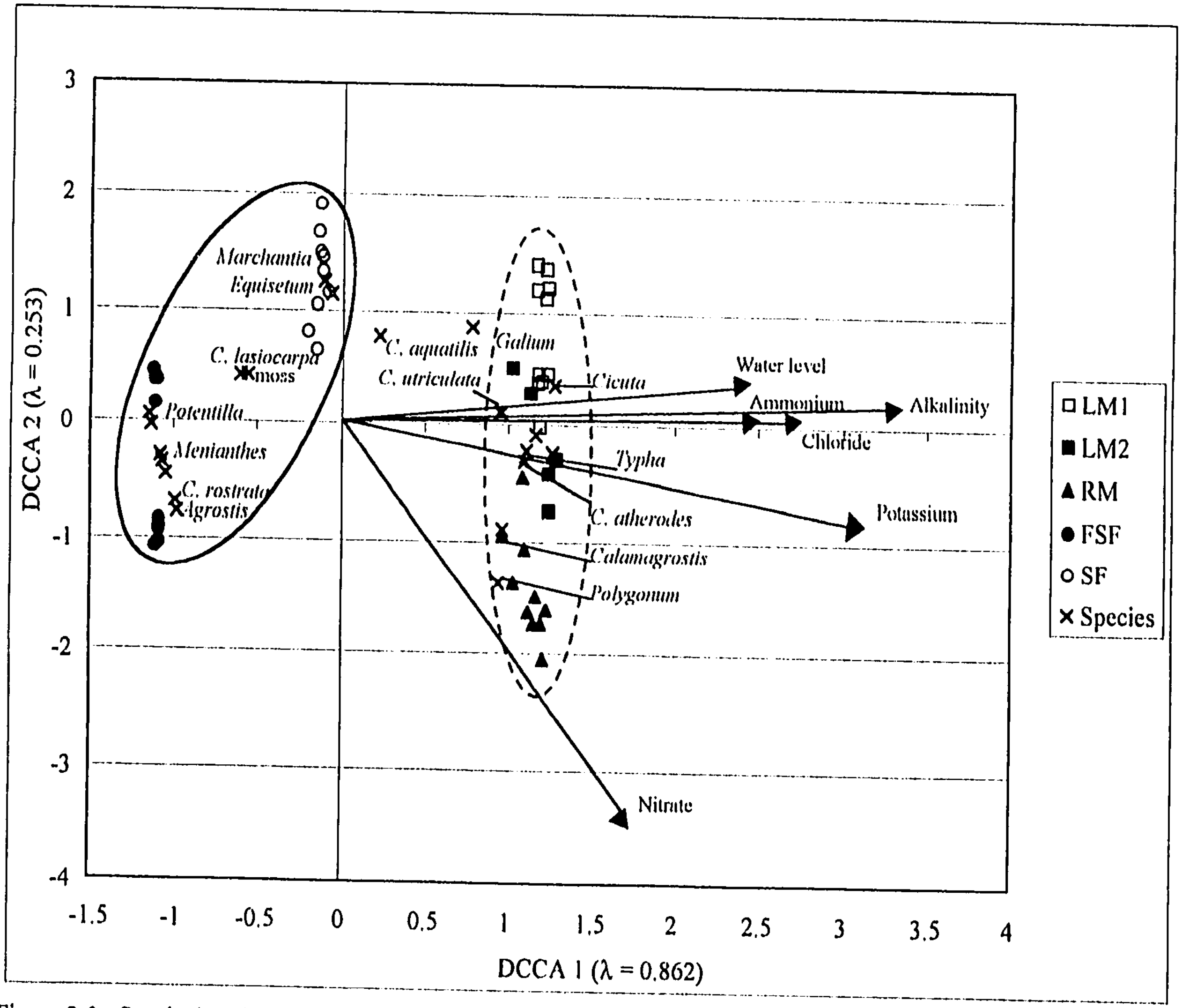

Figure 2-3: Species/ environment biplot from detrended canonical correspondence analysis of relative abundance and selected environmental data for the five wetlands. The dashed line encircles the sites classified as marshes, while the solid line encircles the sites classified as fens, as grouped in the first TWINSPAN division.

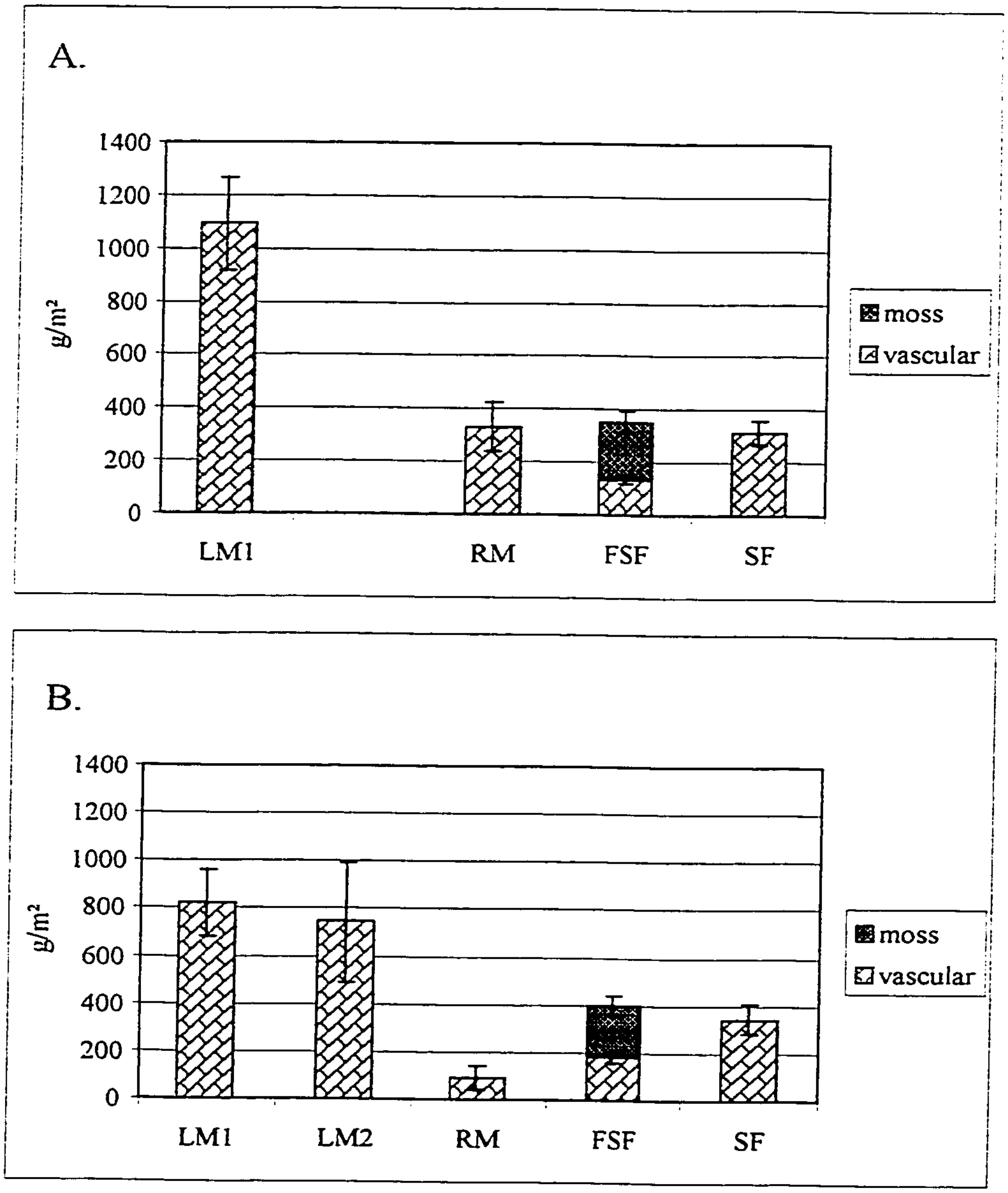

Figure 2-4: Peak biomass estimates for A. 1995 and B. 1996.

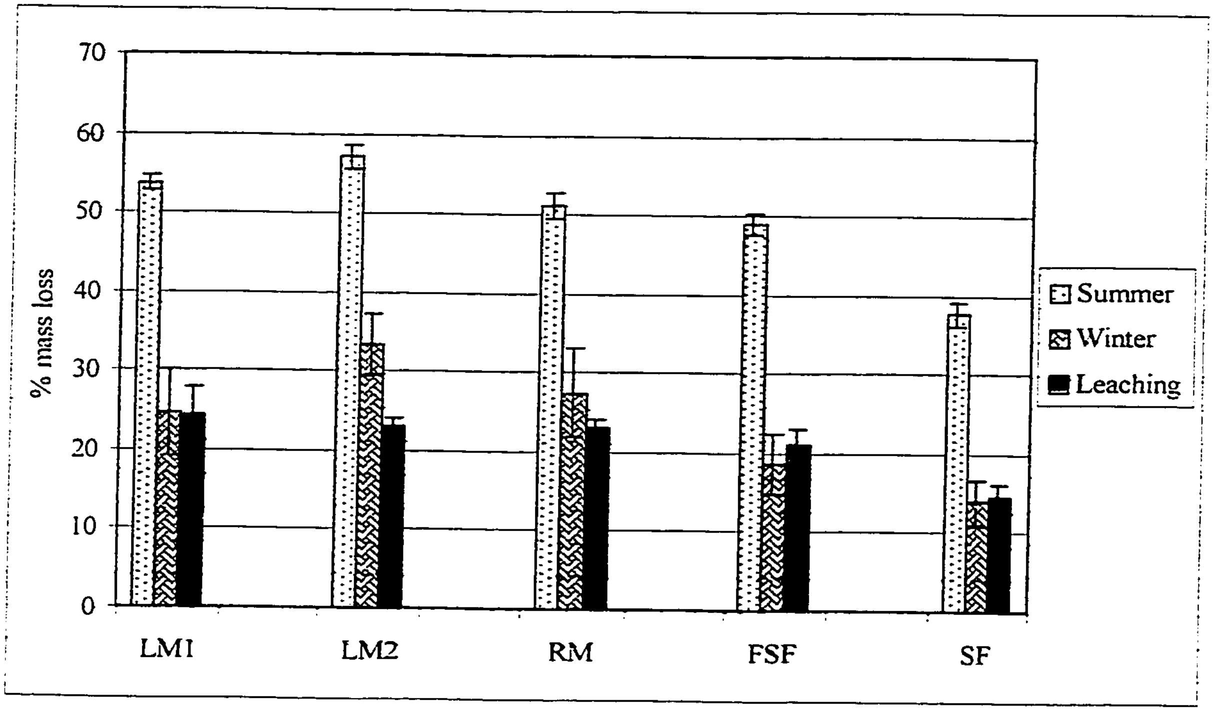

Figure 2-5: Short term (30 day) decomposition mass losses.

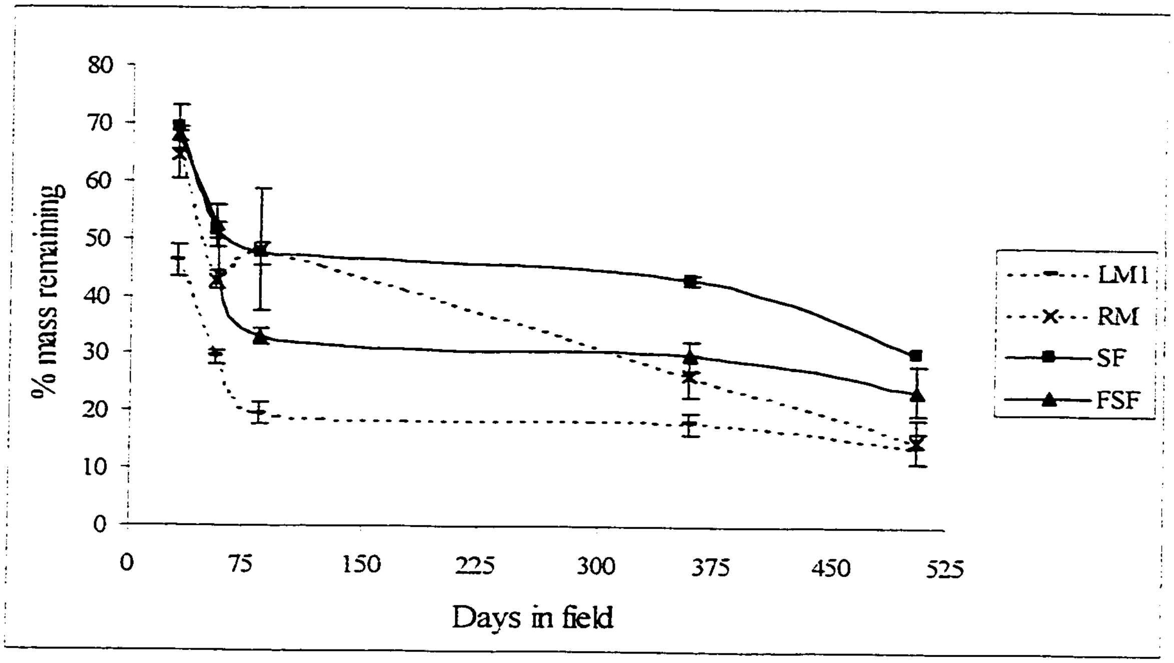

Figure 2-6: Long term (506 day) decomposition results, expressed as mass remaining. Plant litter was initially placed in the field on June 6th, 1995.

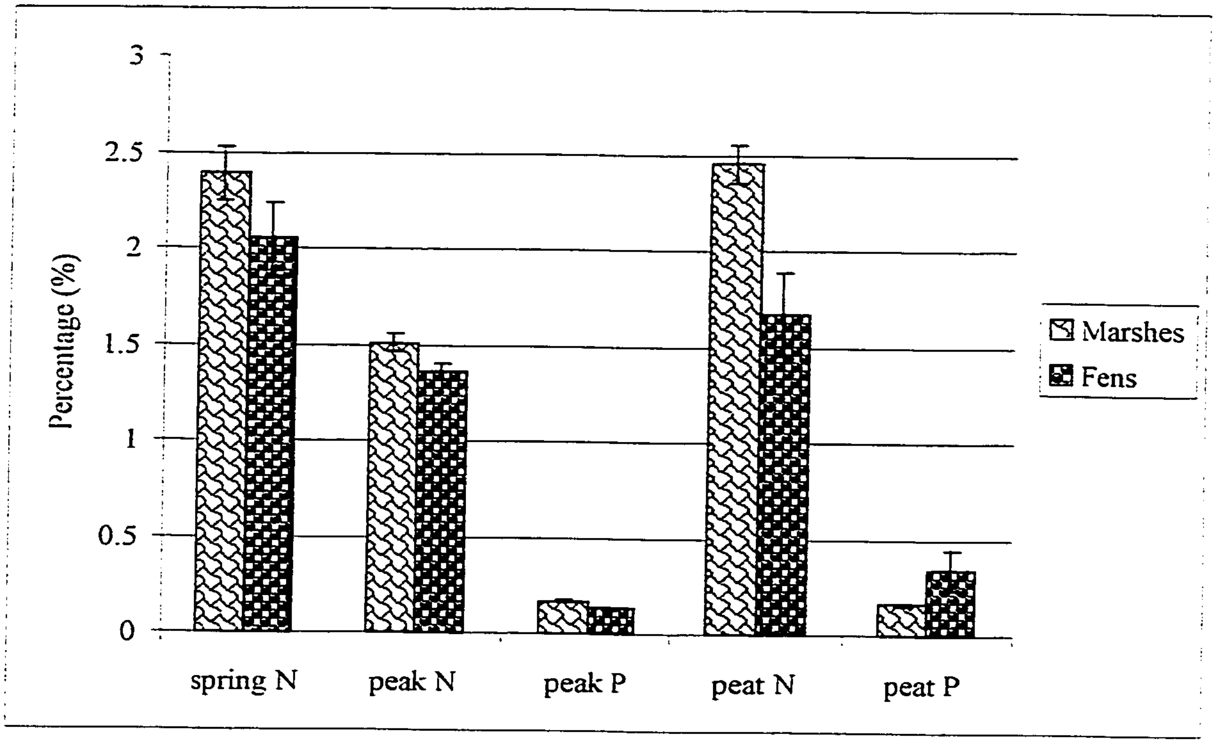

Figure 2-7: Percentage of nitrogen and phosphorus in the plant material biomass in spring 1995 and peak biomass 1996 (late August), and in the top 4cm of peat (1st August 1996).

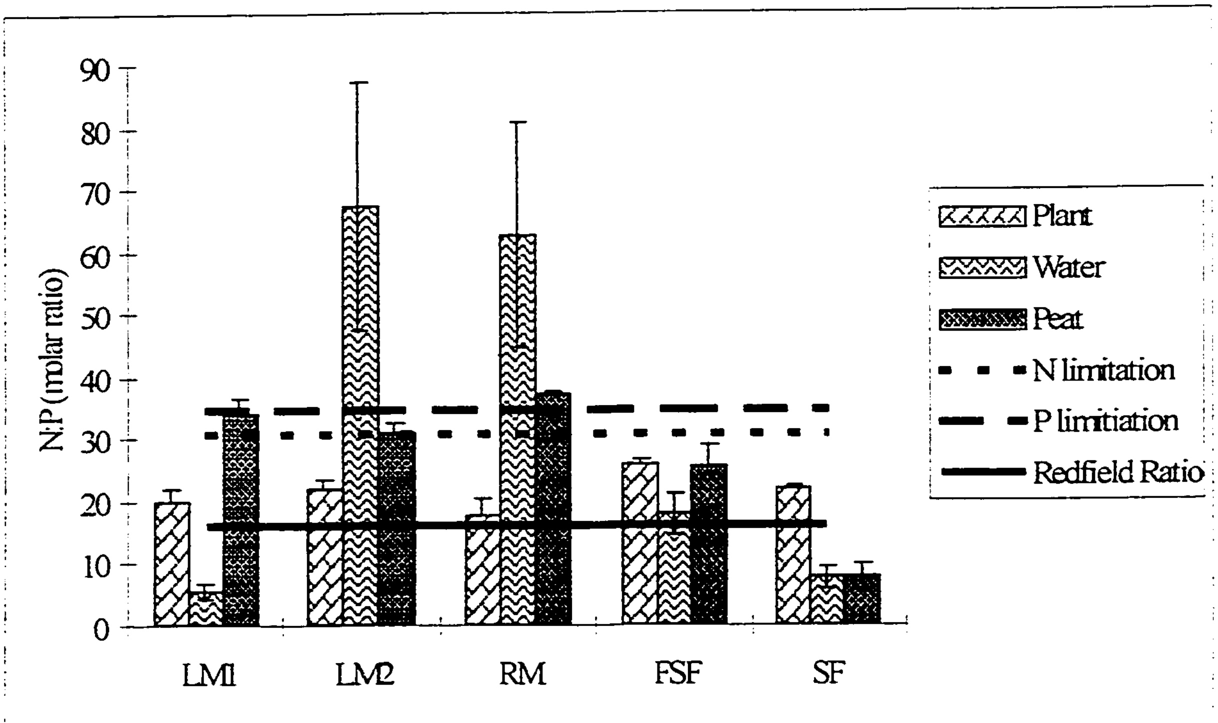

Figure 2-8: N:P quotients (molar basis) for the peak biomass plant tissue, surface water (NH_4^+ &NO_3^-: SRP), and peat (%N:%P) relative to the Redfield ratio and nutrient limitation boundaries suggested by Verhoeven *et al.* (1996). Ratios in peak biomass above the P limitation boundary implies P limitation, while ratios below the N limitation boundary implies N limitation.

Vegetation:	Site: Lacustrine Marsh 1	Lacustrine Marsh 2	Riverine Marsh	Sedge Fen	Floating Sedge Fen
Shrub:	not present	not present	not present	not present	*Salix pedicellaris* Pursh *Andromeda polifolia* L. *Oxycoccos quadripetalus* Gilib.
Herb:	*Carex aquatilis* Wahlenb. *Carex atherodes* Spreng. *Carex utriculata* Boott *Cicuta maculata* var. *angustifolia* Hook *Galium trifidum* L. *Typha latifolia* L.	*Calamagrostis canadensis* (Michx.) Beauv. *Carex aquatilis* Wahlenb. *Carex atherodes* Spreng. *Carex utriculata* Boott *Cicuta maculata* var. *angustifolia* Hook *Mentha arvensis* L. *Petasites sagittatus* (Pursh) A. Gray *Potentilla palustris* (L.) Scop. *Typha latifolia* L.	*Calamagrostis canadensis* (Michx.) Beauv. *Carex aquatilis* Wahlenb. *Carex atherodes* Spreng. *Carex utriculata* Boott *Equisetum fluviatile* L. *Typha latifolia* L.	*Carex aquatilis* Wahlenb. *Carex lasiocarpa* Ehrh. *Carex utriculata* Boott *Equisetum fluviatile* L. *Galium trifidum* L.	*Agrostis scabra* Willd. *Carex diandra* Schrank *Carex lasiocarpa* Ehrh. *Carex limosa* L. *Carex rostrata* Stokes *Drosera rotundifolia* L. *Menyanthes trifoliata* L. *Potentilla palustris* (L.) Scop. *Triglochin maritima* L.
Aquatic:	*Lemna minor* L.	*Lemna minor* L.	*Lemna minor* L. *Polygonum amphibium* L.		
Moss:	not present	not present	*Drepanocladus aduncus* (Hedw.) Warnst.	*Brachythecium mildeanum* (Schimp.) *ex* Milde *Drepanocladus aduncus* (Hedw.) Warnst. *Tomenthypnum nitens* (Hedw.) Loeske	*Aulacomnium palustre* (Hedw.) Schwaegr. *Calliergonella cuspidata* (Hedw.) Loeske *Hamatocaulis vernicosus* (Mitt.) Hedenäs *Sphagnum warnstorfii* Russ.
Liverwort:	not present	not present	not present	*Marchantia polymorpha* L.	not present

Table 2-1: Species found in various sites in 1995 and 1996, as well as those reported in Thormann (1995).

Characteristic	All marshes mean (s.e.)	n	LM1 mean (s.e.)	n	LM2 mean (s.e.)	n	RM mean (s.e.)	n	All fens mean (s.e.)	n	FSF mean (s.e.)	n	SF mean (s.e.)	n	t-test statistic (Prob.)	(d.f.)
pH	7.19 (0.14)	62	6.95 (0.10)	26	7.56 (0.11)	12	7.54 (0.11)	25	6.23 (0.14)	50	5.98 (0.13)	24	6.72 (0.09)	26	5.50 <0.001	50
Conductivity* (µS)	512.2 (15.1)	57	589.9 (18.8)	23	513.5 (13.5)	11	433.9 (22.2)	23	111.8 (9.2)	46	63.2 (3.1)	23	160.4 (11.2)	23	21.4 <0.001	101
Chloride (Cl^-) (mg/L)	33.2 (2.9)	62	53.4 (3.9)	26	4.6 (0.1)	12	25.6 (1.4)	24	0.8 (0.1)	46	0.89 (0.08)	24	0.65 (0.11)	22	11 <0.001	61
Sulfate (SO_4^{2-}) (mg/L)	29.4 (2.4)	62	17.7 (3.3)	26	18.1 (1.8)	12	47.6 (1.8)	24	0.35 (0.07)	35	0.23 (0.06)	15	0.44 (0.11)	20	11.9 <0.001	61
Sodium (Na^+) (mg/L)	50.3 (2.8)	62	67.4 (4.12)	26	29.6 (1.0)	12	42.1 (2.4)	24	2.37 (0.12)	49	1.88 (0.06)	24	2.83 (0.18)	25	17.3 <0.001	61
Potassium (K^+) (mg/L)	12.2 (0.6)	62	12.7 (1.2)	26	14.5 (0.4)	12	10.4 (0.8)	24	1.04 (0.16)	49	1.50 (0.25)	24	0.59 (0.17)	25	17.8 <0.001	70
Calcium (Ca^{2+}) (mg/L)	38.2 (1.4)	62	42.0 (1.6)	26	41.6 (1.3)	12	32.3 (2.7)	24	15.3 (1.3)	49	7.96 (0.39)	24	22.4 (1.5)	25	16.7 <0.001	102
Magnesium (Mg^{2+}) (mg/L)	18.2 (1.1)	62	13.4 (0.4)	26	34.2 (0.7)	12	15.4 (0.6)	24	6.13 (0.38)	49	4.13 (0.21)	24	8.05 (0.47)	25	10.7 <0.001	77
Alkalinity ($CaCO_3$) (mg/L)	195.9 (7.1)	62	207.1 (6.0)	26	276.2 (8.3)	12	143.6 (5.1)	24	53.1 (4.7)	49	24.8 (1.5)	23	78.1 (5.1)	26	11.7 <0.001	109
Ammonium (µg/L)	174.1 (39.0)	62	228.8 (75.8)	26	252.4 (88.1)	12	75.6 (32.8)	24	11.5 (1.5)	44	13.6 (2.6)	21	9.55 (1.51)	23	4.17 <0.001	61
Nitrate (µg/L)	15 (3.5)	65	10.94 (1.56)	27	13.3 (2.8)	13	20.2 (8.8)	25	7.42 (1.27)	49	8.37 (2.56)	23	6.58 (0.81)	26	2.03 0.046	80
TDN (µg/L)	2934 (148.3)	62	3471.5 (289.1)	26	2567.1 (158.5)	12	2535.2 (150.8)	24	1223.3 (38.7)	50	1259.1 (50.2)	24	1190.3 (58.3)	26	11.2 <0.001	69
SRP (µg/L)	115.1 (24.0)	62	233.9 (46.7)	26	69.7 (26.2)	12	9.06 (2.94)	24	10.6 (2.2)	50	6.03 (0.96)	24	14.9 (3.9)	26	4.34 <0.001	62
TP (µg/L)	388 (35.9)	65	617.9 (53.7)	27	354.7 (51.9)	13	157.8 (16.9)	25	98.8 (12.5)	50	95.0 (13.1)	24	102.4 (21.0)	26	7.6 <0.001	79
N:P	38.9 (8.6)	58	5.53 (1.28)	25	67.3 (20.1)	11	62.5 (18.0)	22	12.4 (1.9)	43	17.8 (3.3)	20	7.63 (1.73)	23	3 0.004	63

Table 2-2: Means, standard errors, and sample sizes of surface water parameters collected and estimated in 1995 and 1996. N:P quotients are on a molar basis, t-tests were conducted between all marshes and all fens. *conductivity was corrected to 25°C.

	Water level (cm above peat surface)		Mean water level (cm above peat surface)		Soil (peat) temperature (°C)		Anoxic depth height relative to peat (cm)		Bulk density (Db) (g/cm³)	
Sites	1995	1996	1995	1996	1995	1996	1995	1996	1995	1996
Marshes	15.8 ± 2.9	38.1 ± 2.9	16.8 ± 1.6	29.1 ± 1.3	8.4 ± 0.9	10.4 ± 0.9	2.7 ± 1.9	16.9 ± 1.4	0.160 ± 0.007	0.140 ± 0.007
	(24)	(38)	(24)	(38)	(24)	(38)	(24)	(45)	(54)	(48)
LM1	28.0 ± 1.4	44.2 ± 6.1	23.5 ± 0.6	29.9 ± 2.1	6.7 ± 0.9	8.4 ±1.6	10.3 ± 1.7	19.6 ± 2.5	0.131 ± 0.012	0.105 ± 0.003
	(13)	(13)	(13)	(13)	(13)	(13)	(12)	(15)	(27)	(16)
LM2	n.m.	19.3 ± 0.5	n.m.	20.2 ± 0.8	n.m.	10.5 ±1.6	n.m.	16.2 ± 2.8	n.m.	0.187 ± 0.013
		(12)		(12)		(12)		(15)		(16)
RM	1.4 ± 1.2	49.3 ± 0.4	8.8 ± 0.7	36.5 ± 0.3	10.5 ± 1.5	12.2 ± 1.6	-5.0 ± 1.0	14.9 ± 1.8	0.189 ± 0.006	0.127 ± 0.008
	(11)	(13)	(11)	(13)	(11)	(13)	(12)	(15)	(27)	(16)
Fens	8.5 ± 1.6	13.3 ± 0.8	12.5 ± 1.1	15.3 ± 0.6	8.5 ± 0.9	9.5 ± 1.1	-7.8 ± 3.5	1.1 ± 1.3	0.071 ± 0.004	0.064 ± 0.005
	(24)	(26)	(24)	(26)	(24)	(26)	(24)	(30)	(54)	(24)
SF	13.6 ± 1.9	16.9 ± 0.6	15.4 ± 1.5	17.8 ± 0.4	7.4 ± 1.2	8.6 ± 1.7	-2.4 ± 0.9	7.0 ± 1.0	0.097 ± 0.004	0.085 ± 0.006
	(13)	(13)	(13)	(13)	(13)	(13)	(12)	(15)	(27)	(12)
FSF	2.5 ± 1.6	9.6 ± 0.4	9.1 ± 1.0	12.9 ± 0.4	9.9 ± 1.2	10.3 ± 1.5	-13.2 ±6.7	-4.9 ± 1.0	0.045 ± 0.002	0.044 ± 0.003
	(11)	(13)	(11)	(13)	(11)	(13)	(12)	(15)	(27)	(12)
t-test (d.f.)	2.18 (36)	8.12 (42)	2.19 (41)	9.59 (49)	-0.128 (46)	0.649 (62)	2.66 (35)	7.88 (73)	10.05 (82)	8.43 (69)
Probability	0.035	<0.001	0.034	<0.001	0.899	0.519	0.012	<0.001	<0.001	<0.001

Table 2-3: Means ± S.E. and sample size (n) of physical parameters estimated in 1995 and 1996. T-tests were conducted between the groups marshes and fens.

	Marsh			Fen		
Parameter:	mean	(std error)	n	mean	(std error)	n
spring 1995 plant percent carbon	44.56	(0.24)	6	45.15	(0.32)	6
spring 1995 plant percent nitrogen	2.39	(0.14)	6	2.05	(0.19)	6
spring 1995 plant carbon:nitrogen quotient	22.14	(1.23)	6	26.64	(2.14)	6
plant percent carbon at peak biomass 1996	45.24	(0.26)	9	44.99	(0.16)	6
plant percent nitrogen at peak biomass 1996	1.51	(0.05)	9	1.36	(0.04)	6
plant percent phosphorus* at peak biomass 1996	0.174	(0.02)	9	0.127	(0.002)	6
plant carbon:nitrogen quotient at peak biomass 1996	35.34	(1.2)	9	38.69	(1.31)	6
plant nitrogen:phosphorus quotient* at peak biomass 1996	19.89	(1.26)	9	23.9	(1.)	6
peat percent carbon 1st August, 1996	38.16	(1.51)	9	40.98	(1.87)	6
peat percent nitrogen* 1st August, 1996	2.45	(0.1)	9	1.66	(0.22)	6
peat percent phosphorus* 1st August, 1996	0.161	(0.01)	9	0.343	(0.11)	6
peat carbon:nitrogen quotient 1st August, 1996	18.26	(0.64)	9	32.28	(6.25)	6
peat nitrogen:phosphorus quotient* 1st August, 1996	34.05	(1.25)	9	16.82	(4.29)	6
peat percent carbon* pooled monthly samples 1995-96	37.88	(0.54)	113	41.25	(0.5)	88
peat percent nitrogen* pooled monthly samples 1995-96	2.26	(0.03)	113	1.75	(0.03)	88
peat carbon:nitrogen quotient* pooled monthly samples 1995-96	19.77	(0.29)	113	28.65	(0.8)	88

Table 2-4: Percentages of carbon, nitrogen and phosphorus, C:N and N:P quotients for various time periods. Quotients are on a molar basis. * indicates significant ($P<0.05$) differences between marshes and fens for that parameter.

3. Net nutrient mineralization and methane evolution in marshes and fens in the southern boreal region of Alberta, Canada.

Introduction:

Gradients between wetland classes for water chemistry, plant community structure, and hydrology have long been demonstrated and accepted (Mitsch and Gosselink, 1993). Marshes and fens are wetland classes that exist in the boreal forest region and differ in hydrology, species composition, pH, and peat accumulation (National Wetlands Working Group, 1997). Marshes have higher water levels and water level fluctuations, in contrast to fens, which have relatively stable water levels and less fluctuations in the supply of water and minerals (chapter two; Vitt, 1994; Zoltai and Vitt, 1995). The productivity of plant species present in marshes is higher than fens, and the species found in marshes are adapted to higher nutrient supply and fluctuating water levels (National Wetlands Working Group, 1997). Fens usually have a greater diversity of species adapted to nutrient deficient conditions and stable water levels (Zoltai and Vitt, 1995; Bedford *et al.*, 1999). The plant community differences that exist between marshes and fens have been assumed to be related to nutrient availability (Verhoeven *et al.*, 1988). The surface water pH of marshes is circumneutral, while fens have a weakly acidic surface water pH and peat accumulation is higher in fens than marshes. Despite these classification differences between marshes and fens there are common elements between the two classes in the boreal region that include domination by sedge species, influence from ground water, and significant (>40cm) peat deposits (Thormann and Bayley, 1997d).

Wetland systems such as marshes and fens are more "open" than many terrestrial ecosystems, in that water flows can import materials/nutrients, and at the same time export materials/nutrients (Mitsch and Gosselink, 1993). Sources of nutrients in wetlands, therefore, are some combination of nutrients in the water and soil, those deposited from the air, those released from microbes, and those chemically "fixed" (e.g. nitrogen fixation by blue green algae and bacteria) (Bowden, 1987). In general, wetlands are nutrient deficient systems (Bowden, 1987), and northern wetlands are show greater deficiencies than temperate or tropical systems (Jonasson *et al.*, 1993).

Nutrient availability is assumed to be equivalent to and often is measured as nutrient mineralization (Verhoeven, 1986). Mineralization provides the internal supply of nutrients as microbes decompose organically bound elements to liberate their inorganic forms: carbon and nutrients (nitrogen (N) and phosphorus (P)) for energy and growth (Gambrell and Patrick, 1978; Paul and Clark, 1996). Of these three elements the microbial demand is highest for carbon, and often in obtaining carbon during the decomposition process the microbes release excess nitrogen and phosphorus into the environment (Tate, 1994). These nutrients may then be taken up by plants, microbes, and non-biological fixation in the soil (Jonasson *et al.*, 1993).

Net mineralization is the net amount of nitrogen converted via microbial decomposition from organically bound nitrogen to ammonium (Nadelhoffer *et al.*, 1983). Because ammonium may be oxidized to nitrate by nitrifiers, net nitrogen mineralization estimates are obtained by summing the changes in ammonium and nitrate over time (Nadelhoffer *et al.*, 1983), and is assumed to indicate the amount of nutrients available for plant uptake (Brown, 1982). A decrease in concentration of the nutrients measured in the soil extract over time is termed immobilization, and it is assumed that the bacteria or geochemical processes have sequestered the nutrients (Jonasson and Shaver, 1999).

The net effect of organic matter degradation (decomposition) in wetlands is to conserve N and P within the peat while C is respired away (Bowden, 1987). Microbial respiration of carbon results in a carbon dioxide and/ or methane flux from the soil, depending on local moisture and microbial fauna (Moosavi *et al.*, 1996). Flooded environments often result in high fluxes of methane, or high activity of anaerobic bacteria producing methane and low oxidation of that methane at the peat/ water interface (Harriss and Frolking, 1991). Methane is a greenhouse gas of concern due to rising levels in the atmosphere, and wetlands release globally significant levels of methane (Schlesinger, 1991). Few studies have looked at carbon and nutrient relationships in boreal peatlands (Thormann and Bayley, 1997a; Humphrey and Pluth, 1996), despite the central role nutrients play in ecosystem structure and function (Bridgham *et al.*, 1996).

Previous work in this region has shown that nitrogen to phosphorus ratios are below 14:1 in the peak biomass (Thormann, 1995), suggesting that nitrogen is limiting for plant growth (Verhoeven *et al.*, 1996). In addition, increasing net nitrogen mineralization with increasing pH and surface water nutrient supply has been observed (Bayley unpubl.). Similar nitrogen mineralization results were obtained during laboratory incubations of northern Minnesota wetlands along a gradient of pH and alkalinity (Bridgham *et al.*, 1996), suggesting that wetlands with higher pH and surface water nutrient concentrations have higher nitrogen mineralization rates. I have demonstrated that marshes have different species assemblages and higher production, decomposition, plant phosphorus tissue concentrations, peat nutrient concentrations, and surface water nutrient/ ion concentrations than fens (chapter two).

Net nitrogen mineralization rates have been used as a key indicator of the potential biomass production and the driving force behind the differences observed between wetland communities (Tate, 1994; Verhoeven *et al.*, 1988). I hypothesize that the trend detected by Bayley (unpubl.) and Bridgham *et al.* (1996) will hold at the high end of the wetland gradient, and that marshes, with a higher pH and higher external nutrient availability, will have higher net mineralization rates than fens, with lower pH and lower external nutrient availability. Nitrogen mineralization is the sum of two processes, ammonification (the production of ammonia) and nitrification (the production of nitrate). Nitrate is generally not present in significant amounts in wetlands, due to the flooded anoxic conditions (Gambrell and Patrick, 1978). I am expecting that net nitrogen mineralization rates will be dominated by net ammonification in these boreal sites. Summer (June, July and August) is expected to have higher mineralization rates than winter (September, October, and September-June), likely related to the temperature differences (Stanford *et al.*, 1973).

A comparison of methane evolution under uniform conditions should indicate relative levels of anoxic microbial degradation of organic matter to compare to nutrient mineralization rates. Methane emissions in this study were investigated in laboratory incubations to enhance the understanding of the relative turnover rates of organic matter between marshes and fens, given uniform flooding in the cores of all sites. Methane emissions are known to be low in northern peatlands (Gorham, 1991; Mitsch and Gosselink, 1993), but I propose that I will see higher potential methane production in marshes relative to fens, as there are increased nutrients in marshes to support higher decomposer populations.

Study Sites:

This study focussed on 2 fens and 3 marshes, all located in central Alberta, Canada in the boreal ecozone (Rowe, 1972). The 2 fens are located near the town of Perryvale, with the Floating Sedge Fen (FSF) located at 54° 28' N, 113° 19' W and the Sedge Fen (SF) located at 54° 28' N, 113° 18' W. The marshes are between the towns of Clyde and Nestow. The Lakeside Marsh One (LM1) is located north of the town of Clyde at 54° 10' N, 113° 34' W. The Riverine Marsh (RM) is located east of the town of Nestow, along a portion of the river called Helliwell Lake, at 54° 15' N 133° 37' W. The Lakeside Marsh Two (LM2) is located on the south tip of Duggan's Lake, at 54° 12.5' N 133° 25' W. This area is characterized by mild summers and cold, snowy winters, with a long term mean annual temperature of 1.7°C (Thormann and Bayley, 1997a).

Four of the sites were initially chosen in spring 1995, 2 marshes (the LM1 and the RM) and 2 fens (FSF and SF). Analysis of the water chemistry data following the 1995 field season indicated that the RM was more similar to the fens in water nutrient concentrations than to the LM1. In an attempt to improve marsh replication, a third marsh was chosen in 1996, the LM2. The LM1 and both fens were previously studied and classified by Thormann and Bayley (1997a), where additional site and climate descriptions can be found. Detailed species lists are presented in chapter two.

Lacustrine Marsh One

The Lacustrine Marsh One is a sedge dominated wetland on the north end of Wakomao Lake (360 ha), and is the lacustrine marsh of Thormann and Bayley (1997a). Water drains from the north to the south of the lake into the Redwater river. Periodic flooding of the marsh occurs due to heavy spring run off and occasional beaver (*Castor canadensis*) activity at the south end outflow. The marsh is highly productive and may receive secondarily treated wastewater from the town of Clyde (population <1000) in addition to agricultural run off. Average surface water pH over the two years was 7.1, and the peat depth was 1.5- 1.75 m. The dominant vegetation species are *Carex* *utriculata* Boott. and *Typha latifolia* L., with an abundant surface layer of *Lemna minor* L. No moss species were observed at this site.

Lacustrine Marsh Two

Located on the south tip of Duggan's Lake, this marsh is not adjacent to an inflow or outflow. There was considerable evidence of beaver activity through the 1996 field season, as willow and trees upland of the marsh were cut down by late August. The average pH of the surface water over the 1996 field season was 7.6, and the peat depth was approximately 80 cm. The vascular vegetation is dominated by *Typha latifolia* L., *Carex utriculata* Boott, and *Carex aquatilis* Wahlenb.. *Lemna minor* L. is also present. No moss species were observed.

Riverine Marsh

This marsh is similar to the riverine marsh of Thormann and Bayley (1997a) both in vegetation and in water chemistry. The site was chosen in an attempt to decrease extreme water fluctuations caused by beaver activity. The marsh is on the edge of Helliwell Lake, at the headwaters of the Tawatinaw River where it is quite wide (400 m) but with definite flow. Beaver were present nearby, as evidenced by a well-established lodge. In 1995, the water levels in the marsh were quite low, approximately 5 cm above the peat. In 1996, the area was inundated for the entire season at an average of 50 cm above the peat (possibly due to beaver activity downstream). The average pH of the surface water over the two field seasons was 7.8 and the peat depth was approximately 90 cm. The vascular vegetation is dominated by *Typha latifolia* L., *Carex utriculata* Boott, *Carex aquatilis* Wahlenb., with *Polygonum amphibium* L. common. A single moss species (*Drepanocladus aduncus* (Hedw.) Warnst.) was observed in 1995, but not in 1996.

Sedge Fen

The Sedge Fen is part of an extensive wetland complex adjacent to a large lake, and is the same Riverine Sedge Fen described in Thormann and Bayley (1997a). This wetland substrate has a distinct oxidized layer at the surface that is orange-red, while the peat below is brown-black. Analysis of recent water chemistry has demonstrated iron rich ground waters surfacing in this fen (Thormann, unpub.). The average pH of the surface water over the two field seasons was 6.8, and the peat depth was greater than one meter. The vegetation is dominated by *Carex aquatalis* Wahlenb., *Carex utriculata* Boott, and *Carex lasiocarpa* Ehrh., while the moss species are sparsely distributed.

Floating Sedge Fen

The Floating Sedge Fen surrounds a small pond and is a floating peat mat (about 1–1.5m thick) that fluctuates with the water level of the pond. The pond substrate is also composed of peat approximately 1-1.5m in depth. Thormann and Bayley (1997a) and Szumigalski and Bayley (1996) have previously described this wetland. The average pH of the surface water over the two field seasons was 6.1. This site is very species diverse, and has a moss strata dominated by *Sphagnum warnstorfii* Russ. and *Aulacomnium palustre* (Hedw.) Loeske, a herbaceous strata dominated by *Carex lasiocarpa* Ehrh., and a shrub strata of *Salix pedicellaris* Pursh, *Andromeda polifolia* L. and *Oxycoccus quadripetalus* Gilib..

Methods:

Nutrient Mineralization and Extractable Nutrients

Net mineralization rates of nitrogen and phosphorus for the 3 marshes and 2 fens were measured monthly in June, July and August 1995, over winter from September 1995 until June 1996, and monthly in June, July, August, September and October 1996. One transect was set up at each site in an area dominated by *Carex* species, with 5 stakes representing 5 sampling stations 1-2m apart. After the initial sample was collected along the transect, cores were taken non-randomly adjacent to the last core in an effort to decrease variability between sequential samples.

Field procedures

Incubation procedure followed the buried bag technique of Eno (1960). Peat cores were taken with a 15cm diameter stovepipe sheet metal corer to approximately the 10cm depth. Cores were removed, cut to 10 cm and placed in large polyethylene

(Ziploc™) bags for transport to the lab. The cores were transported on ice and held at 4°C until processed. All cores were processed the day they were extracted from the field. In the lab, cores were cut in two sections of depth, a 0-4 cm depth and a 4-10 cm depth. Each of these depth sections was then cut in half vertically, one half provided an initial sample and the other half was returned to the field for incubation in the original hole it was collected from. The initial sample was weighed and stored in the freezer at -10 °C until laboratory extraction. The incubated sample remained in the field between 28-32 days, then was collected and frozen at -10 °C until laboratory extraction.

Laboratory procedures

Cores were extracted for ammonia/ammonium, nitrate and acid soluble phosphorus using approximately 10g (wet weight) of sample (initially 20g of sample was used in the fen sites). Ammonia/ ammonium samples were extracted using 100 mL of 1 N KCl. Nitrate was extracted using 100 mL of distilled deionized water (DDW), as previous work (Bayley, unpub.) demonstrated contamination using reagent grade chemicals to extract nitrate. Phosphorus samples were extracted using 100 mL 0.03 N NH_4F/ 0.03 N H_2SO4 following Alberta Provincial Laboratory procedures, based on Bray and Kurtz (1945). Nitrate samples were filtered using a 0.45 μm HAWP millipore filter, while ammonium samples were not filtered. Both nitrate and ammonium were analyzed on a Technicon Auto Analyser II. Extracted phosphorus was analyzed in the same manner as soluble reactive phosphorus, according to Menzel and Corwin (1965).

Concentrations of nutrients extracted from the initial samples (on a dry weight basis) were reported as extractable nutrients, while differences between initial extractable and final extractable nutrients (after approx. 30 days) divided by the number of days incubated were the net mineralization rates. Both the extractable nutrients and the calculated mineralization rates were weighted by depth (for 0-4 cm layer the extractable concentration/ mineralization rate was multiplied by 0.4, and 4-10 layer extractable concentration/ mineralization rate was multiplied by 0.6) to give a depth integrated extractable concentration/ mineralization rate. This was done to give a more accurate picture of extractable concentration and nitrogen turnover relative to the whole core and facilitate comparisons of nitrogen release between wetland classes.

At the same time as nutrient extraction, each peat sample was also subsampled for total carbon (%C) and total nitrogen (%N). The subsample was dried at 48°C and was ground using a electric hand grinder and analyzed for total nitrogen (TN) and total carbon (TC) using a Control Equipment Corporation 440 element analyzer. Total phosphorus (TP) was analyzed on three dried and ground samples from the August 1996 set of cores using a persulfate oxidation digestion following Menzel and Corwin (1965), with modifications as outlined in Prepas and Rigler (1982). The nutrients were expressed as % carbon (%C) and % nitrogen (%N) of total dry weight. TP was expressed as μg/g dry weight and converted to % phosphorus (%P). Once again the results for the samples were weighted by depth (for 0-4 cm layer the peat concentration was multiplied by 0.4, and 4-10 layer peat concentration was multiplied by 0.6) to give a depth integrated peat concentration.

Environmental factors

Water chemistry data

Water chemistry samples were taken bimonthly from May until October of each year. Samples were taken from the same point each time, except for two samples in May at the LM1, where extreme water levels prevented entry to the wetland. Collection was made in acid washed 1 L Nalgene and 75 mL polypropylene bottles, and stored on ice. Field measurements of pH were made using a Fisher Accumet 925 pH meter.

Laboratory analysis estimated the water chemistry parameters nitrate (NO_3^- and NO_2^-), ammonium (NH_4^+), soluble reactive phosphorus (SRP), total phosphorus (TP), chloride (Cl^-), sulfate (SO_4^{2-}), sodium (Na^+), alkalinity (total), and conductivity. Nitrate samples were filtered using a 0.45 μm HAWP millipore filter, while ammonium samples were not filtered. Both nitrate and ammonium were analyzed on a Technicon Auto Analyser II. SRP was analyzed using the methods of Menzel and Corwin (1965). TP was analyzed using the Bierhuizen and Prepas (1985) persulfate method following digestion and measured spectrophoto-metrically *as per* APHA (1992). Water samples analyzed for anions (Cl^- and SO_4^-) were initially filtered with a GFC filter and then analyzed on a Dionex Series 2000 i/sp with a conductivity detector and a AS4A-SC ion pac 4mm column. Water samples analyzed for Na^+ were initially filtered with GFC filters, fixed with 0.5 mL concentrated H NO_3 and then analyzed with a Perkin-Elmer Atomic Absorption Spectrometer. Conductivity was measured with a CDM 83 Bach-Simpson radiometer within 24 hours and corrected for temperature. Analysis of alkalinity was conducted using a Mettler DL21 Titrator with a Mettler ST20 sample changer following APHA (1992).

Water chemistry results (analyzed as previously described) were used to calculate the quotient of nitrogen to phosphorus in the surface waters of the wetlands. Ammonium (NH_4^+) and nitrate (NO_3^- and NO_2^-) concentrations were converted to molar amounts, summed, and this value was divided by the molar amount of soluble reactive phosphorus (SRP) to obtain the N:P quotient for each sample. Other water chemistry parameters measured are presented in chapter two.

Decomposition

Decomposition methods follow Thormann and Bayley (1997a), using 3x6 cm mesh bags, 1-mm mesh gauge. To compare with mineralization, dominant plant litter from each site was collected in early June 1995, dried at 60°C and 1-2 grams was placed in each bag. Bags were put out at the beginning of each mineralization incubation, and retrieved after an average of 30 days (ranging from 28-31 days), resulting in monthly mass loss rates. The LM2 was added as a site in 1996 and no spring plant material was collected for decomposition bags. The RM plant litter was then used in the LM2 as it has similar dominant vegetation. Dried sub-samples were then ground and analyzed for total carbon and total nitrogen using Control Equipment Corporation 440 Element Analyzer, as with the peat samples.

Potential Methane Production

Nitrogen mineralization was the main focus of this study, with net phosphorus mineralization rates investigated at the same time. Carbon dynamics are inferred in this study from potential methane production. Had the study been primarily focussed on carbon and methane dynamics, methane and carbon dioxide would have been measured *in situ* with techniques similar to Roulet *et al.* (1992).

Potential methane production estimates for the 3 marshes and 2 fens were measured monthly for June, July, August, September and October 1996. Potential methane production provides an estimate of the occurrence of methanogenesis in these sites, and is useful to compare these sites relative to each other. Peat cores for estimating methane production were taken at the midpoint of the mineralization transect, on the opposite side from the mineralization coring. Cores were taken within 10cm of each other, to reduce peat compaction but at the same time minimize variation between replicate cores.

Field procedures

To estimate methane production two (three in October) 7.5cm diameter cores 10-17cm in length were taken from each site. Cores were stored in Ziploc® bag and filled to the top with water from the core site. A 20L carboy was filled with surface water from the site, and attempts made to keep out dead litter and solid particles. Cores were transported to the lab on ice and kept at 4°C until placed into gas tight incubation chambers.

Laboratory procedures

Potential methane production was measured in gas tight, glass incubation chambers following Seitzinger (1993). Briefly, cores were placed in air tight glass chambers. Water collected from the site was sparged with a mixture of 21 % O_2 and balance (79%) He, and siphoned into the chambers. The atmosphere of the chambers was replaced with the same mixture of 21 % O_2 and balance He. This procedure was repeated every 48 hours. Gas chromatography (GC) analysis of samples of the overlying gas phase was conducted using a molecular sieve 5A, 2 m x 0.318 o.d. stainless steel with 45/60 mesh column on a HP5890 Series II chromatograph. Initial gas phase analysis occurred on day 4 at 4 hours after the time of water and gas changes (time 0) and at 48 hours, and was repeated every 48 hours for the remainder of the incubation period. Differences between initial and final concentrations of methane were divided by the time between sampling to calculate a daily rate. Experiments were conducted for 14 days at the average soil temperature of the five sites at the time of sampling; measurements from incubations starting the sixth day onward were considered reliable estimates of methane production.

Statistical Procedures:

Wetland classes were analyzed for differences in the various parameters using t-tests in SPSS ver. 7.5 for Windows. T-tests were considered appropriate as there were only two classes (marshes and fens), and the t-tests will give the same results as a single factor ANOVA under these conditions (Zar, 1984). While the data sets all revealed positive kurtosis and some skewness, the t-test is considered robust and the power of this test under these conditions is greater than implied by the stated alpha ($\propto$) (Zar, 1984). Non-parametric tests and multifactor ANOVA (GLM) designs in SAS (1988) were conducted to enhance understanding of the contribution of factors such as year, depth, season, class and site. Correlations were conducted in SPSS to look for relationships within the major factors (nitrogen and phosphorus mineralization, potential methane production, and extractable nutrients). Regressions in SPSS were conducted between major factors; water chemistry variables, soil parameters (presented in chapter two), and climatic data.

Results:

Nitrogen Mineralization

As suspected, net nitrification rates did not significantly contribute to net mineralization rates, and in fact did not differ from zero. Hence net mineralization rates presented for these wetlands are equivalent to net ammonification rates. Monthly net mineralization rates in all sites were higher in the summer months of June, July, and August than in September, October or September to June 1995 (Overwinter) (GLM, $F=2.14$, $Pr<F=0.0003$). While considerable variation exists between months, years and sites (Figure 3-1), in general monthly net mineralization rates were higher in marshes than in fens ($t_{stat}=1.64$, $P_{T\leq t}=0.05$, d.f.=184). In 1995, marshes had higher net mineralization rates than fens, while in 1996 the marshes had higher net mineralization than fens except in July and August (Figure 3-1). When yearly amounts of nitrogen mineralized (calculated from summed, weighted monthly rates) were compared between

the wetland classes, the differences were not significant ($P_{T\leq t}$=0.38), although marshes did have a slightly higher amount of nitrogen mineralized per year than fens. Yearly nitrogen mineralization rates for marshes and the SF showed little variation between years, while the FSF more than doubled between 1995 and 1996 (Figure 3-3a).

To assess the significance of environmental factors on net nitrogen mineralization, regressions between monthly net nitrogen mineralization rates and the environmental factors measured in this study were conducted. The resulting equation explained 64% of the variation in daily nitrogen mineralization rates, using the following variables: the initial percent carbon of the peat before mineralization incubation, the maximum daily air temperature, extractable nitrate (NO_3^-) of the peat, surface water N:P quotient (NH_4^++NO_3^-:SRP), and surface water total sulfate concentration (SO_4^{2-}) (Table 3-1). The factors with the strongest determining influence on net nitrogen mineralization were the extractable nitrate of the peat, the surface water total sulfate concentration (positive associations), and the initial percent carbon of the peat before mineralization incubation (negative association). The maximum daily air temperature was a less influential factor that showed a positive association with nitrogen mineralization. Surface water N:P quotient was a weak but significant factor in the regression equation, with a negative association to nitrogen mineralization rates.

As is difficult to assess the causality of the above factors, correlations were also run to look for significant relationships. Monthly net nitrogen mineralization was significantly correlated with surface water concentrations of total phosphorus (R_s^2=0.405) and soluble reactive phosphorus (R_s^2=0.342). Significant correlations were also detected for the percent carbon remaining in plant litter from the decomposition 30-day incubation (R_s^2=0.383), maximum daily temperature (R_s^2=0.468), and the extractable nitrate concentrations of the peat (R_s^2=0.338), although none of the correlations are particularly strong. Averages for the significant peat and environmental factors are presented in Table 3-2, while climate data including maximum daily temperature are presented in Table 3-3.

Phosphorus Mineralization

Marshes had very little phosphorus mineralization, and only the RM (August 1995) and the LM1 (June and August 1996) exhibited noticeable phosphorus release (Figure 3-2, Figure 3-3b). The fens had variable results, with both high rates of mineralization and immobilization (Figure 3-2). In 1995, the FSF had no or little mineralization, while the SF had some phosphorus mineralization over winter. In 1996, both fens had greater phosphorus mineralization, with the FSF having low rates with net mineralization overall and the SF having extremely variable results, with net immobilization overall (Figure 3-3b). A weak but significant relationship was detected between phosphorus mineralization and the percent carbon remaining in plant litter from the decomposition 30-day incubation (Table 3-1, values for decomposition Table 3-2). Significant correlations were detected for both the initial and final percent carbon of the peat before/after mineralization incubation (R_s^2=0.327, 0.357) as well as pH (R_s^2=-0.355).

Potential Methane Production

Potential methane production did not differ between marshes and fens, however the LM1 did have significantly higher methane production than the other sites (F = 13.5, Prob. <0.001, followed by Tukey's HSD). Peak rates were observed in June, July, August, and September at different sites, and emissions had virtually ceased by October (Figure 3-4). The timing of peak rates differed in marshes and fens, as the fens had peak rates in June (SF) and July (FSF), while rates for the lacustrine marshes peaked in August and September. The riverine marsh is similar to the fens in that the peak methane evolution occurred in June and July, and the magnitude of peak rates for this site are more similar to the fens, with the exception of the FSF in July. A backward regression equation for methane evolution demonstrated significant relationships to the pH of the surface waters, initial percent nitrogen of the peat, surface water nitrate concentrations, the daily maximum temperature for the month, the water level above the peat surface, surface water sodium concentrations, surface water alkalinity concentrations, and surface water soluble reactive phosphorus in order of decreasing strength (Table 3-1). Due to the inherent difficulties with assessing the causality of the above factors, correlations were also run to look for significant relationships. Methane flux was significantly correlated with chloride concentrations in the surface water (R_p^2=0.489), the mean daily temperature (R_s^2=0.557), and the percent carbon remaining in plant litter from the decomposition 30-day incubation (R_s^2=0.402), although none of the correlations are particularly strong. Averages for the significant peat and environmental factors are presented in Table 3-2.

Extractable Nutrients in Peat

Extractable nutrients in general did not show a consistent pattern across wetland classes (Table 3-4). Extractable phosphorus was the only parameter that was significantly different between wetland classes, and it was higher in fens than in marshes (Table 3-4). Extractable ammonium was also significantly higher in fens than in marshes, although values for marsh and fen sites do overlap (Table 3-4). Extractable nitrate concentrations were very low, and were similar between marshes and fens (ranging between 1.03-1.88 μg/g dry material), with marshes having slightly higher extractable nitrate concentrations (Table 3-4). The ratio of extractable nitrogen (ammonium + nitrate) to phosphorus was not significantly different in fens and marshes (Table 3-4). High variation in extractable N:P quotients was evident in the fens and in all sites over winter. In general, extractable nutrients decreased by approximately 50% between the 0-4 cm depth and the 4-10 cm depth, with the exception of fen nitrate values and SF extractable P values, which remained constant (data not shown).

Discussion:

Nitrogen Mineralization

The yearly average nitrogen mineralization rates for my sites are low compared with previous work in this region (Bayley, unpubl.) and other western Canadian estimates (Humphrey and Pluth, 1996; Neill, 1995) (Table 3-5). The values from this study most closely agree with the net nitrogen mineralization rate from moist tundra in subarctic Alaska (Hart and Gunther, 1989; Giblin *et al.*, 1991). Correlation of the growing degree days above 5°C (GDD) and net nitrogen mineralization for the years of this study (1995-96) and those of Bayley (unpubl.) (1990-91) suggest that GDD could be a factor in the differences between net nitrogen mineralization values between the studies (Figure 3-5).

However, caution should be exercised in interpreting this correlation, as there are no data points available in the middle range of GDD values at this time.

Daily net nitrogen mineralization rates were significantly different between marshes and fens, where marshes had greater mineralization on average than the fens. Summed over the two seasons, these differences were not statistically significant as fens showed greater mineralization than marshes in June and in samples incubated over winter. Spring release rates of nitrogen were not directly measured, but interpolation of the rates that were measured points to a large spring release from the fens. I saw little mineralization or immobilization during September and October in the fens, and during the winter the peat surface was frozen solid, so mineralization rates should be zero until thaw. Therefore the bulk of measured over winter (September to October 1995) mineralization I observed in the fens should occur during early spring.

Over winter mineralization rates have been measured in subarctic wet sedge tundra, where net mineralization was only observed in the autumn, winter, and early spring and with net immobilization during the summer (Giblin *et al.*, 1991). The net release over winter in the subarctic is hypothesized to be from the decline of the microbial population (Giblin *et al.*, 1991, Jonasson and Shaver, 1999). In my sites coring was not initiated until after the peat thaw depth was greater than 10 cm at all sites, and I probably missed a spring pulse of nutrients following the thawing of microbial cells frozen over the winter. In addition, the fens thawed faster than the marshes during May of both years, presumably due to the higher amounts of ground water flow (thaw data not shown).

Fen plants would therefore depend on a shorter time frame (from early spring to August) and generally lower release rates of nitrogen available for plant uptake, potentially having to uptake nutrients immediately as the soil thaws (Jonasson and Shaver, 1999). In contrast, the marsh plants had higher average nitrogen release rates for plant uptake during the study time frame and mineralization continued into the fall. This would extend nitrogen production by microbes for plants by 30-60 days (June to September/October). Less over winter accumulation of nitrogen and slower thaw times were measured in marshes, so presumably less of a spring nutrient pulse was missed in marsh sites during this study.

Phosphorus Mineralization

Net phosphorus mineralization rates suggest that phosphorus is conserved in these wetlands, with low P mineralization rates and often P immobilization. The C:N:P molar nutrient ratios contained within the plant tissue and peat in these wetlands also suggest that phosphorus is conserved. Phosphorus will be released if the C:P molar ratio is less than 200:1 (Paul and Clark, 1996). In this study the C:P ratios were considerably higher than the threshold for P mineralization, with the plant tissue C:N:P at 703:20:1 for marshes and 925:24:1 for fens (from averages presented in chapter two), and the peat C:N:P at 619:15:1 for marshes and 587:8:1 for fens (Table 3-2). The C:N:P molar ratio for soil bacteria averages 31:5:1, indicating that in these wetlands the soil bacteria are extremely limited by phosphorus compared to either C or N (Paul and Clark, 1996), which should lead to immobilization of phosphorus, as was generally observed over the course of this study.

The variability observed in phosphorus mineralization the SF could not be linked to water table fluctuations, water chemistry differences or any other parameters. This variability may be related to the extraction technique, which was a dilute acid fluoride extraction. Bray and Kurtz (1945) maintain that the acid extractions are withdrawing easily soluble forms of phosphorus, not adsorbed (chemically bound) forms. However where adsorbed forms are present in high amounts, the acid extraction will extract some amount of adsorbed phosphorus (proportional to the total amount adsorbed) (Bray and Kurtz, 1945). Total phosphorus content of the peat of the SF was much higher than the amount found in other sites (data not presented), indicating some of the variation in the results from this site may be due to high amounts of adsorbed phosphorus.

Recent work in this fen has revealed high iron concentrations (Thormann, pers. comm.), supporting a hypothesis of phosphorus bound in iron complexes (Bridgham *et al.*, 1996). However, this explanation does not account for the variation seen between 1995 and 1996, and no further explanation could be discerned. A significant, although weak negative correlation between net phosphorus mineralization and pH may be a factor of the above variability, as pH was lower in the SF than the marshes (Table 3-2). The significant, although again weak correlations with both initial and final carbon concentrations of the peat and a weak regression equation with the final percent carbon of the plant litter after 30 days of decomposition may relate to carbon substrate limitations of the microbes decomposing the peat/litter as discussed above. Verhoeven et al. (1990) also found only a small percentage of the variation in phosphorus mineralization could be explained by regression of measured factors.

Relationship of Environmental Factors and Nitrogen Mineralization

Nitrogen mineralization was well explained by the measured environmental factors (R^2=0.638, Table 3-1). Extractable nitrate was the strongest factor of the regression equation and was also significantly correlated with monthly net nitrogen mineralization, which is probably related to the higher rates of mineralization supporting a higher amount of nitrate through nitrification. The importance of the substrate factors (initial percent carbon of the peat before mineralization incubation) in the regression equation for net nitrogen mineralization may reflect the importance of substrate quality and the ease of decomposition. Daily net nitrogen mineralization rates were higher in marshes than in fens, and I know that the productivity was higher in marshes (chapter two), which results in a decrease in structural material (Auclaire, 1977). This in turn should lead to a carbon source that is more susceptible to decomposition in marshes in contrast to fens.

Maximum daily air temperature was also a factor in of the regression equation, and the temperature sensitivity of mineralization has long been documented (Stanford, 1973). The inclusion of the N:P quotient of the surface water in the regression equation and correlation with concentrations of TP and SRP of the surface water may relate to the demand for phosphorus relative to nitrogen as discussed above. As already discussed, C:N:P ratios are very high for these sites, so external sources of phosphorus such as TP and SRP in the surface water may be a supply source for microbes (and plants), promoting higher nitrogen mineralization where surface water TP is high, i.e. primarily in the marshes. The high affinity of *Carex* plants for phosphate (Atwell *et al.*, 1980) and the efficient rapid uptake of phosphorus by microbes under ambient loadings (Walbridge and Struthers, 1993) support this suggestion. Phosphorus content of litter and soil has been recognized as a control of nitrogen mineralization rates in terrestrial systems (Pastor *et al.*, 1984) and appears to be an influence in these boreal wetlands.

Potential Methane Production

The relative magnitude of potential methane production is within the ranges reported in fens and marshes from both lab and field studies (Table 3-6). Potential methane production estimates are higher than actual measurements from Vitt *et al.* (1990) and eastern Canada (Table 3-6), which may be related to the laboratory technique as compared to field collection techniques (Vitt *et al.*, 1990). My results are likely over estimates as the laboratory method used in this study maintained the cores in a flooded condition, which would increase the potential anoxic area. This is contrary to the natural conditions of the FSF in particular, where the water level is always at or below the peat surface. In addition the temperature was held constant (as the average daily soil temperature for all sites on that day) over the incubation period, preventing daily temperature fluctuations above or below the mid-day average. These factors may have increased the observed production in the lab compared to the field.

A large portion (77%) of the variation in methane rates was explained by regression of environmental and peat parameters. Whiting and Chanton (1993) suggest that substrate availability has a fundamental role in methane emission rates. I also found substrate availability/ quality as represented by the substrate parameters initial percent nitrogen in the regression equation and litter mass loss (decomposition rate) correlated to potential methane production. Surface water parameters (pH, sodium, nitrate, alkalinity, and SRP) were positively and negatively related to potential methane production, resulting in a moderation of the strongest factor, pH. The high influence of pH is likely related to the higher pH values found in marshes vs. fens, as marshes had a slightly higher methane production compared to fens (Table 3-6). The correlation between potential methane production and surface water chloride concentrations, while weak, could relate to the different hydrology associated with marshes and fens. Increased potential methane production, increased chloride and increased influence of surface water run off supplied to marshes contrasts with the lower potential flux of methane from these fens, their lower chloride levels and increased dependence on groundwater. Further support comes from earlier work that found cation concentrations in the surface water were correlated with methane flux (Vitt *et al.*, 1990).

Methane dynamics from this study indicate that anoxic decomposition and turnover of plant material were slightly faster in the marshes than in the fens, particularly in the LM1. Recent work has demonstrated that sedge biomass is a strong component of methane flux, where stems act as a conduit for methane to the atmosphere (Whiting and Chanton, 1993; Bellisario *et al.*, 1999). This could explain the remaining variation in potential rates observed in this study, as the sedge stems were sometimes present in the cores. The large sedge species of the marshes have a larger stem diameter than the sedges of the fens, presumably leading to a higher rate of methane flux.

Role of Extractable Nutrients

Verhoeven (1986) suggests that extractable nutrient concentrations offer some indication of the amount of nutrients available to plants from the peat at a given moment. Extractable nutrients exhibited similar patterns to Verhoeven *et al.* (1990), those of decreasing concentration with depth. Extractable nitrogen concentrations were similar to Verhoeven and Arts (1987) and Verhoeven *et al.* (1988), while extractable phosphorus was an order of magnitude greater than reported in these studies, undoubtedly due to the more vigorous extraction used in this study. Waughman (1980) and Verhoeven *et al.* (1988) previously reported higher extractable nutrient concentrations in ombrotrophic relative to minerotrophic systems, and suggested as an explanation that plants in acidic environments have a limited nutrient uptake ability (Verhoeven *et al.*, 1988). Our findings offer support for the theory that lower pH can result in higher extractable nutrients present in a nutrient limited system, as higher peat extractable P and N concentrations were observed in the fens relative to marshes. This is in contrast to tissue analysis of the plant peak biomass, which demonstrated significantly lower P and N concentrations in the plant material of fens relative to marshes indicating increased nutrient limitation in fens (chapter two) (Verhoeven *et al.*, 1996).

Conclusions

Yearly net nitrogen mineralization rates were low compared to other studies, ranging between 2.6 and 9.3 kg N/ha/yr. These lower rates may be related to differences in growing degree days above 5°C, as 1995 and 1996 had fewer GDD than a previous study. Daily average net nitrogen mineralization rates were higher in marshes than in fens, which combined with higher potential methane production in marshes suggests that marshes have a higher average turnover rate of organic matter than fens. No differences were observed between the wetland classes in the annual amounts of nitrogen mineralized, suggesting the plant community differences between the wetlands were not related to the overall amounts of nitrogen mineralized, but could be related to differences in the timing of mineralization. The regression equations suggest that substrate quality factors and surface water chemistry concentrations interact to moderate net nitrogen mineralization and potential methane production. Phosphorus mineralization rates and the net nitrogen mineralization regression equation suggest that phosphorus is conserved within these wetlands.

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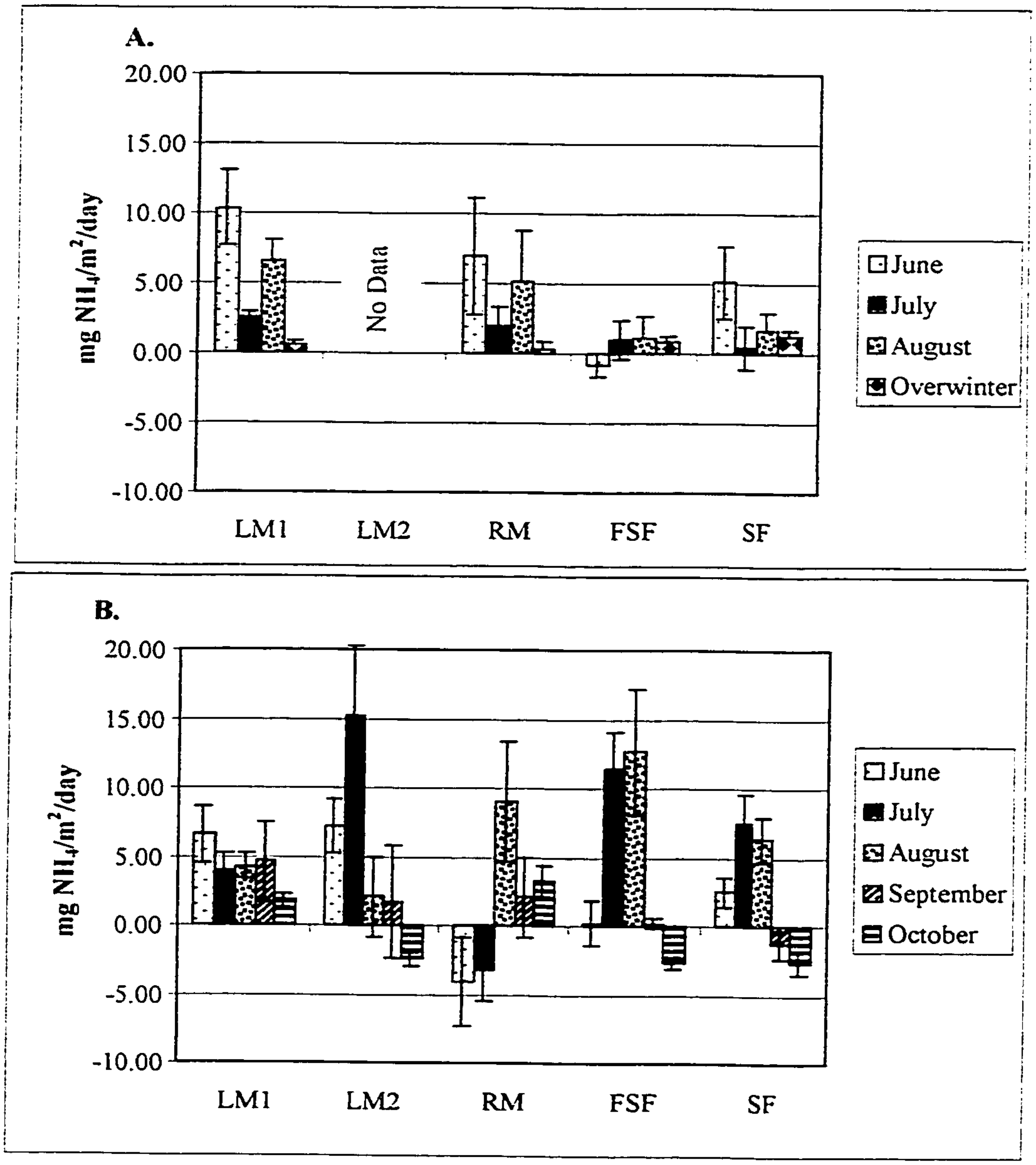


Figure 3-1: Average daily net nitrogen mineralization rates (0-10 cm) by month for 1995 (A) and 1996 (B).

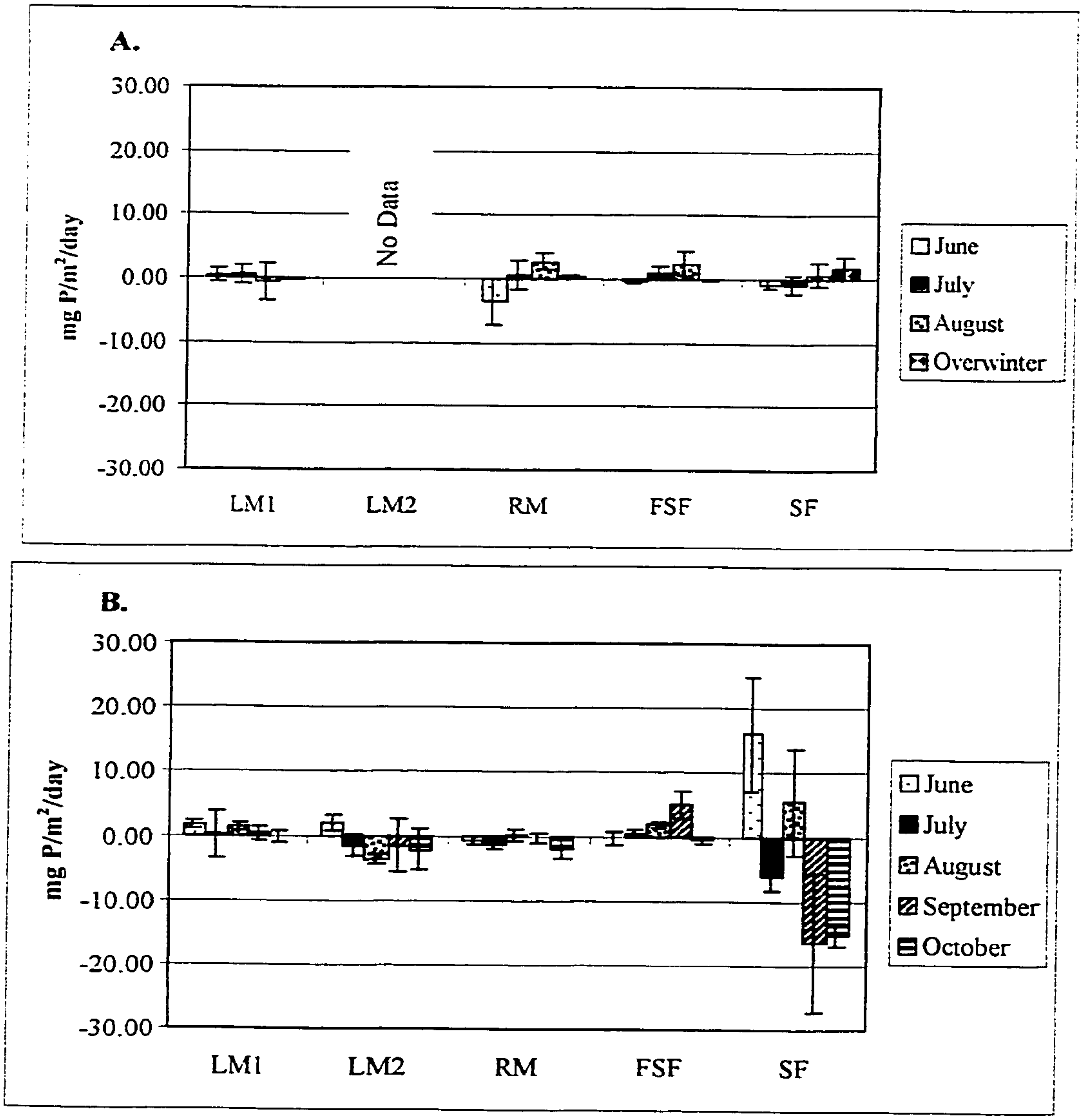
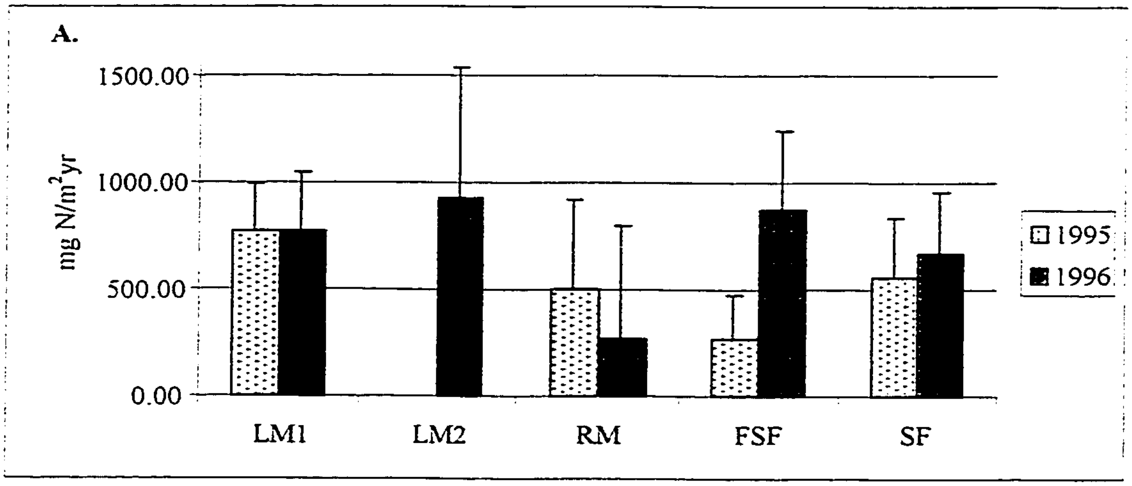


Figure 3-2: Average daily net phosphorus mineralization rates (0-10 cm) by month for 1995 (A) and 1996 (B).



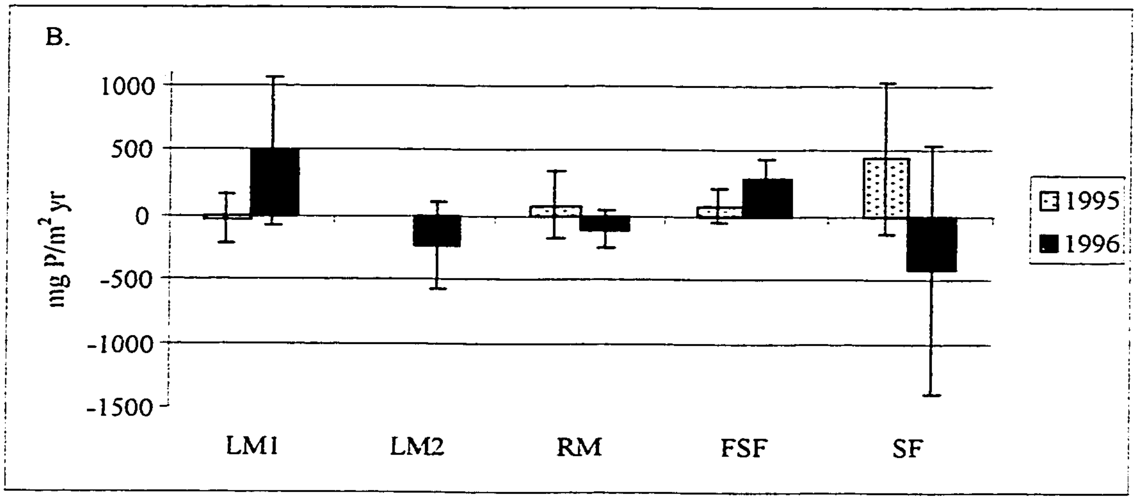


Figure 3-3: Yearly A. Nitrogen and B. Phosphorus net mineralization rates by site for 1995 and 1996. Values are based on weighted monthly averages, 1996 rates include an estimated winter value based on 218 days of winter mineralization at 1995 rates, LM2 winter value is based on an average of LM1 and RM values.

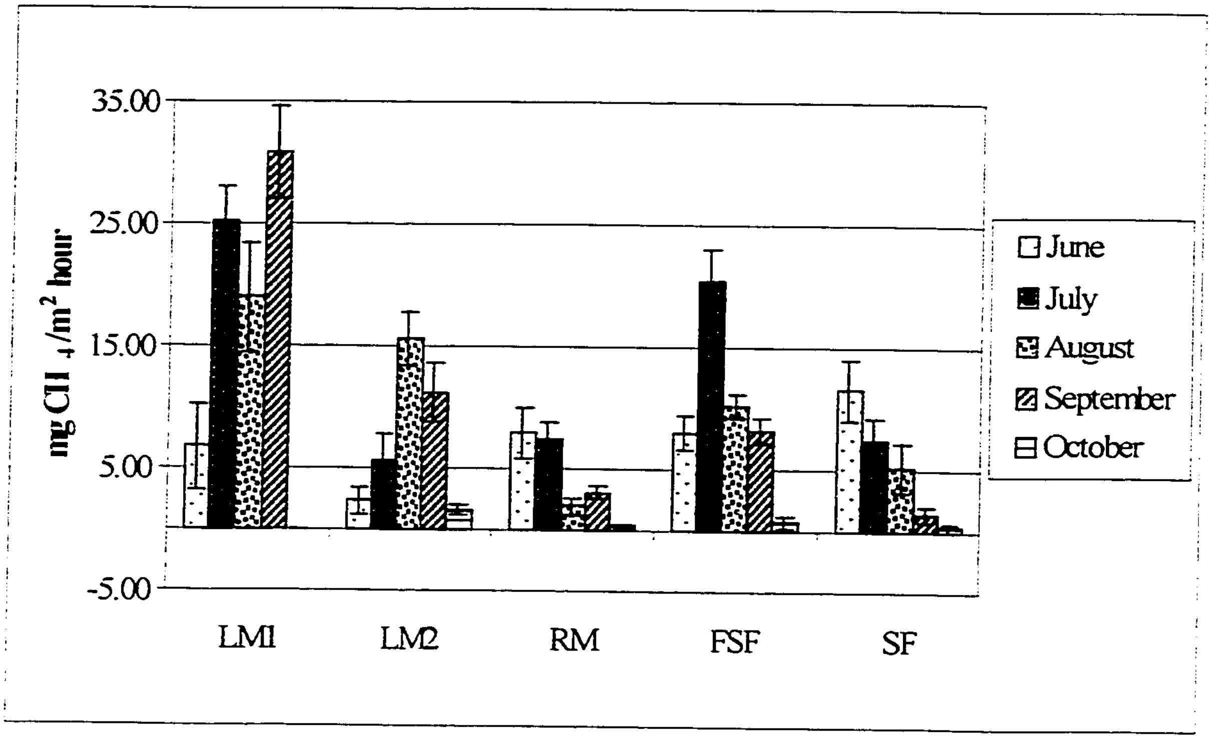


Figure 3-4: Average monthly methane evolution rates for June-October, 1996.

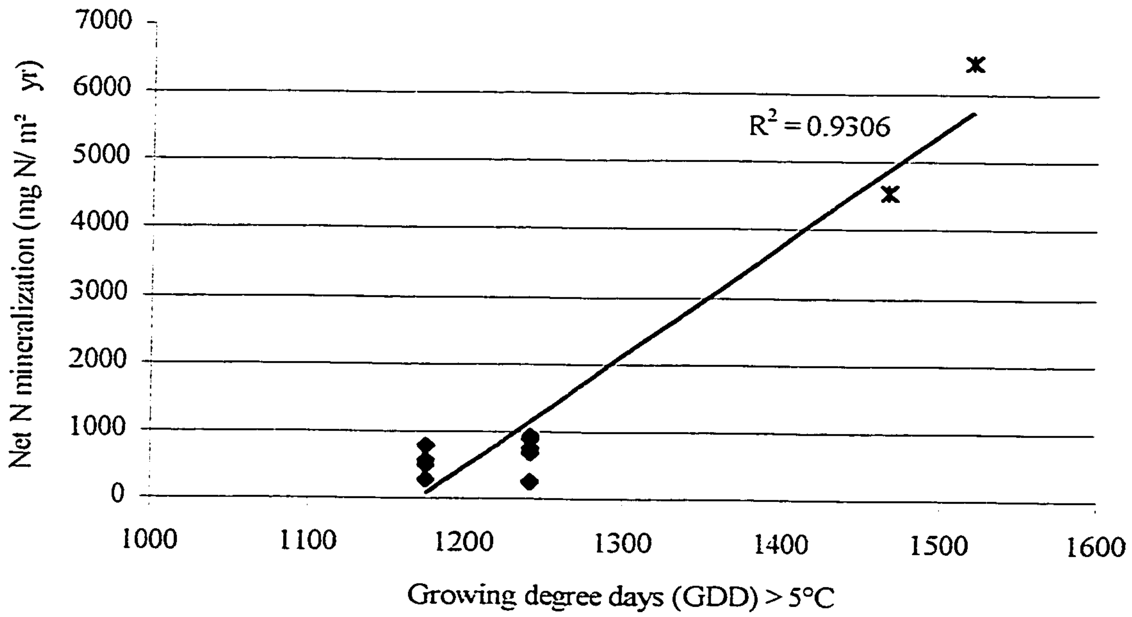


Figure 3-5: Yearly net N mineralization rates from this study and Bayley (unpubl.) graphed against growing degree days (GDD) > 5°C. ◆ indicates values from this study, while * indicates values from Bayley (unpubl.).

Nitrogen mineralization	
Equation	$y= 21.297-0.611(I\%CP)+3.3(ENO_3^-)-0.0405(WN:P)+0.653(SO_4^{2-})+0.29(temp)$
	$R^2=0.638$ F-value=6.346 Prob>F= 0.001
	where I%CP is the initial percent carbon of the peat after 30 days, ENO_3^- is the extractable nitrate concentration of the peat, WN:P is the N:P quotient of the surface water, SO_4^{2-} is the sulfate concentration in the surface water, and temp is the maximum daily temperature for that month.
Phophorus mineralization	
Equation	$y= -61.55+1.289(F\%CL)$
	$R^2=0.114$ F-value=4.496 Prob>F= 0.041
	where F%CL is the final percent carbon of the plant litter after 30 days of decomposition
Potential methane production	
Equation	$y= -65.837-0.226(alk)+1.205(Na^+)+18.6677(pH)+0.111(SRP)-6.971(NO_3^-)+1.554(temp)-1.239(WL)-18.186(I\%NP)$
	$R^2=0.773$ F-value=6.395 Prob>F= 0.001
	Where alk is the alkalinity of the surface water, Na^+ is the sodium concentration in the surface water, pH is the field surface water pH, SRP is the soluble reactive phosphorus concentration in the surface water, and NO_3^- is the nitrate concentration in the surface water. Temp is the maximum daily temperature for that month, WL is the water level at the time of sampling, I%NP is the initial percent nitrogen of the peat after 30 days.

Table 3-1: Backward stepwise regression equations for average daily net nitrogen and phosphorus mineralization rate and average potential methane production rates. Surface water SRP and NO_3^- are in µg/L, Alkalinity, SO_4^{2-}, and Na^+ are in mg/L, quotients are on a molar basis, pH is corrected for temperature, and temperature is in °C, water level is in cm above the peat surface.

Parameter:		Regression abbreviation	Marsh mean	(std error)	n	Fen mean	(std error)	n
Peat	Initial % C*	(I%CP)	34.92	0.55	115	43.06	0.39	89
	Initial % N*	(I%NP)	2.28	0.04	115	1.88	0.03	89
	Initial C:N*		17.91	0.16	115	27.69	0.69	89
	C:N:P		619:15:1		9	587:8:1		6
	Final % C*		34.55	0.58	115	43.22	0.43	90
	Final % N*		2.29	0.04	115	1.96	0.03	90
	Final C:N*		17.65	0.17	115	27.21	0.62	90
Decomposition of plant litter	Proportion of mass loss after 30 days*		0.517	0.010	135	0.422	0.012	108
	% C remaining after 30 days	(F%CL)	47.63	0.15	134	47.27	0.14	107
	% N remaining after 30 days*		2.51	0.04	134	1.82	0.03	107
Surface water	pH*	(pH)	7.19	0.14	62	6.23	0.13	50
(mg/L)	Chloride*		33.2	2.9	62	0.8	0.1	46
(mg/L)	Sulfate*	(SO_4^-)	29.4	2.4	62	0.35	0.07	35
(mg/L)	Sodium*	(Na^+)	50.3	2.8	62	2.37	0.12	49
(mg/L)	Alkalinity*	(alk)	195.9	7.1	62	53.1	4.7	49
(μS)	Conductivity*		512.2	15.1	57	11.8	9.2	46
(μg/L)	Ammonium*		174.1	39.0	62	11.5	1.5	44
(μg/L)	Nitrate*	(NO_3^-)	15.0	3.5	65	7.42	1.27	49
(μg/L)	Soluble reactive phosphorus*	(SRP)	115.1	24.0	62	10.6	2.2	50
(μg/L)	Total phosphorus*		388	36	65	98.8	12.5	50
(μg/L)	N:P*	(WN:P)	38.9	8.6	58	12.4	1.9	43

Table 3-2: Summary table of the environmental and peat nutrient parameters (some presented in chapter 1), with the quotients on a molar basis. WN:P is ammonium + nitrate: soluble reactive phosphorus, and * indicates significant differences (t-test) between marshes and fens.

ATHABASCA 2	Maximum temperature (°C)	Mean temperature (°C)	Total precipitation (mm)
1995 May	18.16	11.17	28.80
June	21.55	15.09	132.90
July	20.73	15.34	83.80
August	17.98	12.51	120.40
Yearly average	6.82	1.36	553.80
1996 May	11.39	6.42	51.90
June	18.92	12.90	104.90
July	21.11	15.22	84.50
August	21.53	15.30	90.90
September	12.37	7.96	86.40
October	7.03	2.16	17.70
Yearly average	4.60	-0.78	614.50

Table 3-3: Average monthly and yearly temperatures and precipitation values for 1995 and 1996 from the Athabasca 2 weather station.

Sites		Number of Observations	Extractable Ammonium mean	stderr	Extractable Nitrate mean	stderr	Extractable Phosphorus mean	stderr	Extractable N:P mean	stderr
Marshes		111	83.64	3.65	1.46	0.09	77.30	4.04	1.66	0.36
	LM1	44	64.89	3.28	1.73	0.13	76.20	7.15	1.11	0.09
	LM2	24	84.04	8.59	1.10	0.13	86.01	7.95	1.06	0.10
	RM	43	102.60	6.24	1.39	0.16	73.49	5.99	2.57	0.91
Fens		86	99.07	5.28	1.29	0.10	212.94	24.17	2.29	0.61
	FSF	42	123.31	6.81	1.76	0.17	104.27	7.92	2.66	1.17
	SF	44	75.92	6.33	0.84	0.06	316.78	41.07	1.94	0.39

		t_{stat}	$P_{T<t}$	t_{stat}	$P_{T<t}$	t_{stat}	$P_{T<t}$	t_{stat}	$P_{T<t}$
Marshes vs.Fens		-2.43	0.016	1.32	0.175	-5.60	<0.001	-0.95	0.344
	d.f.	161.3		200		91.9		200	

Table 3-4: Averages, standard errors and t-test (2-tailed) results from initial extractable nutrients (KCl extractable for ammonium, distilled deionized water extractable for nitrate, and NH_4F/H_2SO_4 extractable for phosphorus). Units are µg N (or P)/g dry material. Extractable N:P quotients are by weight.

Location	Site	Nitrogen Mineralization Estimate		Reference
Alaska, subarctic	moist tundra	4.7	F	Hart and Gunther, 1989
Alaska, northern	wet sedge tundra	5	F	Giblin *et al.*, 1991
	footslope	0.5		
	riverside willow	4		
Boreal Alberta	bog	13	F	Bayley, unpubl.
	poor fen	21		
	FSF	55.4		
Boreal Alberta	fens	2.7-8.7	F	This study
	marshes	2.6-9.3		
Central Alberta	fens	15.7-23.6*	F	Humphrey and Pluth, 1996
Manitoba, Delta Marsh	spring-flooded marsh	124*	F	Neill, 1995
	non-flooded marsh	62*		
Massachusetts	tidal freshwater riverine wetland	180	F	Bowden *et al.*, 1991
Northern Minnesota	bog	43	P	Urban and Eisenreich, 1988
Northern Minnesota	swamp forest	15	F	Zak and Grigal, 1991
Northern Minnesota	white cedar wetland	1	F	Grigal and Homann, 1994
	lowland hardwoods	16.2		
Northern Minnesota	sedge meadow	67.6**	P	Updegraff *et al.*, 1995
	bog peat	1522**		
Northern Minnesota	fen	57**	P	Bridgham *et al.*, 1998
	tamarack swamp	110**		
	beaver meadow	238**		
Netherlands	wet heathlands (*Erica* and *Molina* sp.)	100-130	F	Berendse *et al.*, 1987
Netherlands	fen peats	120.5-1084	F	Verhoeven and Arts, 1987
Netherlands	poor fen	224		Verhoeven *et al.*, 1988
	intermediate fen	220		
	nutrient rich fen	37		
Netherlands	bog	55.8	F	Verhoeven *et al.*, 1990
	fen	45.6		

Table 3-5: Nitrogen mineralization rate estimates (kg N/ha/yr) in a range of northern wetlands. F indicates rate estimates from field based studies, while P indicates potential rates calculated from laboratory incubations. *indicates estimate in kg N/ha for the growing season. ** indicates conversion of units assuming a 10 cm core.

Location	Site	Potential & Field Methane Production Estimates		Reference
Alaska	fen	289	F	Sebacher *et al.*, 1986
	marshes	106		
Boreal Alberta	fens	24-65	F	Vitt *et al.*, 1990
	boreal marsh	147		
	beaver pond	518		
Boreal Alberta	fens	160	P	This study
	marshes	205		
Manitoba	boreal fens-collapse scar	92	F	Bubier *et al.*, 1995
	-Zoltai fen	210		
Manitoba	boreal fens	22-239	F	Bellisario *et al.*, 1999
Quebec	subarctic fens	0.6-125	F	Moore *et al.*, 1990
Quebec	boreal bog	28	F	Moore and Knowles, 1989
	subarctic fen	12		
Quebec	subarctic fens & a pool	15.6 (3.6-27.1)	F	Moore and Knowles, 1990
	temperate swamps	3.3 & 11.5		
Eastern Canada	beaver ponds	30-90	F	Roulet *et al.*, 1992
Minnesota	fens	196 (4-419)	F	Harriss *et al.*, 1985
	sedge meadow	664		
Minnesota	fen	279 (142-372)	F	Crill *et al.*, 1988
Minnesota	beaver pond- annual ave.	22-30	F	Naiman *et al.*, 1991
	peak emissions	100-200		
Minnesota	bog peat	16.8	P	Updegraff *et al.*, 1995
	sedge meadow-beaver pond	0.5		
Minnesota	beaver pond meadow	14.5	P	Bridgham *et al.*, 1998
	tamarack swamp	25.4		
	intermediate fen	53.3		
Michigan	marsh	304	F	Baker-Blocker *et al.*, 1977
New York	*T. latifolia* marshes	14.1 & 90	F	Yavitt, 1997
North Carolina	short pocosin	1.26	P	Bridgham and Richardson, 1992
	tall pocosin	0.66		
	gum swamp	2.92		

Table 3-6: Potential and field methane production rate estimates (mg CH_4/m^2/day) in North American wetlands similar to my sites. Where averages of estimates are presented, the range is in parentheses. F indicates the study measured field rates, while P indicates the study measured potential rates in the laboratory.

4. Denitrification and internal nitrogen budgets of marshes and fens in the southern boreal region of Alberta, Canada.

Introduction:

Marshes and fens are wetland classes that exist in the boreal forest region and differ in hydrology, species composition, pH, and peat accumulation (National Wetlands Working Group, 1997). Wetland systems such as marshes and fens are more "open" than many terrestrial ecosystems, in that water flows can import materials/ nutrients, and at the same time export materials/ nutrients (Mitsch and Gosselink, 1993). In general, wetlands are nutrient deficient systems (Bowden, 1987), and northern wetlands show greater deficiencies than temperate or tropical systems (Jonasson *et al.*, 1993). Relative supply and losses of nitrogen in these wetland systems may be very important to plant community structure and may be related to class differences between wetlands.

The productivity of plant species present in marshes is higher than fens, and the species found in marshes are adapted to higher nutrient supply and fluctuating water levels (National Wetlands Working Group, 1997). Fens usually have a greater diversity of species adapted to nutrient deficient conditions and stable water levels (Zoltai and Vitt, 1995; Bedford *et al.*, 1999). The plant community differences that exist between marshes and fens have been assumed to be related to nutrient availability (Verhoeven *et al.*, 1988). Despite higher levels of nitrogen and phosphorus found in marsh plant tissue, nutrient content of plant tissue harvested at the time of peak biomass (chapter one; Thormann, 1995) has indicated that both northern marshes and fens are nitrogen limited (Verhoeven *et al.*, 1996). Nitrogen supply from mineralization was not significantly different between these wetland classes, although peak biomass, decomposition, surface water nutrients, and peat nutrients were higher in marshes than in fens (chapter two and three). While nitrogen supply (estimated as net nitrogen mineralization) did not differ, it may be that nitrogen losses differ between the two wetland classes, driving the observed differences between marshes and fens (chapter two). Specifically, differences in losses of nitrogen may be related to differences in vegetation community structure, productivity, decomposition, and nutrient content of the plant tissue and peat observed between the marshes and fens.

The primary mechanism of nitrogen loss from wetlands is biological denitrification (Kadlec and Knight, 1996). Biological denitrification is the production of gaseous nitrogen by microbial and fungal reduction of nitrogenous oxides, with the principle products being dinitrogen (N_2) and nitrous oxide (N_2O) (Tiedje *et al.*, 1989). The majority of denitrifying organisms are anaerobic bacteria that prefer to use O_2 as their terminal electron acceptor, but they will use NO_3^- when O_2 is absent (Tate, 1995). Wetland soils provide an ideal place for denitrification, as organic matter accumulates at the soil water interface. This organic matter (primarily plant material) is available for decomposition, releasing ammonium, which is in turn available for oxidation to nitrate (Seitzinger, 1990). Oxygen levels are often limited at the sediment surface, as oxygen diffuses relatively slowly through water compared to consumption in wetland sediments (Arth *et al.*, 1998). This promotes the use of nitrate as a terminal electron acceptor by soil bacteria and hence promotes denitrification in these systems.

Studies from treatment wetlands measuring denitrification relative to other nitrate losses have found that denitrification consumes 99 to 66% of documented nitrate losses (Kadlec and Knight, 1996). The relative importance of denitrification in natural prairie or boreal wetlands is unknown (Crumpton and Goldsborough, 1998; Seitzinger, 1994). Despite the lack of direct measurements, the capabilities of these wetlands for nitrogen removal are presumed high due to nitrogen disappearance over distance and through the year (White, 1997). While denitrification is cited as the most likely cause of nitrogen disappearance, other options such as burial in sediments, groundwater leaching and plant/ microbial uptake exist (Bowden, 1987).

Measurement of denitrification is difficult, as the high background of atmospheric nitrogen (79%) obscures nitrogen gas emissions by microbes. The most popular method of estimating denitrification was the acetylene block method, which uses acetylene and blocks the enzymes that convert N_2O to N_2. The major drawback to this method is that it also blocks the nitrification of ammonium to nitrate (Knowles, 1990), thus blocking the natural supply of substrate to denitrifiers. As a consequence, nitrate is often added to obtain a potential estimate for denitrification, but this estimate has been shown to significantly underestimate denitrification rates relative to other methods (Seitzinger, 1993b). ^{15}N has also been extensively used to estimate denitrification, where the amount of ^{15}N gas produced from ^{15}N labeled ammonium or nitrate is measured over time. This method has the disadvantage of having a potential fertilizer effect since it requires addition of substrate to what is presumably a substrate limited system, and additionally is expensive to analyze. The N_2 flux technique directly measures nitrogen flux out of intact soil cores by replacing the atmosphere in a sealed chamber with 79% helium and 21% oxygen. The main drawback of this method is the long pre-incubation required to deplete atmospheric nitrogen from the cores, and the large time commitment required to generate the fluxes in the laboratory. However, this method produces results comparable to ^{15}N estimates and allows an estimate of denitrification with coupled nitrification (Seitzinger 1993b; Watts, 1997).

I studied two different wetland classes with demonstrably different surface water nitrogen concentrations, different plant tissue and peat nitrogen concentrations (chapter two), and seasonally different mineralization rates (chapter three). I expected differences in denitrification estimates between fens and marshes; I hypothesized that the marshes, having higher pH and higher external nutrient availability, would have higher denitrification estimates than the fens (with lower pH and external nutrient availability). I further hypothesized that summer (July and August) would have higher denitrification estimates than fall (September and October), since high temperatures enhance denitrification (Kadlec and Knight, 1996). Acetylene measurements were compared with N_2 flux data to compare methods within this study, to compare with results of other studies, and to examine the relative contribution of coupled nitrification/denitrification in these systems, as nitrification is blocked with greater efficiency than denitrification by acetylene (Knowles, 1990).

In an effort to demonstrate that extreme high nitrate levels could increase denitrification, a site in the prairie region with known high nitrogen loadings and in particular high nitrate levels was investigated in 1997. Frank Lake was extensively sampled for water chemistry during 1995-96, and was known to have mg/L concentrations of nitrate in contrast to the μg/L concentrations of the boreal marshes (White, 1997). Samples were taken from May to August, 1997 to look at the effect of high nitrogen loading on the denitrification rate.

Study Sites:

This study focussed on a total of 6 wetlands, five of the wetlands (2 fens and 3 marshes) were all located in central Alberta in the boreal ecozone, while the sixth wetland (a marsh) was located in the prairie region of southern Alberta, Canada (Rowe, 1972). The 2 fens are located near the town of Perryvale, with the Floating Sedge Fen (FSF) located at 54° 28' N, 113° 19' W and the Sedge Fen (SF) located at 54° 28' N, 113° 18' W. The boreal marshes are located between the towns of Clyde and Nestow. The Lakeside Marsh One (LM1) is located north of the town of Clyde at 54° 10' N, 113° 34' W. The Riverine Marsh (RM) is located east of the town of Nestow, along a portion of the river called Helliwell Lake, at 54° 15' N 133° 37' W. The Lakeside Marsh Two (LM2) is located on the south tip of Duggan's Lake, at 54° 12.5' N 133° 25' W. This area is characterized by moderately warm summers and cold, snowy winters, with a mean annual temperature range of ⁻2.0-2.0°C (Environment Canada, 1997b). The sixth wetland, Frank Lake Conservation Area, is located 60 km south of Calgary, Alberta at 50° 33' N, 113° 42' W. Short, hot summers and cold, dry winters characterize this region, with a mean annual temperature range of 1.5-3.5°C (Environment Canada, 1997a).

Five of the sites were initially studied for denitrification estimates in spring 1996, 3 marshes (the LM1, the LM2 and the RM) and 2 fens (FSF and SF). In 1997, the LM1 and LM2 were again investigated to estimate denitrification, along with the prairie marsh, Frank Lake. The LM1 and both fens were previously studied and classified by Thormann and Bayley (1997a), where additional site and climate descriptions can be found. Detailed species lists for the LM1, LM2, RM, FSF and SF are presented in chapter two. Frank Lake was described in White and Bayley (1999), where additional site, climate and history descriptions can be found.

Lacustrine Marsh One

The Lacustrine Marsh One is a sedge dominated wetland on north end of Wakomao Lake (360 ha), and is the lacustrine marsh of Thormann and Bayley (1997a). Water drains from the north to the south of the lake into the Redwater river. Periodic flooding of the marsh occurs due to heavy spring run off and occasional beaver (*Castor* *canadensis*) activity at the south end outflow. The marsh is highly productive and may receive secondarily treated wastewater from the town of Clyde (population < 1000) in addition to agricultural run off. Average surface water pH over the two years was 7.1, and the peat depth was 1.5- 1.75 m. The dominant vegetation species are *Carex utriculata* Boott. and *Typha latifolia* L., with a abundant surface layer of *Lemna minor* L. No moss species were observed at this site.

Lacustrine Marsh Two

Located on the south tip of Duggan's Lake, this marsh is not adjacent to an inflow or outflow. There was considerable evidence of beaver activity through the 1996 field season, as willow and trees upland of the marsh were cut down by late August. The average pH of the surface water over the 1996 field season was 7.6, and the peat depth was approximately 80 cm. The vascular vegetation is dominated by *Typha latifolia* L., *Carex utriculata* Boott, and *Carex aquatilis* Wahlenb.. *Lemna minor* L. is also present. No moss species were observed.

Riverine Marsh

This marsh is similar to the riverine marsh of Thormann and Bayley (1997a) both in vegetation and in water chemistry. The site was chosen in an attempt to decrease extreme water fluctuations caused by beaver activity. The marsh is on the edge of Helliwell Lake, at the headwaters of the Tawatinaw River where it is quite wide (400 m) but with definite flow. Beaver were present on the site (as evidenced by a well-established lodge) but did not show evidence of damming activity. In 1995, the water levels in the marsh were quite low, approximately 5 cm above the peat. In 1996, the area was inundated for the entire season at an average of 50 cm above the peat (possibly due to beaver activity downstream). The average pH of the surface water over the two field seasons was 7.8 and the peat depth was approximately 90 cm. The vascular vegetation is dominated by *Typha latifolia* L., *Carex utriculata* Boott, *Carex aquatilis* Wahlenb., with *Polygonum amphibium* L. common. A single moss species (*Drepanocladus aduncus* (Hedw.) Warnst.) was observed in 1995, but not in 1996.

Sedge Fen

The Sedge Fen is part of an extensive wetland complex adjacent to a large lake, and is the same Riverine Sedge Fen described in Thormann and Bayley (1997a). This wetland substrate has a distinct oxidized layer at the surface that is orange-red, while the peat below is brown-black. Analysis of recent water chemistry has demonstrated iron rich ground waters surfacing in this fen (Thormann, unpub.). The average pH of the surface water over the two field seasons was 6.8, and the peat depth was greater than one meter. The vegetation is dominated by *Carex aquatalis* Wahlenb., *Carex utriculata* Boott, and *Carex lasiocarpa* Ehrh., while the moss species are sparsely distributed.

Floating Sedge Fen

The Floating Sedge Fen surrounds a small pond and is a floating peat mat (about 1–1.5m thick) that fluctuates with the water level of the pond. The pond substrate is also composed of peat approximately 1-1.5m in depth. Thormann and Bayley (1997a) and Szumigalski and Bayley (1996) have previously described this wetland. The average pH of the surface water over the two field seasons was 6.1. This site is very species diverse, and has a moss strata dominated by *Sphagnum warnstorfii* Russ. and *Aulacomnium palustre* (Hedw.) Loeske, a herbaceous strata dominated by *Carex lasiocarpa* Ehrh., and a shrub strata of *Salix pedicellaris* Pursh, *Andromeda polifolia* L. and *Oxycoccus quadripetalus* Gilib..

Frank Lake

Frank Lake is 1246 hectare (ha) hemi-marsh (even ratio of open water and emergent vegetation) that receives river water and secondarily treated wastewater from both a slaughterhouse (Cargill Foods Ltd.) and the town of High River (population 6000). Sediment depth in the area studied (Cargill Bay) was 15.4 cm, with a surface pH of 9.00 - 11.00 and a mean water depth of 0.67 m (White, 1997). Further descriptions of this wetland can be found in White and Bayley (1999) and White *et al.* (2000). The vegetation at this site is dominated by the emergent *Scirpu acutus* Muhl., and aquatic plants *Potamogeton pectinatus* L., *P. richardsonii* (Benn.) Rydb., and *Myriophullum albescens* Fern..

Methods:

N_2 Flux Technique

At the five boreal sites (the LM1, LM2, RM, FSF and SF) sampling was initiated to estimate denitrification using the N_2 flux technique in spring 1996. In 1997, the LM1 and LM2 were again investigated to estimate denitrification, along with the prairie marsh, Frank Lake. The 5 boreal sites were sampled on June 17th, July 16th, August 18th, September 12th and October 16th, 1996 to estimate denitrification. In 1997, the LM1, LM2 and Frank Lake were sampled to estimate denitrification on May 30th, July 1st, July 26th, and August 21st.

Field procedures

A number of factors vary between wetland sediments (i.e. water saturation of sediments and temperature). In order to facilitate comparison between the two wetland classes under investigation, all measurements were made at the average soil temperature of the sites on the day of soil collection (Watts, 1997), and all cores were incubated with water-saturated sediment and aerobic overlying water (Seitzinger, 1994). Two or three 7.5cm diameter cores 10-17cm in length were taken from each site, stored in Ziploc® bag and filled to the top with water from the core site. Cores were taken within 10cm of each other, to reduce peat compaction but at the same time minimize variation. At Frank Lake the sediments were highly decomposed and loose, therefore the cores from this site were transported in 8 cm diameter plastic pipe to maintain the integrity of the core. A 20L carboy was filled with surface water from each site, with attempts made to keep out excess dead litter and solid particles. Cores were transported to the lab on ice and kept at 4°C until placed into gas tight incubation chambers.

Laboratory procedures

Denitrification was measured as nitrogen flux in gas tight, glass incubation chambers following Seitzinger (1993a). Briefly, cores were placed in air tight glass chambers and sealed with O-rings and metal clamps. Water collected from the site was sparged for 30 minutes with a mixture of 21 % O_2 and balance (79%) He, and siphoned into the chambers. The atmosphere of the chambers was replaced with the same mixture of 21 % O_2 and balance He. This procedure substitutes helium for N_2 on a percent volume basis to reduce the background N_2 concentration. Chamber atmosphere and water replacement was repeated every 48 hours. Gas chromatography (GC) analysis of samples of the overlying gas phase was conducted using a molecular sieve 5A, 2 m x 0.318 o.d. stainless steel with 45/60 mesh column followed by a TCD (thermal conductivity detector) on a HP5890 Series II chromatograph. Initial gas phase analysis occurred on incubation day 4 at 4 hours after the time of water and gas changes (time 0) and at 48 hours, and was repeated every 48 hours for the remainder of the incubation period. Injection of certified gas standards for nitrogen (3%) and oxygen (10%) were used to calibrate the GC readings each day. Differences between initial and final concentrations of oxygen and nitrogen were used to calculate the total amount of N_2 and O_2 in the gas and water following Seitzinger (1993a). This total amount of N_2 and O_2 was divided by the time between sampling and the core surface area to calculate a m^2 hourly rate following Watts (1997) and Seitzinger (1993a). Measurements of N_2 flux and O_2 consumption (flux) continued every 48 hours for 14 days at the average soil temperature of the five sites at the time of sampling; measurements from incubations starting the eighth day onward were considered reliable estimates of N_2 and O_2 flux.

To assess the contribution of surface water nitrogen to the observed N_2 flux, measurements of the change in surface water ammonium and nitrate were made during the September and October 1996 incubations. A decrease in nitrate or ammonium was assumed to be a flux from the water to the sediment, while an increase was assumed to be a flux from the sediment to the water (Seitzinger, 1994). Surface water nitrate and ammonium in the He-sparged replacement water was measured prior to the water changes, and the final concentration of these nitrogen compounds in the chamber water was measured following the 48 hour incubation. Differences between initial nitrogen and final nitrogen were interpreted as the amount of surface water nitrogen flux to/from the sediment (Seitzinger, 1994). Analysis for nitrate + nitrite and ammonium followed the same procedures as those for surface water chemistry (see below).

Diffusive Flux Model

The N_2 flux measured from the above method is an over-estimate of the actual flux from microbial denitrification, as atmospheric N_2 is also fluxing out of the sediments (degassing). To separate denitrification flux from atmospheric N_2 flux from the sediment, Seitzinger (1993a) recommends waiting until background atmosphere N_2 has been depleted from the cores (3-10 days) before initiating measurements for denitrification. However, work by Nowicki (1994) showed significant atmospheric N_2 flux past day 10 on incubated estuarine sediments. To assess the magnitude of the atmospheric flux, cores (following 14 days incubation as above) were forced to anoxia by replacing the surface water with water sparged with He, and the atmosphere of the core was replaced with He. Incubations proceeded for eight days, and average fluxes calculated from day 2 on (3 fluxes). The results indicated that the marshes had ceased to flux atmospheric nitrogen at this point, but that the fens, in particular the FSF, were still fluxing atmospheric nitrogen. This was interpreted to mean that the fluxes from the earlier days could have a significant contribution from atmospheric N_2 flux (particularly in the fens), which would severely limit the number of samples that could be used to generate an estimate of the flux. To increase the sample size of each site, a diffusive model similar to that found in Watts (1997) was utilized to quantify the proportion of the observed flux that could be attributed to atmospheric N_2 flux.

Theoretical background

As in Watts (1997), it was assumed that the diffusive flux responded according to Fick's first law of diffusion (Glinski and Stepiewski, 1985):

$$f_x = -D_{soil}*(\Delta c/\Delta z) \quad \text{(eq. 1)}$$

where f_x is the flux rate (or diffusion flow), D_{soil} is the diffusion coefficient of the soil, and $\Delta c/\Delta z$ is the change in concentration per change in unit soil depth. To solve this partial differential equation, numerical methods were used to approximate a solution by iteratively calculating the change concentration over small slices of core depth, and repeating this over small intervals of time.

The core depth was arbitrarily divided into 50 slices, and the amount of nitrogen transferred to the section above it was calculated, added to the layer above, the amount of nitrogen transferred to the section above it was calculated, etc., up through the core. The model was run over 1 second intervals for 48 hours, when the headspace and overlying water was reset to 0% N_2, simulating initial setup and water changes. The core was assumed to have less than 3% air filled pore spaces, and started out with an initial concentration of N_2 in the water equal to saturation with the atmosphere (79%), subsequent porewater concentrations were not reset. The resulting model simulated diffusion of N_2 from the core in the absence of N_2 sources.

The calculated amount of transferred nitrogen accumulated in the water and diffused out to the headspace, presumably following Henry's Law (Bunce, 1994):

$K_H = c_{aq}/p_g$ (eq.2)

where K_H is the Henry's law constant, c_{aq} is the concentration of the gas in the liquid in mol/L, and p_g is the partial pressure of the gas in the atmosphere in atm.

As in Watts (1997), the diffusion coefficients of the soil (D_{soil}) were estimated following Rothfuss and Conrad (1994):

$D_{soil} = D_{\text{distilled water}} * (S_t^2)$ (eq. 3)

where $D_{\text{distilled water}}$ was the diffusion coefficient of N_2 from distilled water and was assumed to be $1.9*10^{-5}$ cm^2/sec at 25°C (Glinski and Stepniewski, 1985), and S_t was the total porosity (the proportion of bulk volume not occupied by solids). Total porosity was calculated (modified as a proportion) as (Vomocil, 1965, in Watts, 1997):

$S_t = (1-(D_b/p)$ (eq. 4)

where D_b is the bulk density and p is the particle density. Particle density was assumed to be 0.6 g/cm^3 (as all soils were organic) (Sallam *et al.*, 1984). The bulk density was calculated as (Hausenbuiller, 1985):

D_b = (weight of oven dry soil/volume of soil) (eq. 5)

Acetylene Block Technique

At four of the boreal sites (the LM1, RM, FSF and SF) sampling was initiated to estimate denitrification using the acetylene block technique in summer 1995. These 4 boreal sites were sampled on August 25th, September 17th, 1995 and October 19th, 1996 to estimate denitrification.

Field procedures

Three 5.0 cm diameter cores 10 cm in length were taken from each site, stored in 5.5 cm diameter plastic pipe and filled to the peat surface with water from the core site. Cores were taken within 10cm of each other, to reduce peat compaction but at the same time minimize variation. A 2L plastic container was filled with surface water from each site, with attempts made to keep out excess dead litter and solid particles. Cores were transported to the lab on ice and kept at 4°C until incubation.

Laboratory procedures

Three treatments were conducted during the acetylene inhibition portion of this study; a control treatment with no added acetylene or nitrate, an acetylene treatment with 10% acetylene by gas volume added to the chambers, and a nitrate and acetylene treatment with 100 μg/L of nitrate and 10% acetylene by gas volume added to the chambers. Denitrification was measured as N_2O accumulation in clear PVC pipe incubation chambers capped with a funnel that in turn was sealed by a rubber septum. Briefly, core water height was adjusted to field levels, and cores were then capped with the funnel/ septum. All cores were incubated at room temperature with water-saturated sediment with water at the peat surface. The atmosphere of the chambers was reduced by 13 mL, and 13 mL of acetylene gas was added to bring the gas volume acetylene concentration to 10% as suggested by Tiedje (1982). An initial 30 mL sample was taken of the gas headspace at 2 hours from the injection of acetylene, and a final 30 mL sample taken 4 hours after that. Headspace samples were injected into pre-evacuated 24 mL blood vials, resulting in a pressurized sample that subsequently analyzed for N_2O content. Gas chromatography (GC) analysis of the headspace samples was conducted using a

Poropak Q column followed by a ECD (electron capture detector) on a Varian Star 3400 chromatograph. Differences between initial and final headspace concentrations of N_2O were used to calculate the total N_2O following the formula of Tiedje (1982) to take into account the amount in both the liquid and gas phase. This total N_2O was then divided by the time between sampling and the core surface area to calculate a m^2 hourly rate. Sample measurements from the control treatment at 2 hours were reported as background concentrations (ppbv) of N_2O.

Water chemistry data

Field procedures

Water chemistry samples were taken every 2 weeks from May until October of 1995 and 1996 for the boreal wetlands. Water chemistry samples were taken at the time of core sampling for the LM1, LM2, and Frank Lake sites in 1997. Samples were taken from the same point each time, except for two samples in May at the LM1, where extreme water levels prevented entry to the wetland. Collection was made in acid washed 1 L Nalgene and 75 mL polypropylene bottles, and stored on ice. Field measurements of pH were made using a Fisher Accumet 925 pH meter.

Laboratory procedures

Laboratory analysis estimated the water chemistry parameters nitrate (NO_3^- and NO_2^-), ammonium (NH_4^+), total dissolved nitrogen (TDN), soluble reactive phosphorus (SRP), total phosphorus (TP), alkalinity (total), and conductivity. Nitrate samples were filtered using a 0.45 μm HAWP millipore filter, while ammonium samples were not filtered. Both nitrate and ammonium were analyzed on a Technicon Auto Analyser II. TDN was also analyzed on the Technicon Auto Analyser II following digestion with 4N H_2SO_4 and H_2O_2. SRP was analyzed using the methods of Menzel and Corwin (1965). TP was analyzed using the Bierhuizen and Prepas (1985) persulfate method following digestion and measured spectrophoto-metrically *as per* APHA (1992). Conductivity was estimated with a CDM 83 Bach-Simpson radiometer within 24 hours and corrected for temperature. Analysis of alkalinity was conducted using a Mettler DL21 Titrator with a Mettler ST20 sample changer following APHA (1992).

Internal Nitrogen Budget

Combining nitrogen measurements of this and previous chapters allows me to estimate an internal nutrient budget for marshes and for fens. Measurements of peat total nitrogen, total plant nitrogen from peak biomass, the amount of weight lost through leaching and decomposition, surface water nitrogen concentrations (all from chapter two) along with yearly mineralization rates, extractable nitrogen pools (ammonium and nitrate) (chapter three) and the estimates of denitrification from this chapter were used to estimate the internal nitrogen budget in Figure 4-5 and 4-6. Estimates of the amount of nitrogen received in precipitation came from averaging measurements made at Vegreville, Cold Lake, and Fort McMurray (the closest stations to our sites) (Myrick, AB Environ., pers. comm.). N fixation was assumed to be the same as estimates in Bowden (1987) as there was no better estimate available for wetlands in this area.

Statistical Procedures:

Differences between wetland classes for N_2 flux were analyzed using a non-parametric Mann-Whitney U test, as the data were clearly not normally distributed (Kolmogorov-Smirnov statistic = 0.227, d.f. = 179, sign. <0.001). Differences between sites for N_2 flux were examined with a Kruskal-Walllis test. O_2 flux data had a normal distribution, and so a parametric t-test was used to look for differences in wetland classes, and a single factor ANOVA was used to look for differences between sites. Backwards stepwise linear regression was used to look at possible influences on N_2 and O_2 fluxes. The average values for the fluxes (having a normal distribution) were compared to site water chemistry parameters. The backwards linear regression was considered appropriate as the departure form normality for the water chemistry parameters were not extreme (as evidenced from stem-leaf plots), and regression procedures are robust to all but extreme departures from normality (Zar, 1984; Kleinbaum and Kupper, 1978). Correlation coefficients were used to look at the influence on flux of each water chemistry factor individually, using a bivariate procedure with Pearson's correlation coefficients where the water chemistry parameters approached normal, and Spearman's correlation coefficients where there was extreme non-normality. All tests were conducted in SPSS ver. 7.5 for Windows.

Results:

N_2 Flux and Calculated N_2 Diffusion:

Denitrification rates were not different between wetland classes, and no obvious seasonal trends across the wetlands were observed (Figure 4-1a). Generally rates ranged between 200 and 400 μmol N/m^2 hr, with substantial variation in the LM2 and the FSF. In the marsh, the average rate of N_2 flux from July to October was 325 ± 47 μmol N/m^2 hr, while the fen average was 301 ± 54 μmol N/m^2 hr. When anoxic controls were run at the end of the October sampling, N_2 fluxes from the marshes and SF were below the detection limit (2.5 μmol N/m^2 hr) while the FSF still demonstrated a detectable N_2 flux (85-88 μmol N/m^2 hr).

The diffusion model resulted in an exponentially decreasing amount of atmospheric N_2 attributable to passive diffusion generated from the cores over all time periods (Figure 4–2). The FSF had a higher flux of atmospheric nitrogen from the peat soil than did the SF or the marshes, as demonstrated by atmospheric diffusive flux regression lines (Figure 4-2). After 14 days, approximately 34, 38, and 43 μmol N/m^2 hr could be attributed to atmospheric diffusive flux for the RM and LM2, the SF and LM1, and the FSF, respectively. The bulk densities used in the calculation of the atmospheric N_2 diffusive flux were significantly different (F = 42.734, sign. <0.001) between sites, with the FSF having a significantly lower bulk density and LM2 having a significantly higher bulk density than the other sites (Tukey's HSD test) (Table 4-1).

Monthly averages (adjusted for the diffusive flux) for the boreal sites during 1996 are presented in Figure 4-1a, while monthly averages for the LM1, LM2, FL1 and FL2 are presented in Table 4-2 (not adjusted for atmospheric diffusive flux, as no measurements of bulk density were made on Frank Lake sediments). June denitrification rates for the LM1 and LM2 are presented for the purposes of comparison between 1996 and 1997 (Table 4–2). Due to inexperience with the N_2 flux technique resulting in a large amount of unexplainable variation, other N_2 flux results and statistics from the June 1996 incubation are not presented. Rates measured in 1997 for the LM1 and LM2 did not significantly differ from those measured in 1996, although the average fluxes measured in 1996 were higher than those measured in 1997, they also exhibited higher standard errors.

Results from the Frank Lake denitrification study demonstrated that high levels of nitrate were associated with high levels of denitrification (Figure 4-3). For Cargill Bay at Frank Lake, May had the highest denitrification rates of the months measured in 1997 (F=4.047, Pr>F=0.014, LSD post-hoc test). Cargill Bay also had higher rates of denitrification for the May 30th sampling than in other sites measured at the same time, although not significant (Table 4-2).

The regression equation calculated for N_2 flux over the two years is highly significant with a good explanation of the variance (R^2=0.915) (Table 4-3). The primary factors (those with the largest influence, highest mulitiplicative factor) are pH, the cations Na^+, K^+, and Ca^+, nitrate, and chloride, in decreasing order. Due to the difficulty in assessing the causality of the above factors to the measured flux, correlations were also conducted with water chemistry data at the time of core collection and N_2 flux over both years, and for climatic factors and N_2 flux for the boreal sites in 1996. Only surface water nitrate was significantly correlated with N_2 flux over all sites during both years ($R_p^2 = 0.344$, sign ≤ 0.05), while precipitation and temperature showed a strong negative correlation (precipitation: $R_p^2 = -0.541$, sign ≤ 0.05; temperature: $R_p^2 = -0.628$ sign ≤ 0.01)) to N_2 flux from the boreal sites in 1996.

Nitrate flux ranged from zero to – 400 μmol N/m^2 hr, while ammonium flux was more variable and ranged between 548.9 to –3556.3 μmol N/m^2 hr (data not shown; from September and October). No significant relationship was discernable between nitrate or ammonium uptake from the surface waters of the cores measured in the chambers and the N_2 flux rate (Figure 4-4). When N_2 flux was plotted against nitrate flux from the surface waters, all the points fall above the 1:1 line on the graph indicating that the measured denitrification (as N_2 flux) exceeded the amount of nitrate fluxed out of the surface water (Figure 4-4). In fact, nitrate flux from the surface water appeared to be independent of denitrification except for the LM2 (Figure 4-4).

O_2 Flux (Consumption):

Oxygen flux did not differ between wetland types or over the season (Figure 4-1b), although September had the highest O_2 consumption, and October had the lowest O_2 consumption when all wetlands were pooled (ANOVA F=8.244, sign. <0.001, followed by Tukey's HSD). A backwards regression procedure identified that the mean air temperature and soil temperature were the dominant influences, which in conjunction with other parameters explained 70.6 % of the variation observed. The additional parameters of precipitation, alkalinity, and TDN were also identified, and are listed here in order of decreasing strength (Table 4-3).

Acetylene Block:

Average background levels of N_2O ranged between 344 and 542 ppbv (data not presented), and averaged 431 ± 32 ppbv overall (Table 4-4). Adding acetylene resulted in an increase in the accumulation of N_2O relative to the control chambers, while adding nitrate again resulted in an increase in N_2O accumulation compared to acetylene alone (Table 4-4). Neither of the increases was statistically significant, although an ANOVA was close (F=2.579, Pr>F=0.078). Rates of denitrification estimated with the acetylene block technique were less than 1% of the N_2 flux values (using smallest measured N_2 flux measurement and the highest acetylene block flux measurement).

Internal Nitrogen Budget:

Internal nitrogen budgets are presented in Figure 4-5 for marshes and Figure 4-6 for fens. The largest pool of nitrogen in the wetlands was the peat, for which an active depth of 10 cm was assumed and resulted in estimated storage of 318.7 g N/m^2 in marshes and 121.0 g N/m^2 in fens. The plant biomass from the previous year contained 9.27 g N/m^2 yr in marshes and 4.78 g N/m^2 yr in fens, and was used to estimate the amount of nitrogen required for plant growth. Microbial decomposition estimated over a year resulted in mass losses of 77.6% in marshes and 63.7% in fens. Initial losses from leaching were estimated by assuming nitrogen losses were proportional to leaching weight loss, resulting in losses of 2.18 g N/ m^2 yr (marshes) and 0.8126 g N/ m^2 yr (fens) using peak biomass as the initial amount of litter. While the total nitrogen of plant litter increased over the year by 0.22% in marshes, it decreased by 0.12% in fens.

Surface water nitrogen pools (ammonium + nitrate) were calculated at the average depth of water for 1996 in marshes and fens, and were 70.0 g N/m^2 in marshes and 2.5 g N/m^2 in fens. Mineralization rates over a year were slightly higher in marshes (0.644 g N/m^2 yr) than in fens (0.590 g N/ m^2 yr), while extractable nitrogen concentrations (nitrate and ammonium) followed the same pattern, pool sizes were very small in both wetland classes (0.08-16.9 x 10^{-9} g N/m^2). Denitrification was assumed to occur at average rates, 24 hours a day, and continue for 180 days of the year (corresponding to the ice free season), and was estimated at 19.7 g N/m^2 for marshes and 18.2 g N/ m^2 for fens. Averages of precipitation nitrogen data (Myrick, AB Environ., pers. comm.) resulted in an estimated 0.383 g N/ m^2 yr deposited on both wetland classes. Similarly N-fixation was assumed to be 1 g N/m^2 in a year, following Bowden (1987).

Plant requirements were assumed to be equivalent to the amount of N present in the peak biomass, and this was in turn assumed to be the amount of N available for uptake by plants (uptake, Table 4-5) in the wetland. Inputs were considered relative to the biological pool, and resulted in a total in of 10.87 g N/m^2 yr for marshes and 6.16 g N/m^2 yr for fens (Figure 4-5). The total outputs were to the atmosphere and resulted in a total loss of 22.52 g N/m^2 yr and 19.72 g N/m^2 yr for fens. The resulting net difference, which would be the amount of nitrogen required to balance the nitrogen budget, were 11.65 g N/m^2 yr for marshes and 13.56 g N/m^2 yr for fens.

Discussion:

Calculated N_2 Diffusion:

Diffusion coefficients were calculated for the different temperatures and the resulting diffusive flux was subtracted from the measured N_2 flux. The low bulk densities, height, and water saturation of the cores resulted in the N_2 in the porewater and the N_2 in the airspace of the chamber not reaching equilibrium by day 14 in our model (Figure 4-2). These model results indicate that diffusion through these soils is quite limited, as the cores had twice as long to equilibrate as previous studies (Seitzinger, 1993a; Watts, 1997). Actual measurements in anoxic conditions of N_2 flux following the

October incubations revealed that the marshes and the SF had nitrogen fluxes below our detection limits (25 μmol N), while the FSF still had detectable fluxes.

From this evidence I conclude that the diffusive flux model was reasonably accurate at predicting the flux from the marshes and the SF, but underestimated the diffusive flux in the FSF. As the diffusive flux model did not accurately predict the observed diffusivity in the FSF, it is recommended that further studies on peat cores with low bulk densities and high proportion of the peat derived from mosses utilize anoxic control cores. The anoxic control cores are incubated in conjunction with oxic cores so that the background flux of N_2 can be subtracted from measured N_2 flux, as in Nowicki (1994). While it is difficult to obtain replicate soil cores, the difficulties in measuring all the parameters necessary to accurately model diffusive flux from cores like the FSF make replicate cores a more reasonable solution.

N_2 Flux:

Average rates of denitrification were 325 μmol N/m^{2}hr in marshes and 301 μmol N/m^{2}hr in fens. Denitrification rates did not differ between wetland classes (Figure 4-1a), despite differences in nitrogen concentrations in the surface water, plant tissue and peat between marshes and fens. This suggests that due to low nitrate concentrations in the water (6-20 μg N/L) and in the peat (0.8-1.8 μg N/g dry material), denitrification is limited by supply of nitrate to anoxic sites. Additional evidence comes from Frank Lake (a sewage amended wetland), where the May sampling demonstrated high nitrate concentrations which were measured concurrently with significantly higher N_2 flux rates (632 ± 170 μmol N/m^{2}hr) compared to other sampling times for that site (232 ± 61μmol N/m^{2}hr). The rate observed at Frank Lake was also higher (although not significantly) than other sites during the May sampling (average of sites was 363 ± 77 μmol N/m^{2}hr) (Table 4-2). High denitrification rates (2000 μmol N/m^{2}hr) have also been inferred with high nitrate loadings (2.63-9.53 mg/L) in Colorado based on mass balance estimates (Sjodin *et al.*, 1997).

High rates of denitrification were also presumed from nitrate disappearance at Frank Lake both during this study and a previous study of surface water nutrient concentrations (White, 1997). Sewage concentrations of nitrate and ammonium were

68.7 mg/L and 8.9 mg/L at the inlet pipe to the wetland, while concentrations measured at the sampling location (~250 m from the inlet) were 15.5 mg/L and 4.5 mg/L, respectively. Denitrification was potentially occurring in the water column in addition to the sediment, as nitrate concentrations decreased from the time of sampling (15.5 mg/L) and the start of incubation (7.6 mg/L), six days later, despite storage at 4°C. Nitrate levels also decreased over the season (Figure 4-3), potentially due to increasingly efficient denitrification.

Comparisons of the denitrification estimates in this study with other studies is difficult due to the variety of techniques, which do not always correspond to N_2 flux measurements (Seitzinger, 1993b; 1994). The denitrification estimates of this study are slightly higher than reported for wetlands in the eastern US using this same method (Table 4-6). One difference between the estimates of this study and the estimates of both Seitzinger (1994) and Watts (1997) is the sample size; the previously mentioned studies utilized 14 and 12 organic soil cores respectively, while the estimates of this study are based on the averages of 18 cores for fens and 27 cores for marshes (45 organic cores total). Estimates of denitrification in July agree very closely with the estimates of Seitzinger (1994) and Watts (1997), ranging between 20 and 220 μmol N/m^{2}hr; however estimates from the other months demonstrate considerable variation, increasing the average flux (Figure 4-1a). Estimates of nitrification-denitrification using ^{15}N for wetland soils with plants were similar to our estimates (Reddy *et al.*, 1989), while estimates using a clay soil with added $^{15}NO_3^-$ and $^{15}NH_4^+$ were lower than ours (DeLaune *et al.*, 1998) (Table 4-6).

Frank Lake N losses are a slight underestimate, as the pH, on average, was above 7.5 near the outflow and ammonia volatilization may have been an unaccounted sink for nitrogen to the atmosphere (Reddy and Patrick, 1984). The under-estimation is thought to be slight, as ammonium concentrations ranged between 1.0 and 8.9 mg/L (Table 4-1), which are lower values than the 20 mg/L threshold at which ammonia volatilization losses become significant (Kadlec and Knight, 1996). Ammonia volatilization would not have been a problem in the boreal sites, as the pH did not exceed 7.5 in the fens or the lacustrine marshes (Reddy and Patrick, 1984). The ammonium levels for the riverine marsh (RM) were very low (8 ± 9 µg/L) and below the threshold previously described, although the pH ranged between 7.5 and 8.0 consistently (Table 4-1).

The relationship between nitrate and denitrification was not strong over all sites (R^2=0.344), possibly due to the internal generation of nitrate in the more nitrogen-limited sites. For instance, at Frank Lake in a site more removed from the effluent discharge, the relationship between denitrification and surface water nitrate was weak when nitrate dropped below 100 µg/L, probably due to random variation and coupled nitrification-denitrification in the sediment obscuring the relationship (data not shown). Because in water nitrate diffuses seven times faster than does ammonium, diffusion of ammonium to oxic microsites (to be oxidized to nitrate) is considered the rate limiting step for denitrification (Mitsch and Gosselink, 1993). This would explain the high rates of denitrification observed despite extremely low pore water concentrations of nitrate in the boreal sites (Figure 4-5 and 4-6).

Diffusion of nitrate from the overlying water to the sediment is dependent on concentration (Reddy *et al.*, 1978), so marshes should have more nitrate diffusing into the sediment water than fens. This could support the slightly higher rates of denitrification observed in marshes than in fens. Another strong possibility is that mass flow of ground water may contribute a supply of nitrate to the peat of marshes or fens. As this study was conducted in closed, sealed chambers, the opportunity for constant mass flow was decreased, although the water changes could have enhanced or alternatively underestimated mass flow relative to the natural situation.

Nitrate in the surface water of the denitrification chambers (measured in September and October 1996) either stayed the same or decreased over time. Where nitrate levels in the chamber stayed the same, either there was no change, or the amount of nitrate oxidized from ammonium was equivalent to the amount of nitrate diffusing into the sediment and being denitrified. Where the nitrate levels in the chamber have decreased it appears that nitrate is diffusing into the sediment and denitrifying faster than it can be replaced. In summary, nitrate in the surface water of the chambers was either not a major supply for denitrification, or was a very important supply that was replaced very quickly through ammonium oxidation.

A comparison of the surface water nitrate flux in the chambers to N_2 flux demonstrated higher N_2 fluxes than could be supported through the uptake of nitrate from the surface water in the chambers (Figure 4-4). This is similar to results obtained by Seitzinger (1994) for wetlands impacted by anthropogenic sources of nitrogen. Seitzinger concluded that the additional nitrate required to support the observed denitrification rates should be internally generated through the mineralization of organic matter in the wetlands, and the ratios she observed (greater than 10:1 N2 flux to nitrate) suggest very tight linkages (Seitzinger, 1994).

O_2 Flux:

Unlike previous studies (Seitzinger, 1994; Nowicki, 1994; Heggie *et al.*, 1999) we did not obtain a significant relationship between O_2 flux and N_2 flux (R^2=0.0214). The regression equation for N_2 flux did include O_2 flux, but it was not one of the major influences (Table 4-3). However, Watts (1997) also lacked a relationship with O_2 flux and N_2 flux in her organic peat soils; perhaps peat sediments do not have a linear relationship between N_2 flux and O_2 flux. Additionally, the sample size and magnitude of O_2 flux observed in these sites was generally greater than those observed by Seitzinger (1994), which may indicate that O_2 was required by a different or greater diversity of fauna in our sites compared to hers. The regression equation for O_2 flux indicated that temperature was a strong influence on O_2 consumption. However, it appears that it is the combination of the soil temperature and the air temperature that moderates O_2 consumption, as there is a negative influence of soil temperature and a positive influence of air temperature.

Acetylene Block:

N_2O background emissions were slightly elevated relative to tropospheric concentration of N_2O, 430 ppbv compared to atmospheric concentrations of 300 ppbv (Bunce, 1994), suggesting boreal wetlands may be a source of N_2O to the atmosphere. Measurements of N_2O flux without acetylene suggest that N_2O is not a major product of denitrification in these wetlands, as the background flux rates observed from control cores ranged between 0-0.15 μmol N_2O-N/m²hr. This N_2O flux is at best < 1% of the N_2

flux rates, confirming that denitrification is dominated by N_2 flux in the wetlands investigated.

The average estimate of denitrification from acetylene (without nitrate addition) for the fens (0.19 μmol N_2O-N /m^2hr) is very similar to rates reported by Urban *et al.* (1988) (Table 4-6). The marsh estimate of 0.55 μmol N_2O-N /m^2hr falls in the ranges reported for cores without nitrate addition (Table 4-6). Thus background levels of denitrification estimated by acetylene block without nitrate are similar to other literature values (Table 4-6). Again, calculated rates of denitrification from N_2O were quite variable, which may be related to the use of whole soil cores and associated internal heterogeneity of the soil (Grant and Pattey, 1999).

Estimates with added nitrate (0.23-0.79 μmol N_2O-N /m^2hr) are considerably lower than those listed in Table 4-5. The discrepancy in potential denitrification rates estimated with nitrate addition from this study compared to others may be due to insufficient nitrate added to the cores (0.1 mg/L) as Holmes *et al.* (1996) found that concentration above 1 mg/L were necessary to stimulate denitrification. It may also be that the added nitrate did not disperse quickly enough in the cores to be denitrified and detected.

Limitations on Denitrification:

The acetylene methods, which are more effective at blocking the nitrification of ammonium than the decomposition of N_2O to N_2 (Knowles, 1990), would drastically underestimate the denitrification occurring from organic matter mineralization and subsequent nitrification. This was observed in this study and in two other studies comparing the two methods (Seitzinger, 1993b; Watts, 1997). Certainly, when combined with the nitrate uptake information (Figure 4-4), the results suggest that the majority of nitrate for denitrification is internally generated (coupled nitrification-denitrification) to be denitrified within the core. The strong coupling between nitrification and denitrification that is suggested above would result in nitrate being very transitory and not accumulating in the peat pore water of northern wetlands or in the surface water of natural wetlands, as was previously noted in the second and third chapters. It appears that denitrification removes nitrate as fast as it is produced, and as mentioned in the discussion of N_2 flux above, nitrification may be the limiting step for nitrogen removal from northern wetlands.

1996 Internal Nitrogen Budget:

The internal cycling of nitrogen shows a large pool of nitrogen held in the peat, as discussed by Verhoeven (1986) and Bowden (1987). Much of this is recalcitrant nitrogen and generally unavailable for microbial decomposition (Bowden, 1987). The plant biomass from the previous year is then the most dominant source of labile carbon and nitrogen for microbial decomposition, and is twice as large in marsh sites as in my fen sites. The increase in total nitrogen of the marsh plant litter is presumably due to microbial colonization of the fresh plant litter (Paul and Clark, 1996). Thus microbial mobilization of fresh marsh plant litter does not result in a direct nitrogen source for plants or denitrifiers as there is an increase, or immobilization of nitrogen in marshes. In contrast, microbial mobilization of fresh fen plant litter does release a small (0.12 g N/m^2) amount of N for plants and denitrifiers.

Mineralization of the peat releases a large proportion of nitrogen relative to litter decomposition in both marshes and fens, and it is the only release from marshes identified in this study apart from immediate potential leaching of nitrogen from fresh litter. Relative to mineralization and surface water nitrogen pools, the extractable nutrients in the peat are extremely low (in the nanogram range). By far the largest potential pool for plant uptake is the surface water nitrogen, especially in marshes (70.0 g N/m^2, of which 64.5 is ammonium and 5.5 is nitrate). This is 7 times the estimated plant demand for nitrogen and almost 3.5 times the denitrification estimates, and only 1/3 of the surface water nitrogen pool would need to be nitrified and transferred to the sediment pore water to support the measured denitrification rates. Nitrification can occur in overlying surface water (Reddy and Patrick, 1984), but is limited by low oxygen concentrations and the slower diffusion of ammonium from the sediment porewater. If there is little nitrification of mineralized ammonium from the surface sediment or ammonium in the surface water, the discrepancy of inputs and losses may be reconciled by surface or groundwater inputs.

Differences in the internal budgets of marshes and fens were not evident from the fluxes between pools, which were similar. However, pool sizes were a half to a third in fens relative to marshes. Specifically, in fens there is 2.5 g N/m^2 in the surface water, which is half the amount required for plant growth and approximately a seventh of what is required to support the estimated denitrification. Therefore, to balance the internal nitrogen budget for fens, there must be significant surface water or groundwater inputs of nitrogen not measured in this study, or the entire surface water nitrogen pool must be transferred to the sediment pore water 7 times over the year. Another possibility is that the gross mineralization rate and gross nitrification rate in fens are much greater than the measured net mineralization rates would indicate (see chapter three), which is possible as net mineralization rates are the sum of competing processes (Hart *et al.*, 1994; Hatch *et al.*, 1991).

Further research is required to accurately map nitrogen cycling in these wetlands. Isotope tracer techniques using ^{15}N could be used to tease apart the relative contributions and rates of transfer between the various pools measured in this study. Specifically, characterization of the rates of transfer between the surface water nitrogen pool and the peat porewater relative to the gross rates of mineralization may clarify the nitrogen sources for plants and microbes. Hydrological work may help address the relative importance of mass flow and diffusion in supplying microsites within the peat with ammonium and nitrate.

Considering the evidence that coupled nitrification and denitrification is a large source of nitrate for denitrification (Figure 4-4), indications are that the extractable nitrate pool, while very small, is extremely important in the internal nutrient cycling in boreal wetlands. If this is indeed the case, both the ammonium and nitrate pools must turn over extremely quickly. Denitrification is therefore likely to be limited by diffusion of both ammonium to sites where it can be oxidized and by diffusion of nitrate in the surface water to denitrifying sites within the soil. Further research is needed to determine if gross rates of nitrification are as rapid in northern wetlands as suggested by the circumstantial evidence of this study.

Conclusions:

In conclusion, denitrification removes approximately 19 g N/m^2 yr in both wetland classes, and these estimates are comparable with previous estimates in the literature, although higher than expected due to the low anthropogenic influence, low summer temperatures, and low nitrogen deposition rates in this area. Nitrogen flux was well explained by various factors measured at the time of sampling, but did not correlate with O_2 consumption.

The internal nitrogen budget of both marshes and fens revealed much higher outputs than inputs in these peat based wetlands. Denitrification was the single largest component of the nitrogen budget, leading to speculation about the source of nitrogen for denitrifiers in these wetlands. This imbalance in the internal nitrogen budget could only be addressed with further research to assess the importance of external run-off, nitrogen fixation and nitrogen consumption by microbes. Indications from the N_2 flux data, acetylene data and the nitrogen budget are that denitrification effectively removes nitrate as fast as it is produced in these wetlands, and that surface water nitrate is an important pool of nitrogen, perhaps responsible for some of the observed differences in peat nutrient content, peak biomass estimates and decomposition rates in boreal marshes and fens.

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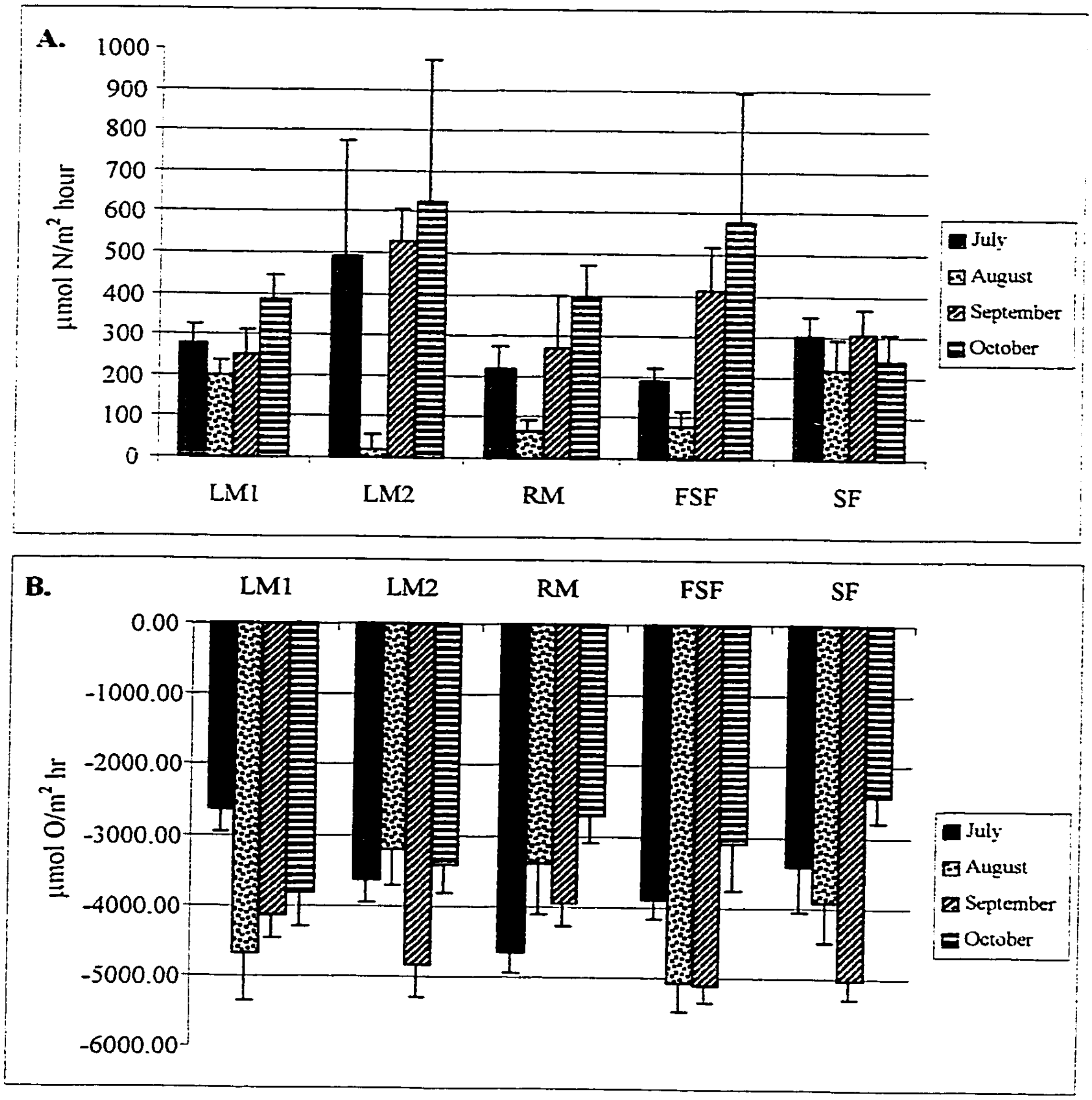

Figure 4-1: Monthly 1996 A. denitrification estimates and B. oxygen consumption estimates from intact field cores.

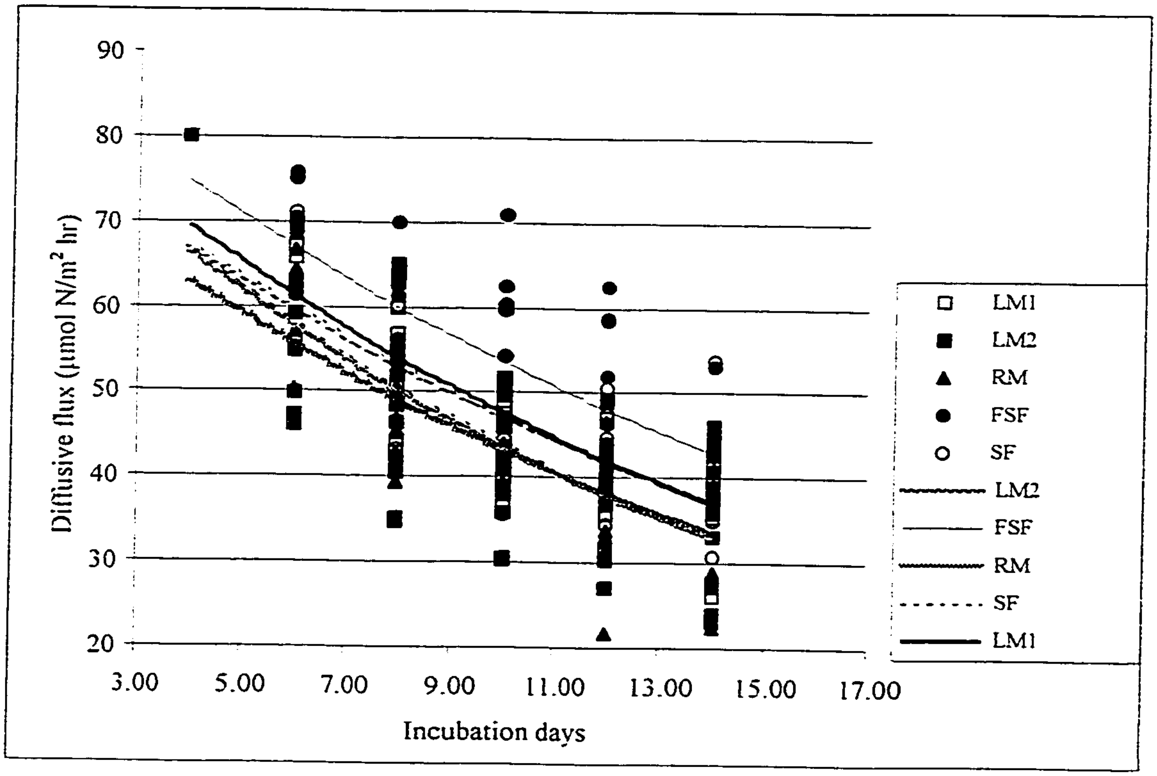

Figure 4-2: Calculated diffusive flux average curves for July – October, 1996.

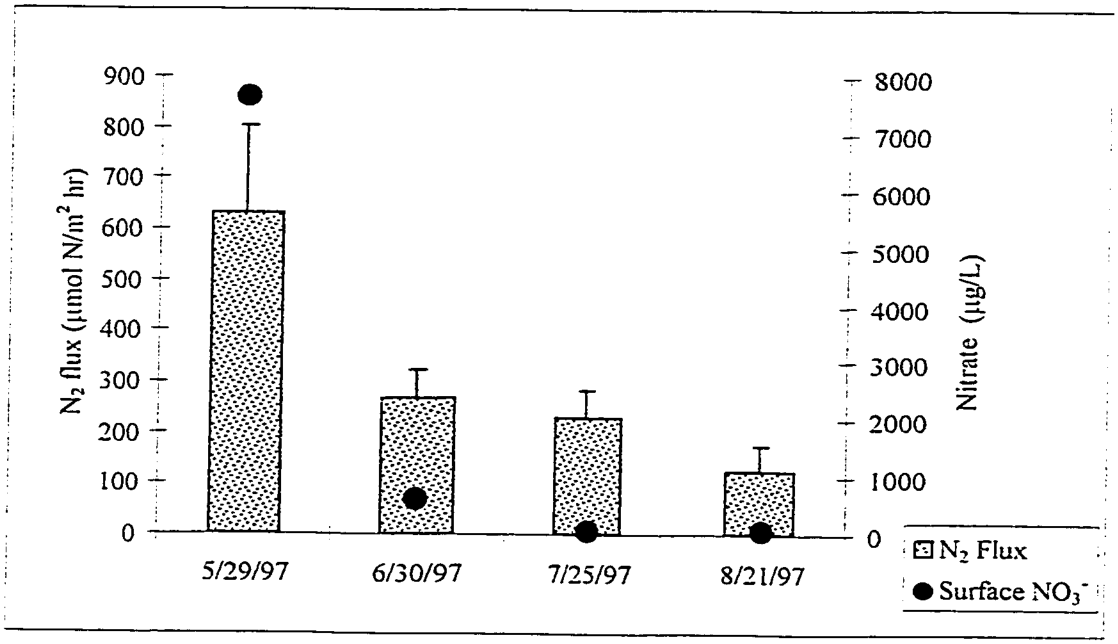

Figure 4-3: Denitrification fluxes and surface water nitrate concentrations at Frank Lake site 1 in 1997.

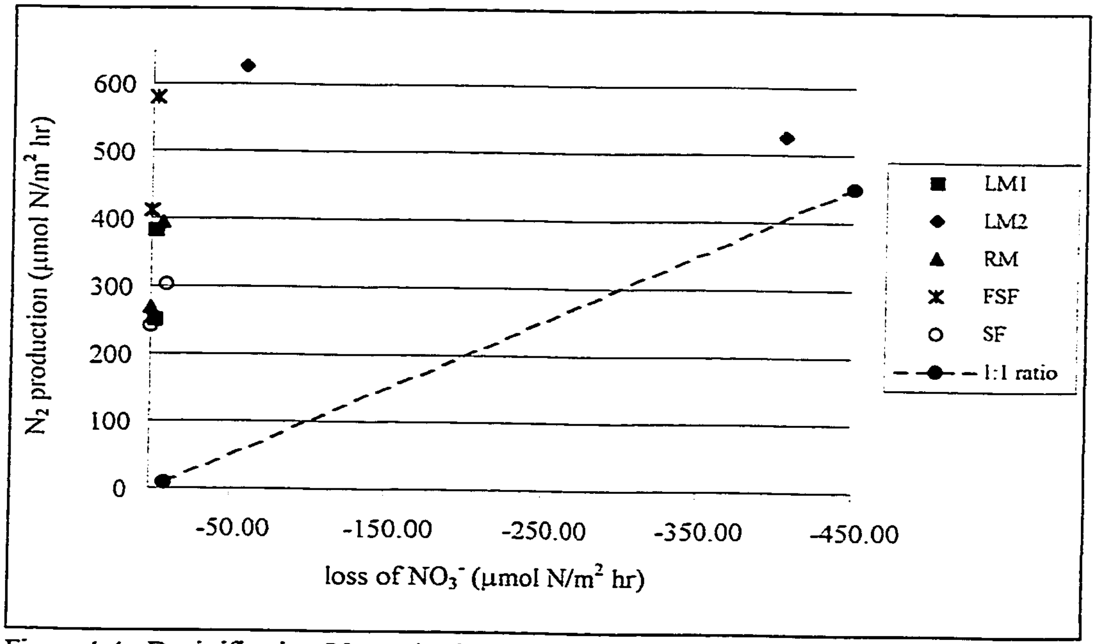

Figure 4-4: Denitrification (N_2 production) rates as a function of the rate of nitrate loss from the surface water. Dashed line indicates a 1:1 ratio of N_2 production to nitrate loss.

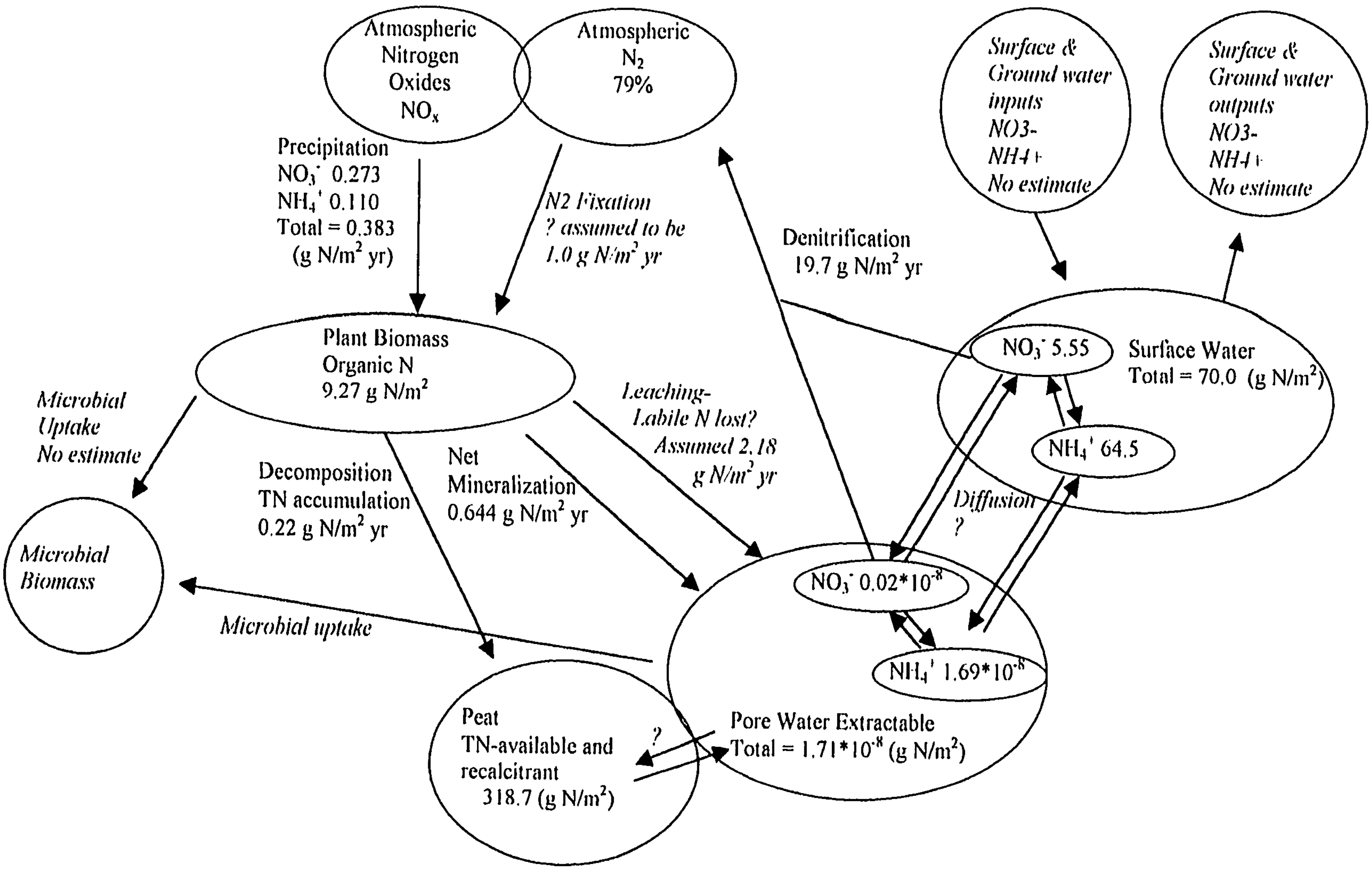

Figure 4-5: Marsh internal nutrient budget, using averages from the boreal marshes of this study. Estimation of the peat total nitrogen assumes an active depth of 10 cm; the surface water estimation assumes an average depth of water for the marshes in 1996; the estimate for plant biomass nitrogen assumes all plant material had the same % nitrogen as *Carex*; the estimate for leaching assumes that nitrogen leaching is proportional to the weight loss during leaching (23.5%); estimation of denitrification assumes average rates for marshes were constant over 24 hours and continued for 180 days (average length of ice free season for this region).

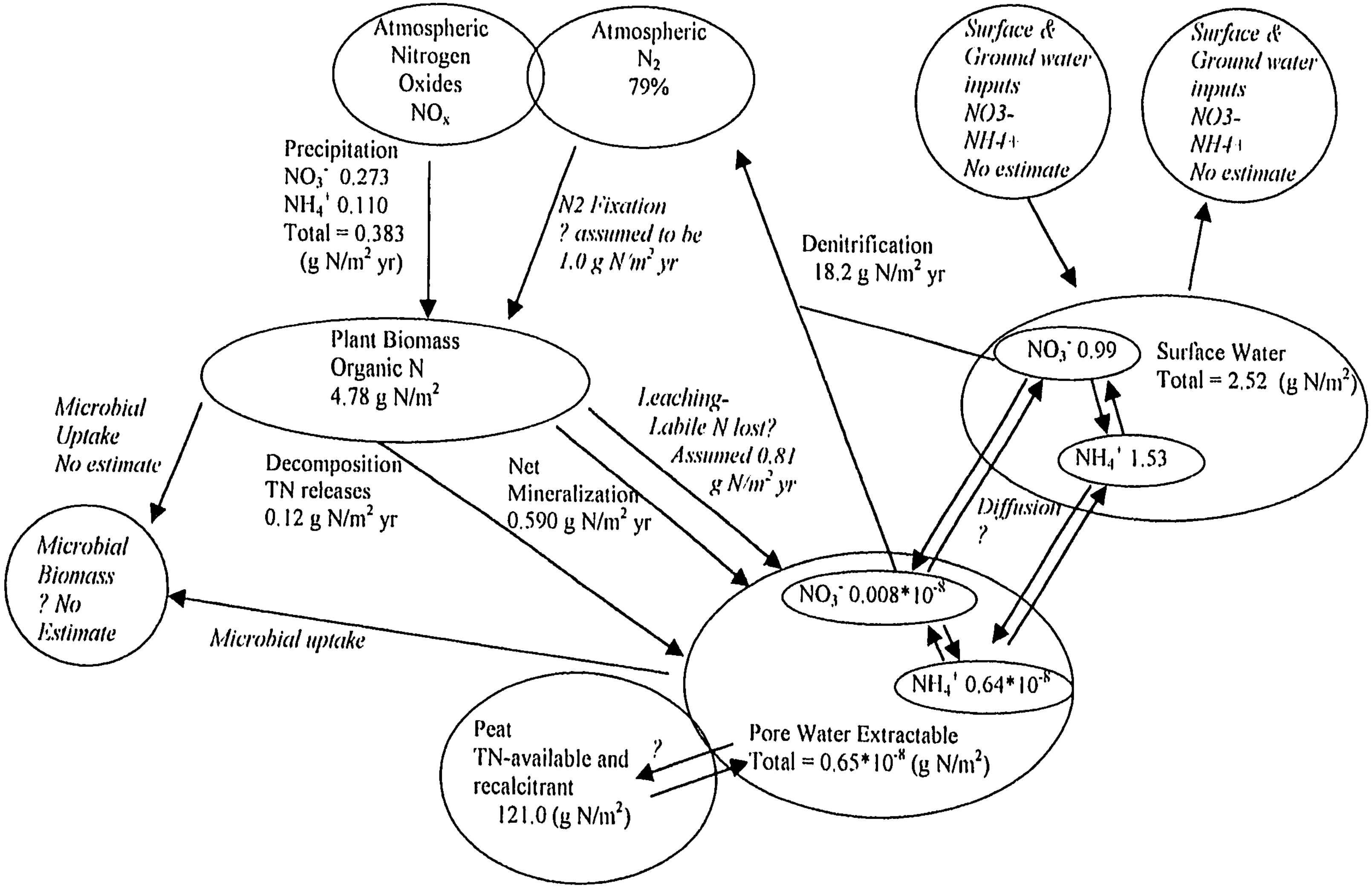

Figure 4-6: Fen internal nutrient budget, using averages from the boreal fens of this study. Estimation of the peat total nitrogen assumes an active depth of 10 cm; the surface water estimation assumes an average depth of water for the fens in 1996; the estimate for plant biomass nitrogen assumes all plant material had the same % nitrogen as *Carex*; the estimate for leaching assumes that nitrogen leaching is proportional to the weight loss during leaching (17%); estimation of denitrification assumes average rates for fens were constant over 24 hours and continued for 180 days (average length of ice free season for this region).

	1996										1997							
	LM1		LM2		RM		FSF		SF		LM1		LM2		FL1		FL2	
Characteristic	mean (stderr)	n	mean (stderr)	n	mean (stderr)	n	mean (stderr)	n	mean (stderr)	n	mean (stderr)	n	mean (stderr)	n	mean (stderr)	n	mean (stderr)	n
pH	6.92		7.56		7.69		6.18		6.83		7.33		7.74		7.70		8.10	
	(0.15)	13	(0.11)	12	(0.15)	13	(0.10)	13	(0.06)	13	(0.21)	4	(0.46)	4	(0.05)	4	(0.50)	4
Bulk Density (D_b)	0.1050		0.187		0.174		0.044		0.085		n.m.		n.m.		n.m.		n.m.	
(g/cm^3)	(.003)	16	(.013)	16	(.082)	16	(.003)	12	(.006)	12								
Conductivity	576.4		513.5		439.5		63.1		148.7		487.2		502.7		1414.1		934.9	
(µS)	4.6	12	(13.5)	11	15.8	1	5.5	12	18.4	12	(36.7)	4	(22.6)	4	(126.3)	4	(98.1)	4
Chloride (Cl^-)	53.4		4.6		25.6		0.89		0.65		12.0		3.9		88.8		44.6	
(mg/L)	(3.9)	26	(0.1)	12	(1.4)	24	(0.08)	24	(0.11)	22	(-)	1	(-)	1	(-)	1	(-)	1
Sodium (Na^+)	60.1		29.6		32.2		1.86		2.66		n.m.		n.m.		n.m.		n.m.	
(mg/L)	4.6	13	1.0	12	1.2	13	(0.07)	13	0.16	12								
Potassium (K^+)	16.3		14.5		11.2		1.65		0.60		n.m.		n.m.		n.m.		n.m.	
(mg/L)	1.5	13	(0.4)	12	(0.2)	13	0.19	13	0.24	12								
Calcium ($Ca2^+$)	47.0		41.6		43.8		7.96		22.0		n.m.		n.m.		n.m.		n.m.	
(mg/L)	(2.0)	13	(1.3)	12	(1.1)	13	(0.66)	13	(2.7)	12								
Alkalinity ($CaCO_3$)	207.5		276.2		160.7		26.2		75.6		219.0		255.1		435.4		325.1	
(mg/L)	(7.7)	13	(8.3)	12	(5.2)	13	2.6	12	8.8	13	(27.6)	4	(9.809)	4	(68.3)	4	(43.4)	4
Ammonium	132.5		252.4		92.7		13.3		9.95		607.7		18.1		2577		144.9	
(µg/L)	(61.6)	13	(88.1)	12	(54.1)	14	(2.0)	13	(2.24)	13	(604.4)	3	(16.4)	4	(569)	5	(83.4)	4
Nitrate	6.95		13.3		26.5		3.7		4.81		7.83		12.73		4774		5.68	
(µg/L)	1.06	14	(2.8)	13	(15.7)	14	(1.74)	12	(0.87)	13	(1.83)	4	(8.56)	4	(3031)	5	(1.38)	5
TDN	2826.0		2567.1		2208.2		1260.8		1112.7		3118		2509		11104		2438	
(µg/L)	(207.1)	13	(158.5)	12	(233.7)	13	(86.4)	24	(71.8)	13	(945)	3	(345)	3	(4191)	4	(470)	4
SRP	115.6		69.7		11.7		5.32		17.5		277.1		16.2		7713		1683	
(µg/L)	(25.8)	13	(26.2)	12	(5.2)	13	(0.91)	13	(7.7)	13	(158.3)	4	(4.2)	4	(1724)	5	(963)	5
TP	471.3		354.7		134.7		104.1		124.9		811.7		325.8		1493		3340	
(µg/L)	(50.8)	14	(51.9)	13	(16.6)	13	(18.6)	13	(38.3)	13	(495.5)	4	(14.3)	4	(5670)	5	(1058)	5

Table 4-1: Selected surface water chemistry concentrations and bulk densities for denitrification sites in 1996 and 1997.

Year	Site Date	LM1 mean (n)	std.err	LM2 mean (n)	std.err	FL1 mean (n)	std.err	FL2 mean (n)	std.err
1996	June 17	1293.0 (8)	607	1370.0 (8)	552	n.m.		n.m.	
	July 17	321.0 (8)	47.5	469.4 (8)	252.2	n.m.		n.m.	
	August 18	243.0 (8)	38.9	57.7 (8)	3.5	n.m.		n.m.	
	September 12	299.7 (8)	59.9	571.0 (8)	80.5	n.m.		n.m.	
	October 16	428.4 (12)	60.8	670.8 (12)	346.5	n.m.		n.m.	
1996 Average		464.3 (44)	121.0	605.5 (44)	155.6	n.m.		n.m.	
1997	May 30	347.8 (9)	74.8	190.0 (8)	67.2	632.1 (12)	169.8	350.3 (9)	24.9
	July 1	190.4 (6)	39.8	317.7 (11)	99.0	268.6 (9)	56.3	365.7 (10)	282.4
	July 26	238.3 (8)	63.2	334.0 (11)	80.3	228.3 (10)	57.8	262.8 (10)	55.1
	August 21	290.8 (11)	117.6	466.4 (11)	237.9	125.0 (11)	48.5	184.2 (11)	37.4
1997 Average		276.2 (35)	46.8	405.6 (41)	119.9	336.9 (42)	60.7	329.1 (42)	66.8

Table 4-2: Detailed measurements of N_2 flux measurements (not adjusted for diffusive flux) in 1996 and 1997 for selected marshes, measurements in µmol N/m^2 hr. The symbol n.m. indicates that no measurements were made at that time.

Nitrogen Flux Regression Equation	$y = -1416.098-32.355(Ca^{+})-26.733(Cl^{-})-3.595(cond)-68.921(K^{+})+81.990(Na^{+})+40.118(NO_3^{-})+533.958(pH)-0.101(O_2\ flux)-2.056(WN{:}P)-0.266(TDN)$ $R^2=0.915$ F-value=7.496 Prob>F= 0.007 where Ca^{+} is the calcium concentration, Cl^{-} is the chloride concentration, cond is the conductivity (corrected for temperature), K^{+} is the potassium concentration, Na^{+} is the sodium concentration, and NO_3^{-} is the nitrate concentration WN:P is the molar ratio of $(NH_4^{+}+NO_3^{-})$:SRP and TDN is the concentration of total dissolved nitrogen in the surface water. pH is also of the surface water.
Oxygen Flux Regression Equation	$y= -1933.997+6.042(alk)+225.135(temp)-26.434(precip)-157.365(soil\ temp)-0.704(TDN)$ $R^2=0.706$ F-value=7.196 Prob>F= 0.001 where alk is the concentration of total alkalinity concentration of the surface water, temp is the average monthly temperature, precip is the average monthly precipitation, soil temp is the soil temperature at the time of sampling, and TDN is the total dissolved nitrogen concentration of the surface water.

Table 4-3: Backward stepwise regression equations for average nitrogen flux for 1996 and 1997 and oxygen flux for 1996 in µmol N or O/m^2 hr. Surface water cations (Ca^{+}, K^{+}, and Na^{+}) and alkalinity are in mg/L, the nutrients TDN and NO_3^{-} are in µg/L, and conductivity is in µS.

	Background Emissions	s.e.	Control	s.e.	Acetylene	s.e.	Nitrate + Acetylene	s.e.
Marshes	418	36	0.14	0.06	0.55	0.32	0.79	0.54
(n)	(27)		(28)		(28)		(28)	
Fens	445	54	0.04	0.02	0.19	0.14	0.23	0.08
(n)	(27)		(28)		(28)		(27)	
Total	432	32	0.09	0.03	0.37	0.18	0.55	0.28
(n)	(54)		(56)		(56)		(55)	

Table 4-4: Background N_2O emissions , in ppb, and denitrification estimates based on the acetylene block technique, in μmol N/m² hr, where s.e.= standard error of the mean. Control treatment has no added acetylene and estimates the natural flux of N_2O from these sites. See text for details on other two treatments. No significant differences were detected among the variables.

Inputs:	Marsh	Fen
Uptake	9.27	4.78
Runoff & surface water	?	?
Precipitation	0.38	0.38
Decomposition gain	0.22	–
Fixation	1	1
Total In	10.87	6.16
Outputs:		
Net mineralization (release by microbes)	0.644	0.59
Denitrification	19.7	18.2
Decomposition loss	–	0.12
Leaching	2.18	0.81
Total Out	22.52	19.72
Net Difference	11.65	13.56

Table 4-5: Table of nitrogen inputs and outputs relative to the plants (g N/m^2 yr). Uptake is assumed to be the same as the plant N requirements/ amount in peak biomass. For other assumptions see Figure 5&6 and text.

Location	Site	Denitrification Estimate	Reference
N_2 flux			
New Jersey	Cedar swamp	20 & 190	Seitzinger, 1994
	mixed hardwood	150 & 250	
	herbaceous	190 & 250	
	unvegetated	190 & 220	
Pennsylvania	heath	260	
New Jersey	Cedar swamp	0-265	Watts, 1997
Boreal Alberta	fens	301	This study
	marshes	325	
^{15}N			
Florida	*Pontederia* (marsh)	365	Reddy *et al.*, 1989
	Juncus (marsh)	305	
Louisiana	clay wetland soil-$^{15}NO_3^-$ added	244	DeLaune *et al.*, 1998
	clay wetland soil-$^{15}NH_4^+$ added	79	
N_2O, no added nitrate			
Boreal Alberta	fens	0.55	This study
	marshes	0.19	
Northern Minnesota	bog	0.01-0.2	Urban *et al.*, 1988
Northern Minnesota	swamp forest	0.22-24	Zak and Grigal, 1991
Northern Minnesota	swamp forest	0.04-0.3	Merrill and Zak, 1992
Arizona	various locations in stream	0.36-10.7	Holmes *et al.*, 1996
N_2O, added nitrate			
Boreal Alberta	fens	0.79	This study
	marshes	0.23	
Florida	cypress swamp	1-16	Dierberg and Brezonik, 1983 in Seitzinger, 1994
Rhode Island	mixed hardwood	110	Groffman *et al.*, 1991 in Seitzinger, 1994
	mixed hardwood	415	
Georgia	grassed wetland	55	Lowrance *et al.*, 1995

Table 4-6: Denitrification rate estimates (μmol N/m^2 hr) in a range of North American wetlands.

5. Conclusions

Five peatlands in the boreal region of Alberta, Canada were studied to compare the classification and functional differences between the hypothesized wetland classes (marshes and fens). The resulting differences were the basis of a further comparison of nitrogen cycling, phosphorus mineralization and potential methane production between the wetland classes. A need for the simultaneous examination of these characteristics has been identified by Bridgeham *et al.* (1996), and few studies look at the differences between marshes and fens (Thormann and Bayley, 1997a-d), despite their joint occurrence in many regions, including the boreal zone (Vitt *et al.*, 1998).

Chapter two examined the ecological characteristics of species assemblages, surface water chemistry, and environmental characteristics to classify five peatlands into wetland classes. Three of the peatlands were hypothesized to be marshes, and distinct in ecological and functional characteristics from the two fens of the study. Multivariate analysis of the ecological data (species relative abundancies and environmental measurements) supported the division of the five peatlands into two groups, two fens and three marshes. The major underlying gradients identified in the DCCA support the views of Vitt (1994), although the marshes of this study demonstrated significant deposits of peat.

Functional characteristics of productivity, decomposition and nutrient pool sizes were then compared between the wetland classes, marsh and fen. Species assemblages, production, decomposition, plant phosphorus tissue concentrations, peat nutrient concentrations, and surface water nutrient/ ion concentrations differed significantly between marshes and fens, supporting the hypothesis of distinct functional differences between wetland classes. Within the marsh class, distinct differences were observed in production and water chemistry/ environmental characteristics between the lacustrine marshes and the riverine marsh of the study.

Chapter three measured monthly net nitrogen and phosphorous mineralization from June 1995 to October 1996 in the 2 boreal fens and 3 boreal marshes. Potential methane production was measured on cores sampled monthly from June 1996 to October 1996. Mean monthly net nitrogen mineralization rates were significantly higher in marshes (4.01±0.16 mg N/m^2/day) than in fens (2.55±0.62 mg N/m^2/day). Yearly sums of net nitrogen mineralization (marsh total = 644 mg N/m^2 yr; fen total = 590 mg N/m^2 yr) were not statistically different between wetland classes. It appears that the marshes and fens differ in the timing of nitrogen mineralization, while yearly amounts of mineralized nitrogen did not differ significantly between wetland types (chapter three). Fens appear to mineralize nitrogen in large amounts early in the spring, while subsequent net mineralization rates are low, presumably due to microbial competition for nitrogen. Marshes have higher rates of mineralization during the summer and fall, but do not show the same flush of nitrogen following spring thaw.

The initial C:N quotient of the peat substrate, final percent carbon of the peat after incubation, and the maximum daily temperature were significantly correlated with net nitrogen mineralization. Phosphorus mineralization was low or showed immobilization in most cases, and was weakly related to the percent carbon of incubated plant litter. Potential methane production was not different between marshes (249± 27 mg CH_4/m^2 day) and fens (200± 20 mg CH_4/m^2 day). Daily temperatures had a strong positive correlation with potential methane production, and regression analysis identified the pH of the surface water and the initial percentage of nitrogen in the peat as particularly important.

Chapter four estimated denitrification using the N_2 flux technique monthly from July 1996 to October 1996 in the 2 boreal fens and 3 boreal marshes. Denitrification estimates were not statistically different between wetland classes and averaged 19.7 g/m^2 yr in marshes and 18.2 g/m^2 yr in fens (assuming 180 ice-free days). Individual wetland fluxes ranged between 20 and 630 μmol N/m^2 hr. The pH, cation, and nitrate concentrations in the surface water at the time of core collection were the dominant factors explaining the variability in denitrification. Evidence from the N_2 flux, acetylene blockage and the internal nitrogen budgets all suggest extremely rapid turnover of sediment pore water nitrate to N_2 gas. It is suggested that denitrification is limited in these systems by the rate of surface water nitrate diffusion into the underlying sediment porewater and diffusion of ammonium to oxic microsites to be nitrified within the sediment porewater (chapter four).

In contrast with these natural wetlands, a sewage-amended marsh in southern Alberta demonstrated higher rates of denitrification when surface water nitrate concentrations were high in May. Denitrification has previously been assumed to be high based on nitrogen removal estimates from this same marsh (White, 1997). While rates were higher than other sites, the differences were not significant, implying that all the wetlands of the current study have the ability to remove nitrogen extremely quickly relative to measured sediment porewater and surface water nitrate concentrations.

The internal budget of the wetlands was unbalanced; more nitrogen was being lost relative to the plants than was being generated within the wetland. This nitrogen budget could be balanced in three ways: 1) if there was abundant ground water and surface water nitrogne inputs, or 2) if the surface water nitrogen pool was transferred to the sediment porewater, presumably through nitrification and subsequent diffusion as the surface water nitrogen concentrations are extremely large relative to the porewater nitrogen concentrations, or 3) if gross rates of ammonification and nitrification are much higher than the net rates indicate. For the marshes, one third of the surface water nitrogen pool would need to be nitrified and diffuse to the sediment porewater. This is in contrast with the fens, which require the total surface water nitrogen pool to nitrify and diffuse to the porewater six times over the year to balance inputs and outputs.

While clear functional differences existed for the parameters of production, decomposition, plant phosphorus tissue concentrations, peat nutrient concentrations, and surface water nutrient/ ion concentrations, only the timing of net nitrogen mineralization differed in the nutrient cycling processes measured. If I assume that the majority of the total nitrogen present in the peat of the wetlands is unavailable for plants and microbes (Verhoeven, 1986), and that run off adds nitrogen to the surface water nitrogen pool, then the only nitrogen pool available to make up the balance of nitrogen missing is the surface water nitrogen pool. Thus it appears that the differences in surface water nitrogen pools between fens and marshes may be the cause of observable functional differences between the wetland classes.

In conclusion, the observations of this study agree with previous suggestions (Vitt, 1994; Zoltai and Vitt, 1995; National Wetlands Working Group, 1997) that marshes and fens are distinct wetland classes where marshes have higher amounts of production, rates of decomposition, nutrient tissue concentration and nutrient surface water concentrations. Our study illustrated that marshes can have greater than 40 cm of peat and still be demonstrably distinct from fens (chapter one), which is contrary to current Canadian definitions (National Wetlands Working Group, 1997). The supply of nutrients from the surface water pool is the inferred mechanism behind the observed differences of this study, although further work with isotope tracer methods is required to support this hypothesis. The denitrification portion of this study suggests that nitrate is the rate-limiting substrate and these wetlands have the capacity to remove nitrate as fast as it is supplied to the sediment, as nitrate does not accumulate in these wetlands. Again, isotope techniques would clarify this hypothesis.

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Appendix: Raw data

				Production		
site	sitecode	type	year	vasc	moss	total
FSF	3	2	95	155.3	169.6	324.9
FSF	3	2	95	98.0	123.9	221.9
FSF	3	2	95	147.3	329.0	476.3
FSF	3	2	95	167.4	300.7	468.1
FSF	3	2	95	105.5	164.7	270.2
FSF	3	2	96	141.1	194.6	335.7
FSF	3	2	96	250.0	137.7	387.7
FSF	3	2	96	163.5	317.3	480.8
FSF	3	2	96	167.1	318.3	485.3
FSF	3	2	96	172.4	124.5	296.9
LM1	1	1	95	1011.7		1011.7
LM1	1	1	95	1564.2		1564.2
LM1	1	1	95	1371.4		1371.4
LM1	1	1	95	555.5		555.5
LM1	1	1	95	957.1		957.1
LM1	1	1	96	465.1		465.1
LM1	1	1	96	1189.4		1189.4
LM1	1	1	96	615.0		615.0
LM1	1	1	96	702.4		702.4
LM1	1	1	96	1116.5		1116.5
LM2	5	1	96	1621.6		1621.6
LM2	5	1	96	931.8		931.8
LM2	5	1	96	620.6		620.6
LM2	5	1	96	391.0		391.0
LM2	5	1	96	150.7		150.7
RM	4	1	95	317.3		317.3
RM	4	1	95	245.1		245.1
RM	4	1	95	106.4		106.4
RM	4	1	95	305.2		305.2
RM	4	1	95	670.7		670.7
RM	4	1	96	10.8		10.8
RM	4	1	96	112.7		112.7
RM	4	1	96	7.0		7.0
RM	4	1	96	271.3		271.3
RM	4	1	96	34.9		34.9
SF	2	2	95	313.3		313.3
SF	2	2	95	433.0		433.0
SF	2	2	95	397.9		397.9
SF	2	2	95	232.2		232.2
SF	2	2	95	185.8		185.8
SF	2	2	96	477.9		477.9
SF	2	2	96	416.8		416.8
SF	2	2	96	419.2		419.2
SF	2	2	96	241.9		241.9
SF	2	2	96	162.6		162.6

Note: units are in g/m^2, where LM1 = Lacustrine marsh 1, LM2 = Lacustrine marsh 2, RM = Riverine marsh, FSF = Floating sedge fen and SF = Sedge fen. Type 1 = marsh, Type 2 = fen.

Relative abundance raw data

		Relative abundance																		
site		caq	cro	cut	cat	cla	cdi	cli	equ	march	trig	pot	dros	sal	and	oxy	cala	agro	typh	poly
FSF	S4195	0	3	0	0	4	2	3	0	0	3	1	2	2	4	4	0	3	0	0
FSF	S4295	0	2	0	0	3	3	3	0	0	3	0	1	3	0	4	0	2	0	0
FSF	S4395	0	3	0	0	4	2	2	0	0	3	1	2	3	1	4	0	4	0	0
FSF	S4495	0	3	0	0	4	3	2	0	0	4	0	1	3	0	4	0	3	0	0
FSF	S4595	0	2	0	0	4	3	3	0	0	2	3	2	2	1	4	0	2	0	0
FSF	S4196	0	2	0	0	3	2	3	0	0	3	2	2	2	0	4	0	0	0	0
FSF	S4296	0	3	0	0	4	3	2	0	0	4	2	1	3	0	4	0	1	0	0
FSF	S4396	0	2	0	0	3	2	2	0	0	4	2	2	3	1	4	0	2	0	0
FSF	S4496	0	3	0	0	4	3	3	0	0	3	3	2	1	0	4	0	2	0	0
FSF	S4596	0	3	0	0	4	3	3	0	0	3	2	1	1	1	4	0	1	0	0
LM1	S1195	1	0	4	2	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0
LM1	S1295	1	0	4	3	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0
LM1	S1395	1	0	4	2	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0
LM1	S1495	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0
LM1	S1595	0	0	4	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
LM1	S1196	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LM1	S1296	1	0	4	3	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0
LM1	S1396	0	0	4	1	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0
LM1	S1496	0	0	4	2	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0
LM1	S1596	1	0	4	2	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0
LM2	S2196	2	0	4	3	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
LM2	S2296	0	0	3	3	0	0	0	0	0	0	0	0	0	0	0	3	0	4	0
LM2	S2396	1	0	4	2	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
LM2	S2496	0	0	2	2	0	0	0	0	0	0	0	0	0	0	0	2	0	1	0
LM2	S2596	0	0	2	2	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
RM	S3195	2	0	4	3	0	0	0	0	0	0	0	0	0	0	0	2	0	0	1
RM	S3295	1	0	3	2	0	0	0	0	0	0	0	0	0	0	0	3	0	0	1
RM	S3395	1	0	3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0
RM	S3495	1	0	3	2	0	0	0	0	0	0	0	0	0	0	0	4	0	4	0
RM	S3595	2	0	4	3	0	0	0	0	0	0	0	0	0	0	0	3	0	4	0
RM	S3196	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	3
RM	S3296	1	0	3	2	0	0	0	0	0	0	0	0	0	0	0	4	0	4	3
RM	S3396	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	1	0	2	1
RM	S3496	1	0	4	3	0	0	0	0	0	0	0	0	0	0	0	3	0	4	3
RM	S3596	0	0	2	2	0	0	0	0	0	0	0	0	0	0	0	2	0	0	1
SF	S5195	4	0	1	0	3	0	0	1	0	0	0	0	0	0	0	0	0	0	0
SF	S5295	4	0	2	0	4	0	0	1	0	0	0	0	0	0	0	0	0	0	0
SF	S5395	4	0	2	0	4	0	0	2	2	0	0	0	0	0	0	0	0	0	0
SF	S5495	4	0	1	0	3	0	0	2	3	0	0	0	0	0	0	0	0	0	0
SF	S5595	4	0	1	0	3	0	0	2	2	0	0	0	0	0	0	0	0	0	0
SF	S5196	4	0	2	0	4	0	0	2	2	0	0	0	0	0	0	0	0	0	0
SF	S5296	4	0	1	0	3	0	0	1	3	0	0	0	0	0	0	0	0	0	0
SF	S5396	4	0	2	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SF	S5496	4	0	2	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SF	S5596	4	0	1	0	3	0	0	0	1	0	0	0	0	0	0	0	0	0	0

Note: Relative abundancies were assigned as a proportion of peak biomass, except in the case of mosses, where it was based on the occurances in each transect. Caq = *Carex aquatilis*, cro = *Carex rostrata*, cut = *Carex utriculata*, cat = *Carex atherodes*, cla = *Carex lasiocarpa*, cdi = *Carex diandra*, cli = *Carex limosa*, equ = *Equisetum fluviatile*, march = *Marchantia polymorpha*, trig = *Triglochin maritima*, pot = *Potentilla palustre*, dros = *Drosers rotundifolia*, sal = *Salix pedicellaris*, and = *Andromeda polifolia*, oxy = *Oxycoccos quadripetalus*, cala = *Calamagrostis canadensis*, agro = *Agrostis scabra*, typh = *Typha latifolia*, poly = *Polygonum amphibium*.

Relative abundance raw data cont.

site		lemn	cicu	gali	peta	ment	meni	drep	brac	tome	calli	hama	spha	aula	moss
FSF	S4195	0	0	0	0	0	3	0	0	0	1	2	4	2	4
FSF	S4295	0	0	0	0	0	0	0	0	0	2	1	4	3	4
FSF	S4395	0	0	0	0	0	0	0	0	0	2	1	4	4	4
FSF	S4495	0	0	0	0	0	1	0	0	0	3	1	4	2	4
FSF	S4595	0	0	0	0	0	0	0	0	0	1	3	4	3	4
FSF	S4196	0	0	0	0	0	3	0	0	0	1	2	4	3	4
FSF	S4296	0	0	0	0	0	3	0	0	0	2	1	4	3	4
FSF	S4396	0	0	0	0	0	1	0	0	0	2	1	4	2	4
FSF	S4496	0	0	0	0	0	2	0	0	0	3	2	4	4	4
FSF	S4596	0	0	0	0	0	2	0	0	0	1	1	4	2	4
LM1	S1195	4	1	1	0	0	0	0	0	0	0	0	0	0	0
LM1	S1295	4	0	0	0	0	0	0	0	0	0	0	0	0	0
LM1	S1395	4	1	1	0	0	0	0	0	0	0	0	0	0	0
LM1	S1495	4	1	1	0	0	0	0	0	0	0	0	0	0	0
LM1	S1595	3	0	1	0	0	0	0	0	0	0	0	0	0	0
LM1	S1196	4	0	0	0	0	0	0	0	0	0	0	0	0	0
LM1	S1296	4	0	1	0	0	0	0	0	0	0	0	0	0	0
LM1	S1396	3	1	1	0	0	0	0	0	0	0	0	0	0	0
LM1	S1496	4	0	1	0	0	0	0	0	0	0	0	0	0	0
LM1	S1596	3	1	1	0	0	0	0	0	0	0	0	0	0	0
LM2	S2196	1	0	0	0	0	0	0	0	0	0	0	0	0	0
LM2	S2296	0	0	0	0	2	0	0	0	0	0	0	0	0	0
LM2	S2396	3	0	0	0	0	0	0	0	0	0	0	0	0	0
LM2	S2496	0	2	0	2	0	0	0	0	0	0	0	0	0	0
LM2	S2596	1	0	0	0	1	0	0	0	0	0	0	0	0	0
RM	S3195	3	0	0	0	0	0	1	0	0	0	0	0	0	1
RM	S3295	3	0	0	0	0	0	0	0	0	0	0	0	0	0
RM	S3395	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RM	S3495	1	0	0	0	0	0	1	0	0	0	0	0	0	1
RM	S3595	1	0	0	0	0	0	0	0	0	0	0	0	0	0
RM	S3196	4	0	0	0	0	0	0	0	0	0	0	0	0	0
RM	S3296	3	0	0	0	0	0	0	0	0	0	0	0	0	0
RM	S3396	2	0	0	0	0	0	0	0	0	0	0	0	0	0
RM	S3496	4	0	0	0	0	0	0	0	0	0	0	0	0	0
RM	S3596	2	0	0	0	0	0	0	0	0	0	0	0	0	0
SF	S5195	0	0	0	0	0	0	4	3	2	0	0	0	0	4
SF	S5295	0	0	0	0	0	0	4	4	3	0	0	0	0	4
SF	S5395	0	0	1	0	0	0	4	3	2	0	0	0	0	4
SF	S5495	0	0	1	0	0	0	4	2	1	0	0	0	0	4
SF	S5595	0	0	1	0	0	0	4	2	1	0	0	0	0	4
SF	S5196	0	0	0	0	0	0	4	2	1	0	0	0	0	4
SF	S5296	0	0	1	0	0	0	4	1	1	0	0	0	0	4
SF	S5396	0	0	0	0	0	0	4	4	3	0	0	0	0	4
SF	S5496	0	0	0	0	0	0	4	3	2	0	0	0	0	4
SF	S5596	0	0	1	0	0	0	4	1	1	0	0	0	0	4

Note: Relative abundancies were assigned as a proportion of peak biomass, except in the case of mosses, where it was based on the occurances in each transect. Lemn = *Lemna minor*, cicu = *Cicuta maculata*, gali = *Galium trifidum*, peta = *Petasites sagittatus*, ment = *Mentha arvensis*.

Water chemistry raw data

Site	Date	code	ID#	NO_3-N	NH_3-N	TDN	SRP	TP	TDP	CL
LM1-7	5/1/95	S1110595	11415	6.4	16.2	1782.9	98.8	328.7		47.8
LM1-8	5/15/95	S1120595	11420	3.8	29.1	2686.4	133.2	709.2		46.96
LM1-5	6/1/95	S1110695	11596	10.2	59.6	2864.7	338.7	670.8		53.34
LM1-6	6/18/95	S1120695	11676	25.2	23.6	4212.8	588	930		43.82
LM1-3	7/4/95	S1110795	11822	11.2	30.5	3764.1	363.2	594		51.21
LM1-4	7/17/95	S1120795	11958	21.7	988	6092.8	676.6	925.6		49.35
LM1-1	8/1/95	S1110895	12144	37.7	1609	8656	1061.5	1527.6		65.94
LM1-2	8/15/95	S1120895	12273	8.4	76	4367.7	349.6	877.2		30.26
LM1-9	8/30/95	S1111395	12431	10.6	62.6	3920.1	271.4	576.2		37.55
LM1-10	9/17/95	S1121395	12575	10.6	622.4	4208.5	273.7	807.6		45.5
LM1-11	9/28/95	S1131395	12619	14.6	544.5	4895.9	283.3	778.8		45.78
LM1-12	10/16/95	S1141395	12675	15	86.5	3196	84.1	652.6		69.45
LM1-13	10/30/95	S1151395	12679	22.6	79.1	2873.2	56.5	685.2		66.59
LM1-14	5/1/96	S1161395	13195	4.3	6.7	2002.1	72.6	375.7		32.58
LM1-15	5/16/96	S1181395	13222	3.7		2108.8	36.1	180.6		23.96
LM1-20	6/1/96	S1110696	13243	12.3	44.3	3383.1	113.4	470		27.06
LM1-21	6/17/96	S1120696	13290	6.5	198.2	3951	284.9	565.2		36.66
LM1-18	7/1/96	S1110796	13518	3.6	35.9	3199.4	109.7	495		110.89
LM1-19	7/16/96	S1120796	13558	4.94	166.88	3683.9	109.6	748.5		93.05
LM1-16	8/1/96	S1110896	13797	6.54	133.94	2651.2	74.7	534.6		81.4
LM1-17	8/15/96	S1120896	14059	13.96	30.34	3525.8	69.2	440.4		61.92
LM1-25	9/1/96	S1110996	14133	10.36	826.69	3571.71	326.2	760.4		54
LM1-26	9/12/96	S1120996	14191	5.85	210.06	2418.46	159.6	441.6		57.54
LM1-23	9/27/96	S1111096	14344	0.4	1.62	1824.2	91.9	297.5		55.4
LM1-24	10/17/96	S1121096	14529	5.52	61.18	2345.78	11.5	307.8		53.8
LM1-22	10/25/96	S1111196	14670	12.92	4.96	2072.21	44	757.8		46.31
LM2-1	5/16/96	S2181395	13221	4.7	0.1	1550.9	49.1	335.8		4.78
LM2-6	6/1/96	S2110696	13244	6.5	7	1968.4	95.2	260.2		4.66
LM2-7	6/17/96	S2120696	13288	4.2	22.5	2756	317.5	617		4.52
LM2-4	7/1/96	S2110796	13516	3.8	24.9	1893.8	163.6	788.7		3.6
LM2-5	7/16/96	S2120796	13561	27.78	656.56	3029.1	81.9	402		4.11
LM2-2	8/1/96	S2110896	13799	15.14	816.62	3047.5	34	482.9		4.2
LM2-3	8/15/96	S2120896	14056	19.34	141.11	2580.3	28.4	305.3		4.97
LM2-11	9/1/96	S2110996	14134	10.74	150.72	2802.39	7.1	430.3		4.58
LM2-12	9/12/96	S2120996	14194	27	734.91	3431.46	33.5	200.1		5.58
LM2-9	9/27/96	S2111096	14343	0.17	246.71	2243.43	10.1	153.7		4.45
LM2-10	10/17/96	S2121096	14528	19.25		2845.63	8.7	190.9		4.72
LM2-8	10/25/96	S2111196	14667	28.99	216.22	2655.7	6.8	200.6		4.74
RM5	6/1/95	S3110695	11593	18.3	73.6	3229.4	8.2	180.7		27.25
RM6	6/18/95	S3120695	11675	28.2	7.7	3430.1	9.5	148.9		26.1
RM3	7/4/95	S3110795	11823	12	56.1	2842.6	14.1	173.8		28.56
RM4	7/17/95	S3120795	11959	3.4	4	3306.1	16.7	154.9		32.64
RM1	8/1/95	S3110895	12146	6.1	2.9	2815.3	2.1	115.4		31.2
RM2	8/15/95	S3120895	12274	4.5	33	3120.3	2.9	394.1		27.08
RM7	8/30/95	S3111395	12430	28.1	40	2624.6	4.8	131		31
RM8	9/17/95	S3121395	12574	7.4	15.5	2533.7	3.3	357.9		25.84
RM9	9/28/95	S3131395	12622	5.9	28.3	3023	1.5	71.1		30.2
RM10	10/16/95	S3141395	12676	10.7		2577.1	2	104.7		36.05
RM11	10/30/95	S3151395	12680	10.8	255.4	2637	0.4	226.6		37.84
RM12	5/1/96	S3161395	13197	215.9	788.5	4731.7	11.8	159.9		15.78
RM13	5/16/96	S3181395	13220	4.6	25.1	1425.1	9.5	197.7		17.48
RM18	6/1/96	S3110696	13247	6.3	33.7	1871.9	1	50.3		18.81
RM19	6/17/96	S3120696	13289	7.5	21.4	2108.5	4.2	74.1		19.62
RM16	7/1/96	S3110796	13517	2.7	21.3	1631.3	2.8	64.2		20.64
RM17	7/16/96	S3120796	13559	1.56	29.98	1752.6	1.5	62.1		25

Site	Date	code	ID#	NO_3-N	NH_3-N	TDN	SRP	TP	TDP	CL
RM14	8/1/96	S3110896	13798	2.41	63.4	1976	8	99.9		23.68
RM15	8/15/96	S3120896	14057	11.8	28.94	1701.2	1.9	115.1		23.8
RM23	9/1/96	S3110996	14137	13.76	72.15	2193.88	6.3	135.5		26.64
RM24	9/12/96	S3120996	14193	2	7.9	1978.5	6.6	226.6		26.34
RM21	9/27/96	S3111096	14345	3.39	15.45	2906.9	12.1	140.2		26.88
RM22	10/17/96	S3121096	14526	4.32	21.61	2107.16	73	222.8		6.94
RM20	10/25/96	S3111196	14669	7.18	115.6	2321.65	13.2	213.9		28.8
FSF5	6/1/95	S4110695	11595	18.3	8.4	1124.5	3.3	58.4		0.77
FSF6	6/18/95	S4120695	11673	18	28.8	1503.2	5.5	40.5		0.61
FSF3	7/4/95	S4110795	11824	6.7	52	1228.5	22.2	80.8		0.57
FSF4	7/17/95	S4120795	11956	8	7.6	1361.2	14.7	92.8		1.84
FSF1	8/1/95	S4110895	12147	9.6	3	1375.4	3.5	257.9		1.06
FSF2	8/15/95	S4120895	12272	2.7	0.7	1336.8	5.1	47		0.87
FSF7	8/30/95	S4111395	12429	7.7		1200.5	3.3	57.6		1.13
FSF8	9/17/95	S4121395	12573	8.8	1.9	1074.9	6.2	77.9		0.89
FSF9	9/28/95	S4131395	12621	3.9		1403.3	5.1	116		0.69
FSF10	10/16/95	S4141395	12674	6.8		1200.3	4.4	51.3		1.54
FSF11	10/30/95	S4151395	12678	57.5	9.7	1019	2.3	47.8		0.45
FSF12	5/1/96	S4161395	13196	3.5	13.2	874.9	4.8	94.2		1.62
FSF13	5/16/96	S4181395	13224	1.7	12.1	927.1	4.5	69.3		0.81
FSF18	6/1/96	S4110696	13245	5.1	20.6	948.3	2.9	21.6		0.4
FSF19	6/17/96	S4120696	13292	5.5	15.2	1620.3	3.9	56.4		0.4
FSF16	7/1/96	S4110796	13515	1.6	17.4	1097.4	6.1	62		0.44
FSF17	7/16/96	S4120796	13562	1.04	19.34	1967.2	9.1	102.2		0.73
FSF14	8/1/96	S4110896	13795	1.5	11.6	1494.01	3.6	151		0.76
FSF15	8/15/96	S4120896	14060	0.1	21.57	1420.6	3.4	253.7		1.06
FSF23	9/1/96	S4110996	14136	22.1	2.06	1263.02	3.9	182.3		1.09
FSF24	9/12/96	S4120996	14192	0.08	15.74	1329.5	5	47.7		0.89
FSF21	9/27/96	S4111096	14347		20.39	1248.67	4.4	48.4		0.78
FSF22	10/17/96	S4121096	14530	1.77	0	1184.3	14.8	172.3		0.82
FSF20	10/25/96	S4111196	14671	0.68	4.19	1015.63	2.8	91.6		1.02
SF7	5/1/95	S5110595	11416	1.3	5.6	936	4.4	148.2		0.59
SF8	5/15/95	S5120595	11419	8.5	18	992.7	4.5	114.2		
SF5	6/1/95	S5110695	11594	8.3	23.1	1816.6	15.7	240.9		0.93
SF6	6/18/95	S5120695	11674	19.6	9.6	1709.4	12.2	40.4		0.32
SF3	7/4/95	S5110795	11821	4.6	7.2	876.8	8.9	28.8		
SF4	7/17/95	S5120795	11957	10.4	4.1	1429.7	15.1	84.9		1
SF1	8/1/95	S5110895	12145	8.9	6.8	1481	29.5	70.9		0.23
SF2	8/15/95	S5120895	12271	8	5.9	1369.2	12.5	34.5		0.46
SF9	8/30/95	S5111395	12428	9.4		1494.8	8.4	81		1.49
SF10	9/17/95	S5121395	12576	10.1	5.1	1105.4	13.8	39.3		1.31
SF11	9/28/95	S5131395	12620	2.9		1413.1	11.1	76.9		1.09
SF12	10/16/95	S5141395	12673	8.2		971.3	14.2	49.9		1.12
SF13	10/30/95	S5151395	12677	8.4	5.1	886	8.2	26.9		1.17
SF14	5/1/96	S5161395	13194	6.5	25.1	1018.2	4.2	63.2		0.39
SF15	5/16/96	S5181395	13223	3.4	0.5	652.7	3	38.6		
SF20	6/1/96	S5110696	13246	4.4	14.7	880.2	4.8	28.2		
SF21	6/17/96	S5120696	13291	4.9	9.6	1356.7	12	46.5		0.1
SF18	7/1/96	S5110796	13514	3.5	9.7	1009.8	3.2	48.4		1.85
SF19	7/16/96	S5120796	13560	0.71	22.32	1189.3	14.2	88.1		0.39
SF16	8/1/96	S5110896	13796	1.73	14.59	1130	15.8	207.8		0.22
SF17	8/15/96	S5120896	14058	10.43	10.09	1714.3	22	271.8		0.091
SF25	9/1/96	S5110996	14135	6.82	2.78	1308.91	108.3	508.7		0.28
SF26	9/12/96	S5120996	14195	0.5	0.64	1106.01	12	171.1		0.14
SF23	9/27/96	S5111096	14346	7.29	13.93	1183.99	10.5	35.8		0.34
SF24	10/17/96	S5121096	14527	3.06	4.33	952.39	10.8	54.3		0.34

Site	Date	code	ID#	NO_3-N	NH_3-N	TDN	SRP	TP	TDP	CL
SF22	10/25/96	S5111196	14668	9.34	1.09	962.38	7.3	61.8		0.48
FLB	5/23/97		16003	5.10	50.10	1584.1	1073.0	1189.2		
FLB	5/29/97		16039	7.40	107.80	1724.4	1905.0	2169.6		44.60
FLB	6/30/97		16246	4.70	390.30	3525.6	6513.6	7349.4	6400.8	
FLB	7/25/97		16499	1.50	31.50		2286.9	2801.4	2450.7	
FLB	8/21/97		16709	9.70		2916.9	1950.9	3192.0	2200.8	
FLSE	5/23/97		16002	15459.10	4476.70	23191.8	6071.0	6726.3		
FLSE	5/29/97		16040	7640.00	1019.60	10262.9	8772.0	9170.7		88.80
FLSE	6/30/97		16245	623.40	2686.00	6091.3	2156.7	2696.4	2228.1	
FLSE	7/25/97		16500	83.10	2748.80		12503.4	19007.1	13225.8	
FLSE	8/21/97		16708	64.40	1953.60	4871.1	9063.6	34364.4	9408	
LM1	5/28/97		16037	5.20		1772.8	129.7	332.0		1.00
LM1	6/30/97		16242	4.30	4.40	2641.1	135.9	260.0	209.1	
LM1	7/25/97		16496	9.90	2.30		91.6	358.0	146.6	
LM1	8/21/97		16705	11.90	1816.50	4941.0	751.2	2296.8	842.7	
LM2	5/28/97		16036	3.30	1.50	2069.4	16.7	97.4		3.90
LM2	6/30/97		16243	2.80	3.50	3189.9	11.2	178.3	44.8	
LM2	7/25/97		16497	6.50	.10		9.2	370.8	49.3	
LM2	8/21/97		16706	38.30	67.30	2266.6	27.7	656.8	72.1	
PM	5/23/97		15999	12.00	967.30	444.8	2550.0	2632.2		
PM	5/29/97		16041	21.40	821.00	3851.1	249.0	2610.0		44.30
PM	6/30/97		16244	44.40	81.00	4335.7	3514.2	3778.8	3613.2	
PM	7/25/97		16498	7.40	57.10		1217.0	1487.0	1377	
PM	8/21/97		16707	2.90	3.50	4187.8	886.0	1488.0	1056	
FLI	5/23/97		16001	68672.80	8306.10	84245.6	13995.0	16223.1		

Note: Site abbreviations are as in production raw data, with the additional sites FLB = Frank lake site 2, FLSE = Frank lake site 1, PM = prairie control marsh (no other data recorded), FLI = Frank lake sewage water from the inlet pipe. NO_3-N, NH_3-N, TDN, SRP, TP, and TDP are in µg/L, while Cl, is in mg/L.

Water chemistry raw data cont.

Site	Date	code	ID#	SO_4	Na	K	Ca	Mg	pH	ALK	HCO_3	Corr. Cond.
LM1-7	5/1/95	S1110595	11415	7.36	56.6	12.26	27.9	10.4	6.55	159.88	194.92	
LM1-8	5/15/95	S1120595	11420	19.68	36	12	32.1	10.85	6.98	181.5	221.29	
LM1-5	6/1/95	S1110695	11596	6.58	104.3	9.42	42.9	14.3	6.83	236.25	288.04	661.1
LM1-6	6/18/95	S1120695	11676	7.64	126.75	8.96	43.1	9.66	6.67	180.75	220.37	511.84
LM1-3	7/4/95	S1110795	11822	11.46	68.9	9.54	31.2	13	7.14	195.13	237.9	510.04
LM1-4	7/17/95	S1120795	11958	8.73	71.7	3.83	43	16.34	7.15	245.5	299.32	613.64
LM1-1	8/1/95	S1110895	12144	13.4	77.6	7.04	39.9	16.88	7.22	223	271.88	689.52
LM1-2	8/15/95	S1120895	12273	17.26	57.54	0.57	27.2	11.75	7.09	162	197.51	456.36
LM1-9	8/30/95	S1111395	12431	10.55	53.2	9.59	31.4	10.7	7.2	176	214.58	486.4
LM1-10	9/17/95	S1121395	12575	6.49	70.2	7.6	40.4	13.18	7.26	237.88	290.02	622.486
LM1-11	9/28/95	S1131395	12619	9.55	80.8	7.68	44.8	15	7.19	268.13	326.9	704.98
LM1-12	10/16/95	S1141395	12675	25.9	76.8	17.3	36.7	12.63	7.01	203.88	248.57	660.74
LM1-13	10/30/95	S1151395	12679	32.5	89.9	14.2	40.2	14.56	6.98	216.75	264.26	733.50
LM1-14	5/1/96	S1161395	13195	50.4	60.8	19.3	41.9	14.4	8.01	202.63	247.04	597.84
LM1-15	5/16/96	S1181395	13222	70.2	31.3	21.4	50.3	15	7.56	167	203.61	
LM1-20	6/1/96	S1110696	13243	55.65	38.3	25.6	63.9	17.9	6.95	225.38	274.78	571.2
LM1-21	6/17/96	S1120696	13290	16.26	50.9	25.1	55.4	18	6.82	270.38	329.65	541.2
LM1-18	7/1/96	S1110796	13518	24.16	96	16	51	14.9	7.15	219.38	267.47	755.04
LM1-19	7/16/96	S1120796	13558	9.08	80	17.4	47.3	12.6	7.22	212.25	258.78	518.4
LM1-16	8/1/96	S1110896	13797	5.32	74.5	16.2	49.7	13.8	6.89	233.88	285.14	729.96
LM1-17	8/15/96	S1120896	14059	4.16	58.2	13.3	40.9	11.2	7.25	191.25	233.17	510.72
LM1-25	9/1/96	S1110996	14133	3.4	62.1	11.3	46.5	13	6.72	221.88	270.51	595.32
LM1-26	9/12/96	S1120996	14191	5.06	59.6	12	43.3	12	6.73	204.5	249.33	557.75
LM1-23	9/27/96	S1111096	14344	5.97	55.5	11.3	40.4	11.7	6.96	190.75	232.57	551.18
LM1-24	10/17/96	S1121096	14529	11.84	57.2	11.2	40.4	12.4	6.63	177.38	216.16	498.48
LM1-22	10/25/96	S1111196	14670	21.72	56.8	11.4	39.6	12.6	6.72	181.25	220.98	489.6
LM2-1	5/16/96	S2181395	13221	17.08	22.4	15.9	42.1	28.7	7.81	231.13	281.79	
LM2-6	6/1/96	S2110696	13244	12.48	29.5	16.4	47.2	36.5	7.55	220.38	268.68	518
LM2-7	6/17/96	S2120696	13288	9.68	31.4	16.3	44.3	37.8	7.32	308.38	375.98	488.4
LM2-4	7/1/96	S2110796	13516	5.16	25.6	12.1	51.9	31.9	7.32	310.63	378.72	525.31
LM2-5	7/16/96	S2120796	13561	18.81	28.9	13.5	40.5	32.7	7.39	274.75	334.98	414
LM2-2	8/1/96	S2110896	13799	18.28	29.3	14.1	40.6	35.4	7.63	291.5	355.4	578.55
LM2-3	8/15/96	S2120896	14056	17.88	28.1	13.7	38.1	33.5	7.49	268.5	327.36	484.98
LM2-11	9/1/96	S2110996	14134	22.7	30.5	14.2	36.8	34.1	7.75	270.5	329.8	522.74
LM2-12	9/12/96	S2120996	14194	20.52	37.5	15.1	42.6	35.3	7.88	311.25	379.48	558.76
LM2-9	9/27/96	S2111096	14343	25.52	31.4	13.8	37.7	34	7.74	282.25	344.12	551.43
LM2-10	10/17/96	S2121096	14528	24.26	30.5	14.6	39.9	34.8	7.59	275.75	337.42	520.48
LM2-8	10/25/96	S2111196	14667	24.84	30	14.1	37.9	35.1	7.71	269.75	328.88	485.76
RM5	6/1/95	S3110695	11593	47.5	52.5	11.8	18.36	17.4	6.8	117.63	143.41	455.94
RM6	6/18/95	S3120695	11675	54.84	49.66	10.37	16.92	22.8	8	117.88	143.71	434.72
RM3	7/4/95	S3110795	11823	47.58	51.5	2.14	17.98	16.76	7.61	117.75	143.56	448.4
RM4	7/17/95	S3120795	11959	54.3	58.2	10.57	16.5	16.42	7.15	115.5	140.82	0
RM1	8/1/95	S3110895	12146	56.28	54	11.9	15.5	18.08	8.57	108.38	132.13	493.58
RM2	8/15/95	S3120895	12274	49.76	61.6	0.76	17.7	15.05	7.7	110.13	134.27	434.91
RM7	8/30/95	S3111395	12430	48.72	50.4	8.45	17.05	15.4	7.73	113.75	138.69	411.4
RM8	9/17/95	S3121395	12574	52.6	52.9	13.52	20	14.9	7.59	130.13	158.65	483.34
RM9	9/28/95	S3131395	12622	55.15	56.5	14.16	21.25	6.42	7.95	139.75	170.69	522.11
RM10	10/16/95	S3141395	12676	49.85	52.29	1.49	20.1	13.96	7.4	133.75	163.07	499.59
RM11	10/30/95	S3151395	12680	50.16	53.3	17.36	24.1	17.92	7.38	153.5	187.15	522.34
RM12	5/1/96	S3161395	13197	44.91	24.1	11.1	43.2	11.8	7.83	138.63	169.01	426.12
RM13	5/16/96	S3181395	13220	49.66	26.2	11.4	47	12.9	8.55	147.75	180.14	
RM18	6/1/96	S3110696	13247	50.04	28.4	11.8	47.1	14.2	7.74	152.63	186.08	418.6
RM19	6/17/96	S3120696	13289	47.85	29.4	10.4	40.7	14	7.49	145.38	177.24	373.2
RM16	7/1/96	S3110796	13517	46.6	29.9	9.52	39.5	13.8	7.62	145.13	176.94	398.64
RM17	7/16/96	S3120796	13559	50.24	32.1	10.2	38.1	14.4	7.64	141.38	172.37	333.6

Site	Date	code	ID#	SO_4	Na	K	Ca	Mg	pH	ALK	HCO_3	Corr. Cond.
RM14	8/1/96	S3110896	13798	47.86	32.3	11	38.8	15	7.52	153.25	186.84	498.96
RM15	8/15/96	S3120896	14057	48.04	32.1	10.9	39.5	15	7.73	152.75	186.24	417.52
RM23	9/1/96	S3110996	14137	45.68	35	11.6	44.1	16	7.88	175	213.36	481.4
RM24	9/12/96	S3120996	14193	47.44	37	11.8	45.6	16.5	7.95	177.63	198.27	489.6
RM21	9/27/96	S3111096	14345	44.64	35.9	12	46.6	16.6	8.58	183	223.12	515.06
RM22	10/17/96	S3121096	14526	10.74	38.2	12.1	47.9	16.7	7.64	186.5	227.38	469.14
RM20	10/25/96	S3111196	14669	42.48	37.4	12.3	50.7	17.8	7.31	190.25	231.96	452.1
FSF5	6/1/95	S4110695	11595		1.86	2.89	7.22	4.19	5.47	25.38	30.94	72.01
FSF6	6/18/95	S4120695	11673		0.87	1.24	7.15	3.82	6.12	21.75	26.52	55.35
FSF3	7/4/95	S4110795	11824		1.95	5.74	8.46	4.72	6.04	29.38	35.81	75.40
FSF4	7/17/95	S4120795	11956	0.64	2.05	1.08	9.02	5.13	5.61	27.63	33.68	74.59
FSF1	8/1/95	S4110895	12147	0.82	2.37	0.8	9.6	4.71	5.87	25.25	30.79	70.91
FSF2	8/15/95	S4120895	12272	0.46	1.82	1.01	9.46	4.34	6.83	26	31.7	64.07
FSF7	8/30/95	S4111395	12429		2.05	0.74	8.61	4.44	6.07	24.63	30.02	60.6
FSF8	9/17/95	S4121395	12573		2.09	0.35	8.17	4.12	5.91	22.25	27.13	62.57
FSF9	9/28/95	S4131395	12621	0.2	2.06	0.22	7.81	3.7	5.61	21.88	26.67	63.53
FSF10	10/16/95	S4141395	12674	0.13	1.96	0.37	6.59	3.04	5.73	16.13	19.66	50.932
FSF11	10/30/95	S4151395	12678	0.13	1.84	0.13	5.45	3	5.95	15.38	18.75	46.14
FSF12	5/1/96	S4161395	13196	0	1.4	3.28	4.91	2.48	6.16	17.38	21.18	48.548
FSF13	5/16/96	S4181395	13224		1.6	2.23	5.21	2.65	6.28	17.25	21.03	
FSF18	6/1/96	S4110696	13245		1.65	1.74	6.33	3.38	5.97	50	60.96	49.14
FSF19	6/17/96	S4120696	13292		1.88	1.53	7.56	3.83	6.21	23.13	28.19	52.8
FSF16	7/1/96	S4110796	13515		1.7	0.99	6.03	2.99	6.15	18.38	22.4	44.16
FSF17	7/16/96	S4120796	13562	0.13	1.93	1.27	7.38	3.61	6.06	27.5	33.53	44.16
FSF14	8/1/96	S4110896	13795	0.07	2.01	1.68	10.36	5.4	6.36	34.38	41.91	95.27
FSF15	8/15/96	S4120896	14060	0.23	2.09	2.2	11.6	5.84	6.13	37.88	46.18	82.35
FSF23	9/1/96	S4110996	14136	0.12	2.32	1.84	12.7	6.34	6.4	43.75	53.34	97.48
FSF24	9/12/96	S4120996	14192	0.07	2.05	1.68	6.73	3.58	6.49	16.88	20.57	53.55
FSF21	9/27/96	S4111096	14347	0.07	1.82	1.35	8.5	5.42	5.89	29.5	35.97	72.14
FSF22	10/17/96	S4121096	14530	0.27	1.91	1.01	7.51	3.44	6.42	20.84	25.41	57.59
FSF20	10/25/96	S4111196	14671	0.07	1.83	0.61	8.62	4.84	6.21	27.25	33.22	60.11
SF7	5/1/95	S5110595	11416	0.99	2.85	2.83	16.78	7.58	6.28	65.38	79.71	
SF8	5/15/95	S5120595	11419	0.6	6.44	0.19	17.58	7.72	6.83	63.38	77.27	
SF5	6/1/95	S5110695	11594	1.33	3.64	0.34	17.7	7.79	6.54	67.38	82.14	151.98
SF6	6/18/95	S5120695	11674	0.68	1.32	0.47	20.85	8.41	6.36	71.75	87.48	149.35
SF3	7/4/95	S5110795	11821		2.5	0.08	16.5	6.28	6.56	59	71.93	121.92
SF4	7/17/95	S5120795	11957	0.58	2.92	0.13	27.1	9.86	7.38	89.5	109.12	189.58
SF1	8/1/95	S5110895	12145		2.88	0.17	29.35	10.78	6.8	98.13	119.64	211.11
SF2	8/15/95	S5120895	12271	1.69	2.22	0.58	18.7	7.53	6.73	56.63	69.04	121.37
SF9	8/30/95	S5111395	12428		2.53	0.23	23.5	8.37	6.76	75.5	92.05	157.04
SF10	9/17/95	S5121395	12576		2.95	0.07	31.65	10.28	6.73	112.13	136.7	223.56
SF11	9/28/95	S5131395	12620	0.14	2.69	2.45	31.75	11.51	6.67	113.5	138.38	229.40
SF12	10/16/95	S5141395	12673	0.17	3.05	0.07	25	8.77	6.92	100.13	122.07	197.05
SF13	10/30/95	S5151395	12677	0.19	2.9	0.09	19.1	6.98	6.51	74.38	90.68	151.54
SF14	5/1/96	S5161395	13194	1.1	1.93	3.1	14.9	5.08	6.79	53.75	65.53	116.18
SF15	5/16/96	S5181395	13223		2.12	1.16	11.8	3.86	7.08	40.63	49.53	
SF20	6/1/96	S5110696	13246	0	2.63	0.58	16.2	5.48	6.9	56.38	68.73	101.36
SF21	6/17/96	S5120696	13291		2.87	0.29	21.5	6.8	6.66	69.25	84.43	123.36
SF18	7/1/96	S5110796	13514	0.33	2.14	0.09	16.6	5.52	6.94	51.5	62.79	96.88
SF19	7/16/96	S5120796	13560	0.21	2.19	0.11	21.1	6.84	6.7	66.25	80.77	98.64
SF16	8/1/96	S5110896	13796	0.14	3.02	0.15	32	10.4	6.99	103.88	126.65	225.72
SF17	8/15/96	S5120896	14058	0.21	2.62	0.33	25.5	8.4	6.81	78.25	95.4	143.51
SF25	9/1/96	S5110996	14135	0.34	3.98	0.12	46.5	15.1	6.83	163.38	199.19	311.19
SF26	9/12/96	S5120996	14195	0.07					6.87	100.75	122.84	187.2
SF23	9/27/96	S5111096	14346	0.12	2.7	0.39	20.1	7.62	6.76	68.38	83.36	139.31
SF24	10/17/96	S5121096	14527	0.17	2.83	0.44	19.8	7.48	6.83	68.5	83.52	129.12

Site	Date	code	ID#	SO_4	Na	K	Ca	Mg	pH	ALK	HCO_3	Corr. Cond.
SF22	10/25/96	S5111196	14668	0.17	2.89	0.41	18.2	6.86	6.76	62.5	76.2	112.19
FLB	5/23/97		16003									
FLB	5/29/97		16039	65.60					7.98	209.75	255.73	691.60
FLB	6/30/97		16246						7.73	307.76	375.23	864.00
FLB	7/25/97		16499						8.83	380.54	384.52	1061.40
FLB	8/21/97		16709						8.90	402.29	403.27	1122.70
FLSE	5/23/97		16002									
FLSE	5/29/97		16040	87.10					7.65	262.51	320.06	1056.00
FLSE	6/30/97		16245						7.69	415.73	506.86	1422.00
FLSE	7/25/97		16500						7.76	471.81	575.40	1558.20
FLSE	8/21/97		16708						7.71	591.65	721.35	1620.00
LM1	5/28/97		16037	35.00					7.61	168.99	206.33	429.50
LM1	6/30/97		16242						7.41	193.92	236.43	476.40
LM1	7/25/97		16496						7.34	216.53	263.99	449.40
LM1	8/21/97		16705						7.12	296.61	361.63	593.60
LM2	5/28/97		16036	14.80					7.99	261.18	318.40	500.60
LM2	6/30/97		16243						8.12	231.13	281.80	446.50
LM2	7/25/97		16497						7.99	250.06	304.88	506.70
LM2	8/21/97		16706						7.35	277.85	338.76	556.90
PM	5/23/97		15999									
PM	5/29/97		16041	1305.90					8.16	463.78	565.44	3266.00
PM	6/30/97		16244						8.10	639.64	779.86	3806.40
PM	7/25/97		16498						9.39	523.56	395.30	4301.40
PM	8/21/97		16707						9.42	522.05	366.11	5285.80

Note: Site abbreviations are as in production raw data, with the additional sites FLB = Frank lake site 2, FLSE = Frank lake site 1, PM = prairie control marsh (no other data recorded), FLI = Frank lake sewage water from the inlet pipe. SO_4, Na, K, Ca, Mg, alkalinity and bicarbonate are in mg/L. Corr. Cond. is conductivity temperature corrected to 25°C.

Physical parameter raw data

Site	Date	Water	Week	anoxic	soil	thaw
LM1-7	5/1/95	36.7			1.96	8
LM1-8	5/15/95	34.7			3.92	10
LM1-5	6/1/95	29.3	24.57	37.6	6.86	14
LM1-6	6/18/95	31	23.70		6.86	36
LM1-3	7/4/95	30.9	26.51	9.8	9.8	50
LM1-4	7/17/95	25.7	23.05		7.84	100
LM1-1	8/1/95	23.8	20.65	13.3	11.76	100
LM1-2	8/15/95	32.9	25.30		7.84	100
LM1-9	8/30/95	28.7	25.66	5.6	10.78	100
LM1-10	9/17/95	24.3	24.21		7.84	100
LM1-11	9/28/95	22.7	21.82	2.7	4.9	100
LM1-12	10/16/95	22.6	20.56		2.94	100
LM1-13	10/30/95	21.3	20.77		1.96	100
LM1-14	5/1/96	100	20.54		0	4
LM1-15	5/16/96	82.1	51.49		3.92	4
LM1-20	6/1/96	39.15	31.19	29.7	8.82	16
LM1-21	6/17/96	30.05	24.81		4.9	30
LM1-18	7/1/96	50.5	36.65	30.7	12.74	35
LM1-19	7/16/96	38.65	30.93		7.84	46
LM1-16	8/1/96	39.3	30.57	17.7	15.68	100
LM1-17	8/15/96	41.6	32.19		12.74	100
LM1-25	9/1/96	31.65	27.27	8.3	13.72	100
LM1-26	9/12/96	31.2	26.49		17.64	100
LM1-23	9/27/96	31.1	26.12	11.8	5.88	100
LM1-24	10/17/96	30	25.22		3.92	100
LM1-22	10/25/96	29	24.96		1.96	100
LM2-1	5/16/96	21	24.46		2.94	22
LM2-6	6/1/96	21	24.46	22.7	11.76	42
LM2-7	6/17/96	21	23.87		10.78	70
LM2-4	7/1/96	21.3	20.07	16	14.7	100
LM2-5	7/16/96	20.5	19.60		15.68	100
LM2-2	8/1/96	17.2	19.48	15.3	17.64	100
LM2-3	8/15/96	19.8	19.31		15.68	86
LM2-11	9/1/96	16.4	17.90	3.5	13.72	100
LM2-12	9/12/96	17.7	18.26		10.78	76
LM2-9	9/27/96	19.1	18.28	17	6.86	51.4
LM2-10	10/17/96	18.65	18.55		3.92	100
LM2-8	10/25/96	18.05	18.20		1.96	100

Site	Date	Water	Week	anoxic	soil	thaw
RM5	6/1/95	6.7	11.53	-3.8	13.72	80
RM6	6/18/95	2.9	9.60	-3.8	11.76	100
RM3	7/4/95	5.7	10.92	-6.8	17.64	90.5
RM4	7/17/95	-0.7	7.49	-6.8	13.72	100
RM1	8/1/95	-1.6	6.67	-0.8	13.23	100
RM2	8/15/95	6	10.88	-0.8	12.74	91
RM7	8/30/95	5.95	10.70	-8.3	13.23	100
RM8	9/17/95	-1.9	10.71	-8.3	9.8	100
RM9	9/28/95	-3.2	6.96	-6.8	4.9	100
RM10	10/16/95	-2.65	5.56	-6.8	2.94	100
RM11	10/30/95	-2.1	5.79	-6.8	1.96	100
RM12	5/1/96	47.9	35.46		4.9	13
RM13	5/16/96	47.55	35.46		7.84	18
RM18	6/1/96	47.9	35.66	40.3	12.74	42
RM19	6/17/96	48.8	36.10		16.66	91
RM16	7/1/96	50.5	37.15	13.9	16.66	76
RM17	7/16/96	50.5	37.27		18.62	97
RM14	8/1/96	49.9	37.73	19.6	19.6	84
RM15	8/15/96	51.8	37.92		16.66	100
RM23	9/1/96	51	37.48	11.5	16.66	100
RM24	9/12/96	47.4	35.75		11.76	93.5
RM21	9/27/96	50	36.71	7.8	7.84	100
RM22	10/17/96	49.3	36.45		4.9	100
RM20	10/25/96	47.8	35.63		3.92	100
FSF5	6/1/95	-5.8	0.00	-14	13.72	100
FSF6	6/18/95	7.3	11.88		7.84	100
FSF3	7/4/95	5.7	11.49	-5.7	12.74	100
FSF4	7/17/95	0.1	8.92		13.72	100
FSF1	8/1/95	1.7	8.72	-3.3	13.72	100
FSF2	8/15/95	7.3	12.81		11.76	100
FSF7	8/30/95	5.5	11.00	-4.7	11.76	100
FSF8	9/17/95	2.1	10.94		9.8	100
FSF9	9/28/95	0.2	9.07	-11.8	6.86	100
FSF10	10/16/95	1.2	7.96		4.9	100
FSF11	10/30/95	2.6	7.66		1.96	100
FSF12	5/1/96	12.6	9.07		4.9	16
FSF13	5/16/96	10.9	14.10		6.86	100
FSF18	6/1/96	9.65	13.57	-5.5	11.76	100
FSF19	6/17/96	8.7	12.99		12.74	100
FSF16	7/1/96	10.8	14.55	-2.6	17.64	100
FSF17	7/16/96	9	12.99		14.7	100
FSF14	8/1/96	8.9	13.05	-8.7	16.66	100
FSF15	8/15/96	10.7	13.87		14.7	100
FSF23	9/1/96	8.45	13.05	-6.7	12.74	100
FSF24	9/12/96	7.05	11.64		10.78	100
FSF21	9/27/96	9.8	12.69	-1.3	5.88	100
FSF22	10/17/96	9.8	13.34		2.94	100
FSF20	10/25/96	8.75	12.76		1.96	100

Note: Water is the water level above the peat surface (cm) on that date, week is the average water level above the peat surface of the 7 days preceding that date (in cm), anoxic is the anoxic depth below the peat surface in cm, soil is the temperature of the peat on that date, and thaw is the thaw depth/peat depth in cm, values were not recorded past 1 m.

Decomposition raw data

Year	Month	Site	Replicate	Transect #	Tag #	Date Picked up	Expt.	Lab ID #	% Weight Loss
95	June	LM1	1	1	245	95-07-06	30	5036	53.56
95	June	LM1	2	1	19	95-07-06	30	5037	42.46
95	June	LM1	3	1	196	95-07-06	30	5038	61.64
95	June	LM1	1	2	49	95-07-06	30	5039	54.28
95	June	LM1	2	2	231	95-07-06	30	5040	59.52
95	June	LM1	3	2	226	95-07-06	30	5041	50.53
95	June	FSF	1	1	117	95-07-06	30	5000	34.56
95	June	FSF	2	1	85	95-07-06	30	5001	39.83
95	June	FSF	3	1	15	95-07-06	30	5002	17.45
95	June	FSF	1	2	159	95-07-06	30	5003	22.83
95	June	FSF	2	2	127	95-07-06	30	5004	37.08
95	June	FSF	3	2	215	95-07-06	30	5005	40.45
95	June	SF	1	1	103	95-07-06	30	5066	26.75
95	June	SF	2	1	187	95-07-06	30	5067	35.54
95	June	SF	3	1	200	95-07-06	30	5068	29.90
95	June	SF	1	2	83	95-07-06	30	5069	31.31
95	June	SF	2	2	123	95-07-06	30	5070	29.35
95	June	SF	3	2	115	95-07-06	30	5071	31.26
95	June	RM	1	1	114	95-07-06	30	5030	18.00
95	June	RM	2	1	119	95-07-06	30	5031	41.32
95	June	RM	3	1	204	95-07-06	30	5032	29.20
95	June	RM	1	2	31	95-07-06	30	5033	38.35
95	June	RM	2	2	157	95-07-06	30	5034	43.81
95	June	RM	3	2	18	95-07-06	30	5035	43.04
95	July	LM1	1	1	137	95-08-01	30	5043	53.35
95	July	LM1	2	1	232	95-08-01	30	5044	66.07
95	July	LM1	3	1	77	95-08-01	30	5047	63.32
95	July	LM1	1	2	92	95-08-01	30	5051	53.21
95	July	LM1	2	2	51	95-08-01	30	5052	72.14
95	July	LM1	3	2	2	95-08-01	30	5053	56.75
95	July	FSF	1	1	290	95-08-01	30	5008	57.38
95	July	FSF	2	1	281	95-08-01	30	5009	46.91
95	July	FSF	3	1	274	95-08-01	30	5011	59.55
95	July	FSF	1	2	280	95-08-01	30	5012	55.73
95	July	FSF	2	2	267	95-08-01	30	5016	52.50
95	July	FSF	3	2	274	95-08-01	30	5017	45.16
95	July	SF	1	1	288	95-08-01	30	5018	48.32
95	July	SF	2	1	266	95-08-01	30	5019	42.87
95	July	SF	3	1	271	95-08-01	30	5023	45.83
95	July	SF	1	2	265	95-08-01	30	5025	44.14
95	July	SF	2	2	296	95-08-01	30	5028	39.08
95	July	SF	3	2	276	95-08-01	30	5029	39.41
95	July	RM	1	1	284	95-08-01	30	5057	49.73
95	July	RM	2	1	278	95-08-01	30	5058	52.74
95	July	RM	3	1	268	95-08-01	30	5059	51.35
95	July	RM	1	2	282	95-08-01	30	5060	41.63
95	July	RM	2	2	258	95-08-01	30	5062	43.52
95	July	RM	3	2	269	95-08-01	30	5065	35.03
95	August	LM1	1	?	304	95-08-31	30	5098	51.81
95	August	LM1	2	?	311	95-08-31	30	5099	56.36
95	August	LM1	3	?	302	95-08-30	30	5100	52.44
95	August	LM1	4	?	315	95-08-30	30	5104	52.06
95	August	LM1	5	?	320	95-08-30	30	5105	57.73

Year	Month	Site	Replicate	Transect #	Tag #	Date Picked up	Expt.	Lab ID #	% Weight Loss
95	August	LM1	6	?	305	95-08-30	30	5106	47.20
95	August	FSF	1	1	322	95-08-31	30	5085	49.75
95	August	FSF	2	1	323	95-08-31	30	5089	50.87
95	August	FSF	3	1	301	95-08-31	30	5091	52.38
95	August	FSF	1	2	270	95-08-31	30	5095	55.90
95	August	FSF	2	2	317	95-08-31	30	5096	53.34
95	August	FSF	3	2	263	95-08-31	30	5097	54.92
95	August	SF	1	1	316	95-08-31	30	5112	45.23
95	August	SF	2	1	312	95-08-31	30	5113	46.68
95	August	SF	3	1	327	95-08-31	30	5114	51.15
95	August	SF	1	2	283	95-08-31	30	5116	41.63
95	August	SF	2	2	308	95-08-31	30	5119	40.74
95	August	SF	3	2	306	95-08-31	30	5120	43.25
95	August	RM	1	1	319	95-08-31	30	5072	45.59
95	August	RM	2	1	260	95-08-31	30	5073	46.01
95	August	RM	3	1	300	95-08-31	30	5075	45.54
95	August	RM	1	2	309	95-08-31	30	5080	46.56
95	August	RM	2	2	307	95-08-31	30	5082	46.00
95	August	RM	3	2	326	95-08-31	30	5083	49.76
96	OverWinter	LM1	1	1	369	96-06-01	30	5135	60.68
96	OverWinter	LM1	2	1	331	96-06-01	30	5136	66.52
96	OverWinter	LM1	3	1	381	96-06-01	30	5137	62.55
96	OverWinter	LM1	1	2	378	96-06-01	30	5138	65.21
96	OverWinter	LM1	2	2	328	96-06-01	30	5139	64.12
96	OverWinter	LM1	3	2	376	96-06-01	30	5142	61.14
96	OverWinter	FSF	1	2	367	96-06-02	30	5123	55.55
96	OverWinter	FSF	2	2	379	96-06-02	30	5124	56.65
96	OverWinter	FSF	3	2	364	96-06-02	30	5126	60.50
96	OverWinter	FSF	1	1	382	96-06-02	30	5128	57.91
96	OverWinter	FSF	2	1	374	96-06-02	30	5129	59.21
96	OverWinter	FSF	3	1	362	96-06-02	30	5131	53.76
96	OverWinter	SF	1	1	341	96-06-02	30	5154	47.86
96	OverWinter	SF	2	1	349	96-06-02	30	5155	46.13
96	OverWinter	SF	3	1	363	96-06-02	30	5156	48.50
96	OverWinter	SF	1	2	377	96-06-02	30	5158	47.09
96	OverWinter	SF	2	2	365	96-06-02	30	5159	46.24
96	OverWinter	SF	3	2	353	96-06-02	30	5162	51.18
96	OverWinter	RM	1	2	368	96-06-01	30	5143	61.74
96	OverWinter	RM	1	1	373	96-06-01	30	5150	64.67
96	OverWinter	RM	2	1	371	96-06-01	30	5151	58.27
96	OverWinter	RM	3	1	366	96-06-01	30	5152	65.00
96	June	LM1	1	2	426	96-06-30	30	5163	58.23
96	June	LM1	2	2	430	96-06-30	30	5164	53.99
96	June	LM1	3	2	446	96-06-30	30	5165	55.86
96	June	LM1	1	1	467	96-06-30	30	5166	52.09
96	June	LM1	2	1	470	96-06-30	30	5167	58.15
96	June	LM1	3	1	450	96-06-30	30	5168	49.07
96	June	LM2	1	1	465	96-06-30	30	5180	56.89
96	June	LM2	2	1	474	96-06-30	30	5180	47.64
96	June	LM2	1	2	471	96-06-30	30	5182	57.65
96	June	LM2	2	2	479	96-06-30	30	5183	64.51
96	June	LM2	3	2	480	96-06-30	30	5184	62.73
96	June	FSF	1	1	458	96-06-30	30	5174	51.24
96	June	FSF	2	1	460	96-06-30	30	5175	44.34
96	June	FSF	3	1	459	96-06-30	30	5176	50.11

Year	Month	Site	Replicate	Transect #	Tag #	Date Picked up	Expt.	Lab ID #	% Weight Loss
96	June	FSF	1	2	419	96-06-30	30	5177	45.56
96	June	FSF	2	2	437	96-06-30	30	5178	47.37
96	June	FSF	3	2	406	96-06-30	30	5179	47.63
96	June	SF	1	1	403	96-06-30	30	5185	36.43
96	June	SF	2	1	423	96-06-30	30	5186	39.95
96	June	SF	3	1	428	96-06-30	30	5187	35.00
96	June	SF	1	2	431	96-06-30	30	5188	31.68
96	June	SF	2	2	462	96-06-30	30	5189	33.99
96	June	SF	3	2	417	96-06-30	30	5190	34.20
96	June	RM	1	1	447	96-06-30	30	X	54.64
96	June	RM	2	1	405	96-06-30	30	5169	49.80
96	June	RM	3	1	481	96-06-30	30	5170	59.83
96	June	RM	1	2	482	96-06-30	30	5171	55.76
96	June	RM	2	2	469	96-06-30	30	5172	60.84
96	June	RM	3	2	413	96-06-30	30	5173	60.00
96	July	LM1	1	1	484	96-07-31	30	5191	58.09
96	July	LM1	2	1	497	96-07-31	30	5192	50.48
96	July	LM1	3	1	495	96-07-31	30	5193	49.86
96	July	LM1	1	2	513	96-07-31	30	5194	63.16
96	July	LM1	2	2	488	96-07-31	30	5195	56.32
96	July	LM1	3	2	514	96-07-31	30	5196	62.86
96	July	LM2	1	1	487	96-07-31	30	5215	67.52
96	July	LM2	2	1	524	96-07-31	30	5216	70.81
96	July	LM2	3	1	496	96-07-31	30	5217	59.05
96	July	LM2	1	2	493	96-07-31	30	5218	57.51
96	July	LM2	2	2	501	96-07-31	30	5219	63.66
96	July	LM2	3	2	503	96-07-31	30	5220	69.48
96	July	FSF	1	2	505	96-07-31	30	5209	45.50
96	July	FSF	2	2	523	96-07-31	30	5210	55.32
96	July	FSF	3	2	522	96-07-31	30	5211	52.46
96	July	FSF	1	1	527	96-07-31	30	5212	56.88
96	July	FSF	2	1	494	96-07-31	30	5213	57.16
96	July	FSF	3	1	525	96-07-31	30	5214	52.03
96	July	SF	1	1	489	96-07-31	30	5203	47.65
96	July	SF	2	1	516	96-07-31	30	5204	43.87
96	July	SF	1	2	483	96-07-31	30	5205	40.54
96	July	SF	3	1	528	96-07-31	30	5206	56.56
96	July	SF	2	2	529	96-07-31	30	5207	44.50
96	July	SF	3	2	526	96-07-31	30	5208	43.30
96	July	RM	1	2	492	96-07-31	30	5197	63.42
96	July	RM	2	2	502	96-07-31	30	5198	65.50
96	July	RM	3	2	472	96-07-31	30	5199	62.09
96	July	RM	1	1	486	96-07-31	30	5200	59.97
96	July	RM	2	1	504	96-07-31	30	5201	63.57
96	July	RM	3	1	429	96-07-31	30	5202	61.64
96	August	LM1	1	1	575	96-08-30	30	5233	52.39
96	August	LM1	2	1	561	96-08-30	30	5234	49.39
96	August	LM1	3	1	549	96-08-30	30	5235	66.04
96	August	LM1	1	2	571	96-08-30	30	5236	53.55
96	August	LM1	2	2	579	96-08-30	30	5237	60.47
96	August	LM1	3	2	596	96-08-30	30	5238	53.78
96	August	LM2	1	1	555	96-08-30	30	5239	58.89
96	August	LM2	2	1	541	96-08-30	30	5240	61.21
96	August	LM2	3	1	577	96-08-30	30	5241	57.35
96	August	LM2	1	2	612	96-08-30	30	5242	45.89

Year	Month	Site	Replicate	Transect #	Tag #	Date Picked up	Expt.	Lab ID #	% Weight Loss
96	August	LM2	2	2	543	96-08-30	30	5243	59.74
96	August	LM2	3	2	540	96-08-30	30	5244	62.78
96	August	FSF	1	1	615	96-08-30	30	5227	56.51
96	August	FSF	2	1	572	96-08-30	30	5228	58.42
96	August	FSF	3	1	576	96-08-30	30	5229	59.75
96	August	FSF	1	2	409	96-08-30	30	5230	57.82
96	August	FSF	2	2	565	96-08-30	30	5231	59.63
96	August	FSF	3	2	573	96-08-30	30	5232	58.25
96	August	SF	1	1	550	96-08-30	30	5221	43.38
96	August	SF	2	1	595	96-08-30	30	5222	41.17
96	August	SF	3	1	592	96-08-30	30	5223	-2.44
96	August	SF	1	2	551	96-08-30	30	5224	43.78
96	August	SF	2	2	548	96-08-30	30	5225	49.85
96	August	SF	3	2	560	96-08-30	30	5226	43.14
96	August	RM	1	1	427	96-08-30	30	5245	67.72
96	August	RM	2	1	536	96-08-30	30	5246	66.21
96	August	RM	3	1	567	96-08-30	30	5247	67.74
96	August	RM	1	2	580	96-08-30	30	5248	68.30
96	August	RM	2	2	539	96-08-30	30	5249	64.13
96	August	RM	3	2	532	96-08-30	30	5250	61.43
96	September	LM1	1	1	702	96-09-30	30	5263	44.25
96	September	LM1	2	1	727	96-09-30	30	5264	41.84
96	September	LM1	3	1	739	96-09-30	30	5265	43.35
96	September	LM1	1	2	754	96-09-30	30	5266	37.96
96	September	LM1	2	2	715	96-09-30	30	5267	39.43
96	September	LM1	3	2	753	96-09-30	30	5268	42.88
96	September	LM2	1	1	709	96-09-30	30	5275	49.55
96	September	LM2	2	1	602	96-09-30	30	5276	50.56
96	September	LM2	3	1	721	96-09-30	30	5277	34.36
96	September	LM2	1	2	713	96-09-30	30	5278	51.06
96	September	LM2	2	2	716	96-09-30	30	5279	53.76
96	September	LM2	3	2	746	96-09-30	30	5280	53.61
96	September	FSF	1	1	719	96-09-30	30	5269	49.39
96	September	FSF	2	1	742	96-09-30	30	5270	46.80
96	September	FSF	3	1	741	96-09-30	30	5271	44.94
96	September	FSF	1	2	750	96-09-30	30	5272	44.84
96	September	FSF	2	2	745	96-09-30	30	5273	43.81
96	September	FSF	3	2	735	96-09-30	30	5274	44.02
96	September	SF	1	1	708	96-09-30	30	5257	22.05
96	September	SF	2	1	707	96-09-30	30	5258	31.73
96	September	SF	3	1	604	96-09-30	30	5259	26.08
96	September	SF	1	2	508	96-09-30	30	5260	25.02
96	September	SF	2	2	611	96-09-30	30	5261	28.58
96	September	SF	3	2	466	96-09-30	30	5262	30.42
96	September	RM	1	2	700	96-09-30	30	5251	45.50
96	September	RM	2	2	723	96-09-30	30	5252	42.00
96	September	RM	3	2	712	96-09-30	30	5253	38.19
96	September	RM	1	1	729	96-09-30	30	5254	47.67
96	September	RM	2	1	728	96-09-30	30	5255	49.95
96	September	RM	3	1	714	96-09-30	30	5256	44.88
96	October	LM1	1	1	830	96-10-26	30	5287	42.52
96	October	LM1	2	1	593	96-10-26	30	5288	28.61
96	October	LM1	3	1	464	96-10-26	30	5289	33.91
96	October	LM1	1	2	827	96-10-26	30	5290	40.66
96	October	LM1	2	2	839	96-10-26	30	5291	46.72

Year	Month	Site	Replicate	Transect #	Tag #	Date Picked up	Expt.	Lab ID #	% Weight Loss
96	October	LM1	3	2	563	96-10-26	30	5292	35.80
96	October	LM2	1	1	838	96-10-26	30	5318	26.63
96	October	LM2	2	1	732	96-10-26	30	5319	24.06
96	October	LM2	3	1	831	96-10-26	30	5320	20.12
96	October	LM2	1	2	747	96-10-26	30	5321	31.81
96	October	LM2	2	2	607	96-10-26	30	5322	42.77
96	October	LM2	3	2	706	96-10-27	30	5323	34.79
96	October	FSF	1	1	587	96-10-26	30	5281	27.29
96	October	FSF	2	1	814	96-10-26	30	5282	26.35
96	October	FSF	3	1	803	96-10-26	30	5283	26.91
96	October	FSF	1	2	809	96-10-26	30	X	31.46
96	October	FSF	2	2	841	96-10-26	30	5285	27.07
96	October	FSF	3	2	583	96-10-26	30	5286	27.93
96	October	SF	1	1	837	96-10-26	30	5312	22.68
96	October	SF	2	1	811	96-10-26	30	5313A	22.58
96	October	SF	3	1	843	96-10-26	30	5314	24.13
96	October	SF	1	2	610	96-10-26	30	5315A	18.28
96	October	SF	2	2	842	96-10-26	30	5316	21.52
96	October	SF	3	2	834	96-10-26	30	5317	11.89
96	October	RM	1	2	828	96-10-26	30	5293	38.74
96	October	RM	2	2	823	96-10-26	30	5294	42.53
96	October	RM	3	2	418	96-10-26	30	5295	32.31
96	October	RM	1	1	613	96-10-26	30	5296	36.06
96	October	RM	2	1	434	96-10-26	30	5297	36.37
96	October	RM	3	1	598	96-10-26	30	5298	36.20
95	July	FSF	1	1	95	95-08-01	506	5006	43.79
95	July	FSF	2	1	233	95-08-01	506	5007	49.74
95	July	FSF	3	1	156	95-08-01	506	5010	52.23
95	July	FSF	1	2	45	95-08-01	506	5013	48.15
95	July	FSF	2	2	131	95-08-01	506	5014	49.41
95	July	FSF	3	2	138	95-08-01	506	5015	43.74
95	July	SF	1	1	217	95-08-01	506	5020	46.96
95	July	SF	2	1	13	95-08-01	506	5021	38.65
95	July	SF	3	1	167	95-08-01	506	5022	45.72
95	July	SF	1	2	203	95-08-01	506	5024	64.94
95	July	SF	2	2	134	95-08-01	506	5026	50.94
95	July	SF	3	2	144	95-08-01	506	5027	45.23
95	July	LM1	1	1	236	95-08-01	506	5042	73.51
95	July	LM1	2	1	169	95-08-01	506	5045	70.11
95	July	LM1	3	1	160	95-08-01	506	5046	67.98
95	July	LM1	1	2	188	95-08-01	506	5048	74.05
95	July	LM1	2	2	88	95-08-01	506	5049	66.83
95	July	LM1	3	2	122	95-08-01	506	5050	71.92
95	July	RM	1	1	101	95-08-01	506	5054	61.93
95	July	RM	2	1	36	95-08-01	506	5055	56.49
95	July	RM	3	1	130	95-08-01	506	5056	61.29
95	July	RM	1	2	202	95-08-01	506	5061	57.45
95	July	RM	2	2	175	95-08-01	506	5063	52.51
95	July	RM	3	2	75	95-08-01	506	5064	53.86
95	August	RM	1	1	161	95-08-31	506	5074	66.97
95	August	RM	3	1	20	95-08-31	506	5077	62.97
95	August	RM	1	2	237	95-08-31	506	5078	53.50
95	August	RM	2	2	235	95-08-31	506	5079	65.20
95	August	RM	3	2	248	95-08-31	506	5081	63.96
95	August	FSF	1	1	241	95-08-31	506	5084	64.29

Year	Month	Site	Replicate	Transect #	Tag #	Date Picked up	Expt.	Lab ID #	% Weight Loss
95	August	FSF	2	1	179	95-08-31	506	5086	70.84
95	August	FSF	3	1	165	95-08-31	506	5090	63.34
95	August	FSF	1	2	93	95-08-31	506	5092	69.26
95	August	FSF	2	2	105	95-08-31	506	5093	61.45
95	August	FSF	3	2	140	95-08-31	506	5094	72.84
95	August	LM1	1	?	43	95-08-30	506	5101	83.10
95	August	LM1	2	?	151	95-08-30	506	5102	85.15
95	August	LM1	3	?	1	95-08-30	506	5103	81.54
95	August	LM1	4	?	96	95-08-30	506	5107	77.81
95	August	LM1	5	?	239	95-08-30	506	5108	74.64
95	August	SF	1	1	107	95-08-31	506	5109	56.17
95	August	SF	2	1	155	95-08-31	506	5110	52.96
95	August	SF	3	1	172	95-08-31	506	5111	48.96
95	August	SF	1	2	104	95-08-31	506	5115	50.00
95	August	SF	2	2	133	95-08-31	506	5117	57.74
95	August	SF	3	2	9	95-08-31	506	5118	50.45
95	OverWinter	FSF	1	2	21	96-06-02	506	5121	71.88
95	OverWinter	FSF	2	2	72	96-06-02	506	5122	69.15
95	OverWinter	FSF	3	2	40	96-06-02	506	5125	70.18
95	OverWinter	FSF	1	1	33	96-06-02	506	5127	72.27
95	OverWinter	FSF	2	1	59	96-06-02	506	5130	67.78
95	OverWinter	LM1	1	1	145	96-06-01	506	5132	76.16
95	OverWinter	LM1	2	1	152	96-06-01	506	5133	82.22
95	OverWinter	LM1	3	1	126	96-06-01	506	5134	80.19
95	OverWinter	LM1	1	2	185	96-06-01	506	5140	85.14
95	OverWinter	LM1	2	2	55	96-06-01	506	5141	86.73
95	OverWinter	RM	1	2	100	96-06-01	506	5144	72.35
95	OverWinter	RM	2	2	125	96-06-01	506	5145	59.75
95	OverWinter	RM	3	2	94	96-06-01	506	5146	70.67
95	OverWinter	RM	1	1	69	96-06-01	506	5147	85.67
95	OverWinter	RM	2	1	73	96-06-01	506	5148	82.35
95	OverWinter	RM	3	1	214	96-06-01	506	5149	72.13
95	OverWinter	SF	1	1	163	96-06-02	506	X	65.31
95	OverWinter	SF	2	1	80	96-06-02	506	5153	59.92
95	OverWinter	SF	1	2	247	96-06-02	506	5157	55.45
95	OverWinter	SF	2	2	81	96-06-02	506	5160	54.70
95	OverWinter	SF	3	2	68	96-06-02	506	5161	50.22
96	October	FSF	1	2	223	96-10-26	506	5284	76.35
96	October	RM	1	1	244	96-10-26	506	5299	77.99
96	October	RM	2	1	23	96-10-26	506	5300	85.79
96	October	RM	1	2	158	96-10-26	506	5301	95.11
96	October	RM	2	2	26	96-10-26	506	5302	81.32
96	October	LM1	1	1	150	96-10-26	506	5303	88.58
96	October	LM1	2	1	24	96-10-26	506	5304	80.24
96	October	LM1	3	1	136	96-10-26	506	5305	92.17
96	October	LM1	4	1	168	96-10-26	506	5306	84.28
96	October	SF	1	1	224	96-10-26	506	5307	76.96
96	October	SF	2	1	249	96-10-26	506	5308	75.12
96	October	SF	1	2	250	96-10-26	506	5309	74.50
96	October	SF	2	2	118	96-10-26	506	5310	53.65
96	October	SF	3	2	234	96-10-26	506	5311	69.86
		LM1	1				ddw		5.33
		LM1	2				ddw		47.00
		LM1	3				ddw		32.57
		LM1	4				ddw		22.37

Year	Month	Site	Replicate	Transect #	Tag #	Date Picked up	Expt.	Lab ID #	% Weight Loss
		LMI	5				ddw		26.90
		LMI	1				fung		17.06
		LMI	2				fung		19.40
		LMI	3				fung		18.41
		LMI	4				fung		35.23
		LMI	5				fung		17.92
		SF	1				ddw		17.03
		SF	2				ddw		15.62
		SF	3				ddw		14.62
		SF	4				ddw		19.04
		SF	5				ddw		0.63
		SF	1				fung		22.09
		SF	2				fung		13.64
		SF	3				fung		14.30
		SF	4				fung		11.97
		SF	5				fung		15.48
		FSF	1				ddw		19.48
		FSF	2				ddw		20.49
		FSF	3				ddw		30.40
		FSF	4				ddw		12.17
		FSF	5				ddw		16.13
		FSF	1				fung		0.00
		FSF	2				fung		0.00
		FSF	3				fung		25.67
		FSF	4				fung		23.52
		FSF	5				fung		19.63
		RM	1				ddw		23.45
		RM	2				ddw		24.05
		RM	3				ddw		19.81
		RM	4				ddw		24.51
		RM	5				ddw		19.80
		RM	1				fung		28.85
		RM	2				fung		20.72
		RM	3				fung		22.65
		RM	4				fung		18.72
		RM	5				fung		27.47

Note: Site abbreviations are as for production raw data, expt refers to the experimental treatment, 30 = 30 day incubation, 506 = long term incubation, ddw = leaching with distilled deionized water, and fung = leaching with ddw and a fungicide, bengal rose.

Peat and plant nutrient contents, spring and August samples

Peat Initial Samples				Spring Plant samples		Peak plant samples			Peak	Spring	Peat	Peak	Peat
	mgP/gm Dry	%C	%N	%C	%N	mgP/gm Dry	%C	%N	C:N	C:N	C:N	N:P	N:P
LM1-2	1.89	43.26	2.53	44.83	2.21	1.94	44.3	1.42	31.20	20.29	17.10	7.32	13.39
LM1-3	1.74	40.18	2.76	43.86	2.01	1.39	45.51	1.45	31.39	21.82	14.56	10.43	15.86
LM1-4	1.61	40.61	2.75	43.92	2.05	1.79	44.26	1.68	26.35	21.42	14.77	9.39	17.08
LM2-2	1.94	36.42	2.83			1.56	45.25	1.39	32.55		12.87	8.91	14.59
LM2-3	1.82	38.52	2.25			1.62	45.09	1.54	29.28		17.12	9.51	12.36
LM2-4	1.67	44.38	2.49			1.09	45.53	1.24	36.72		17.82	11.38	14.91
RM2	1.25	31.82	2.11	45.38	2.52	2.57	44.6	1.59	28.05	18.01	15.08	6.19	16.88
RM3	1.27	31.54	2.15	44.55	2.64	1.58	46.6	1.65	28.24	16.88	14.67	10.44	16.93
RM4	1.31	36.75	2.17	44.83	2.89	2.15	46.06	1.59	28.97	15.51	16.94	7.40	16.56
SF2	5.53	40.61	2.35	45.81	1.54	1.3	44.86	1.23	36.47	29.75	17.28	9.46	4.25
SF3	7.13	35.81	1.34	44.44	1.82	1.35	45.56	1.41	32.31	24.42	26.72	10.44	1.88
SF4	4.26	35.14	2.02	44.71	1.9	1.27	45.38	1.23	36.89	23.53	17.40	9.69	4.74
FSF2	0.89	45.01	0.85	46.42	2.92	1.2	44.71	1.43	31.27	15.90	52.95	11.92	9.55
FSF3	1.51	44.43	1.62	44.74	2.06	1.21	44.87	1.45	30.94	21.72	27.43	11.98	10.73
FSF4	1.25	44.9	1.81	44.79	2.06	1.26	44.56	1.43	31.16	21.74	24.81	11.35	14.48

Note: C and N are %, while P is mg P/ gm of dry material. C:N and N:P quotients are on a weight basis here.

Mineralization rate raw data

	Mineralization				mg N/m2/day	
4-10	site	yr	rep	month	0-4	4-10
15.80	FSF	1995	1	June	1.20	-6.80
0.14	FSF	1995	2	June	3.49	-3.60
18.12	FSF	1995	3	June	3.12	0.47
4.52	FSF	1995	4	June	1.67	-1.91
1.78	FSF	1995	5	June	-0.54	-1.39
-6.68	FSF	1995	1	July	-0.53	0.63
0.46	FSF	1995	2	July	-0.51	-4.92
-1.13	FSF	1995	3	July	3.15	-1.88
-0.73	FSF	1995	4	July	5.19	0.99
6.58	FSF	1995	5	July	-3.25	10.53
18.96	FSF	1995	1	August	2.94	-2.96
0.19	FSF	1995	2	August	2.32	1.82
	FSF	1995	3	August	2.27	-0.48
0.95	FSF	1995	4	August	13.75	1.16
-2.47	FSF	1995	5	August	-6.88	-0.24
0.19	FSF	1995	1	Overwinter	1.14	0.71
2.73	FSF	1995	2	Overwinter	1.88	out
1.25	FSF	1995	3	Overwinter	1.11	1.36
1.24	FSF	1995	4	Overwinter	-0.08	-0.15
0.96	FSF	1995	5	Overwinter	1.96	0.97
0.64	FSF	1996	1	June	7.31	
0.98	FSF	1996	2	June		
1.29	FSF	1996	3	June	4.10	-5.06
-0.54	FSF	1996	4	June	2.23	4.30
0.53	FSF	1996	5	June	-0.29	-2.20
4.74	FSF	1996	1	July	29.01	7.76
-1.27	FSF	1996	2	July	-1.64	7.24
3.72	FSF	1996	3	July	16.20	-0.15
1.86	FSF	1996	4	July	34.83	2.40
-0.10	FSF	1996	5	July	15.62	15.31
out	FSF	1996	1	August	12.58	21.30
1.21	FSF	1996	2	August	23.34	22.76
3.19	FSF	1996	3	August	0.65	1.25
4.80	FSF	1996	4	August	7.72	-1.44
3.40	FSF	1996	5	August	15.12	21.68
-1.05	FSF	1996	1	September	0.57	-1.55
out	FSF	1996	2	September	1.54	-0.58
1.63	FSF	1996	3	September	0.49	1.72
-0.07	FSF	1996	4	September	-2.12	1.49
-5.32	FSF	1996	5	September	out	-0.57
-3.19	FSF	1996	1	October	-2.96	-3.98
-2.48	FSF	1996	2	October	-2.97	-2.87
1.86	FSF	1996	3	October	-1.37	-1.39
-1.70	FSF	1996	4	October	-1.63	-4.19
-0.23	FSF	1996	5	October	-1.82	-2.43

				mg N/m^2 day	
site	yr	rep	month	0-4	4-10
RM	1995	1	June	0.54	-11.16
RM	1995	2	June	17.64	8.18
RM	1995	3	June	17.98	10.64
RM	1995	4	June	-2.07	3.10
RM	1995	5	June	11.59	16.93
RM	1995	1	July	4.06	out
RM	1995	2	July	1.04	1.54
RM	1995	3	July	2.39	-1.72
RM	1995	4	July	2.81	5.62
RM	1995	5	July	out	15.62
RM	1995	1	August	-1.92	19.40
RM	1995	2	August	11.27	5.51
RM	1995	3	August	-2.52	16.95
RM	1995	4	August	3.32	-16.32
RM	1995	5	August	11.54	3.34
RM	1995	1	Overwinter	-0.86	0.60
RM	1995	2	Overwinter	1.56	2.00
RM	1995	3	Overwinter	-1.46	-0.74
RM	1995	4	Overwinter	-0.06	1.91
RM	1995	5	Overwinter	-2.46	0.89
RM	1996	1	June	6.45	2.75
RM	1996	2	June	-7.77	0.72
RM	1996	3	June	-27.75	out
RM	1996	4	June	-18.62	-0.02
RM	1996	5	June	-26.76	0.00
RM	1996	1	July	-16.52	14.08
RM	1996	2	July	-21.64	1.53
RM	1996	3	July	-13.49	-5.94
RM	1996	4	July	-16.25	5.31
RM	1996	5	July	-9.00	9.70
RM	1996	1	August	-1.58	-3.08
RM	1996	2	August	1.91	16.03
RM	1996	3	August	34.85	9.63
RM	1996	4	August	32.28	6.89
RM	1996	5	August	-0.68	1.04
RM	1996	1	September	6.85	0.48
RM	1996	2	September	5.68	5.62
RM	1996	3	September	10.62	10.76
RM	1996	4	September	14.93	5.06
RM	1996	5	September	4.93	2.72
RM	1996	1	October	-7.09	5.82
RM	1996	2	October	7.87	2.73
RM	1996	3	October	4.79	5.73
RM	1996	4	October	-1.92	4.46
RM	1996	5	October	0.54	out

Mineralization

				mg N/m^2 day	
site	yr	rep	month	0–4	4–10
LM1	1995	1	June	24.20	2.25
LM1	1995	2	June	41.15	-1.28
LM1	1995	3	June	7.52	-0.41
LM1	1995	4	June	22.68	4.44
LM1	1995	5	June	5.18	out
LM1	1995	1	July	0.85	out
LM1	1995	2	July	-5.03	5.47
LM1	1995	3	July	4.37	2.60
LM1	1995	4	July	0.38	3.42
LM1	1995	5	July	0.47	4.90
LM1	1995	1	August	6.41	-1.92
LM1	1995	2	August	15.03	1.65
LM1	1995	3	August	16.30	7.86
LM1	1995	4	August	9.76	4.18
LM1	1995	5	August	15.15	0.73
LM1	1995	1	Overwinter	0.17	1.72
LM1	1995	2	Overwinter	0.42	0.09
LM1	1995	3	Overwinter	0.24	-0.10
LM1	1995	4	Overwinter	missing	missing
LM1	1995	5	Overwinter	2.35	0.19
LM1	1996	1	June	8.92	7.28
LM1	1996	2	June	2.09	11.49
LM1	1996	3	June	8.90	-0.93
LM1	1996	4	June	1.97	0.72
LM1	1996	5	June	7.38	16.77
LM1	1996	1	July	2.51	2.97
LM1	1996	2	July	-0.75	6.78
LM1	1996	3	July	4.65	11.40
LM1	1996	4	July	1.24	2.77
LM1	1996	5	July	-4.58	7.17
LM1	1996	1	August	8.32	-2.46
LM1	1996	2	August	3.44	2.63
LM1	1996	3	August	0.46	8.83
LM1	1996	4	August	9.47	0.81
LM1	1996	5	August	7.80	6.20
LM1	1996	1	September	6.93	0.04
LM1	1996	2	September	-12.13	-0.69
LM1	1996	3	September	13.76	10.64
LM1	1996	4	September	21.59	-1.26
LM1	1996	5	September	2.81	7.96
LM1	1996	1	October	5.18	2.22
LM1	1996	2	October	-1.80	2.99
LM1	1996	3	October	3.45	0.10
LM1	1996	4	October	3.98	1.51
LM1	1996	5	October	-1.73	2.15

				mg N/m^2 day	
site	yr	rep	month	0–4	4–10
SF	1995	1	June	4.13	15.80
SF	1995	2	June	-6.41	0.14
SF	1995	3	June	-0.41	18.12
SF	1995	4	June	0.71	4.52
SF	1995	5	June	4.92	1.78
SF	1995	1	July	0.65	-6.68
SF	1995	2	July	2.22	0.46
SF	1995	3	July	0.44	-1.13
SF	1995	4	July	-0.45	-0.73
SF	1995	5	July	4.54	6.58
SF	1995	1	August	out	18.96
SF	1995	2	August	2.51	0.19
SF	1995	3	August	4.90	
SF	1995	4	August	2.62	0.95
SF	1995	5	August	1.43	-2.47
SF	1995	1	Overwinter	-0.64	0.19
SF	1995	2	Overwinter	0.65	2.73
SF	1995	3	Overwinter	0.06	1.25
SF	1995	4	Overwinter	2.21	1.24
SF	1995	5	Overwinter	3.82	0.96
SF	1996	1	June	5.26	0.64
SF	1996	2	June	7.32	0.98
SF	1996	3	June	12.81	1.29
SF	1996	4	June	1.31	-0.54
SF	1996	5	June	0.46	0.53
SF	1996	1	July	29.75	4.74
SF	1996	2	July	17.08	-1.27
SF	1996	3	July	11.75	3.72
SF	1996	4	July	16.63	1.86
SF	1996	5	July	4.23	-0.10
SF	1996	1	August	out	out
SF	1996	2	August	13.56	1.21
SF	1996	3	August	-0.01	3.19
SF	1996	4	August	14.64	4.80
SF	1996	5	August	15.68	3.40
SF	1996	1	September	-5.73	-1.05
SF	1996	2	September	9.00	out
SF	1996	3	September	-2.75	1.63
SF	1996	4	September	2.58	-0.07
SF	1996	5	September	-0.19	-5.32
SF	1996	1	October	-8.76	-3.19
SF	1996	2	October	-1.07	-2.48
SF	1996	3	October	-3.16	1.86
SF	1996	4	October	-5.89	-1.70
SF	1996	5	October	-5.85	-0.23

Mineralization				mg N/m² day	
site	yr	rep	month	0-4	4-10
LM2	1996	1	June	19.41	out
LM2	1996	2	June	-0.40	2.75
LM2	1996	3	June	13.20	8.16
LM2	1996	4	June	-0.30	13.61
LM2	1996	5	June	15.45	4.89
LM2	1996	1	July	15.91	out
LM2	1996	2	July	21.12	3.55
LM2	1996	3	July	69.03	4.72
LM2	1996	4	July	-9.16	20.12
LM2	1996	5	July	3.58	16.65
LM2	1996	1	August	23.08	out
LM2	1996	2	August	7.48	4.21
LM2	1996	3	August	0.93	-2.39
LM2	1996	4	August	20.34	0.13
LM2	1996	5	August	-3.62	-5.02
LM2	1996	1	September	10.57	7.33
LM2	1996	2	September	-3.72	0.53
LM2	1996	3	September	11.05	5.47
LM2	1996	4	September	-0.15	out
LM2	1996	5	September	-21.69	0.13
LM2	1996	1	October	1.78	-2.92
LM2	1996	2	October	out	out
LM2	1996	3	October	-1.13	-3.69
LM2	1996	4	October	-4.62	-1.20
LM2	1996	5	October	-3.72	-3.28

Note: Site abbreviations are as in production raw data. Units mg N/m² day

Total carbon and nitrogen raw data for mineralization cores

Total Carbon and Nitrogen					0-4 cm								4-10 cm							
Site	year	month	Core #:	Height	ID#	initial c	initial n	initial c:n	ID#	final c	final n	final c:n	ID#	initial c	initial n	initial c:n	ID#	final c	final n	final c:n
LM1	95	6	1	4	12753	39.61	2.39	16.57	12755	39.75	2.36	16.84	12754	35.29	2.69	13.12	12756	34.70	2.67	13.00
LM1	95	6	2	4	12757	36.67	2.64	13.89	12759	39.82	2.48	16.06	12758	37.23	2.51	14.83	12760	36.25	2.65	13.68
LM1	95	6	3	4	12761	38.98	2.42	16.11	12763	39.38	2.60	15.15	12762	31.67	2.53	12.52	12764	34.92	2.73	12.79
LM1	95	6	4	4	12765	42.92	2.38	18.03	12767	41.59	2.45	16.98	12766	39.15	2.74	14.29	12768	39.08	2.61	14.97
LM1	95	6	5	4	12769	42.27	2.50	16.91	12771	38.52	2.61	14.76	12770	36.90	2.58	14.30	12772	36.56	2.68	13.64
LM1	95	7	1	4	12837	43.17	2.42	17.84	12839	42.03	2.59	16.23	12838	36.53	2.77	13.19	12840	37.62	2.70	13.93
LM1	95	7	2	4	12841	46.15	2.19	21.07	12843	46.42	1.98	23.44	12842	42.85	2.31	18.55	12844	41.44	2.57	16.12
LM1	95	7	3	4	12845	39.41	2.66	14.82	12847	39.13	2.85	13.73	12846	37.29	2.82	13.22	12848	35.79	2.84	12.60
LM1	95	7	4	4	12849	40.42	2.72	14.86	12851	39.32	2.70	14.56	12850	36.55	2.94	12.43	12852	36.74	2.86	12.85
LM1	95	7	5	4	12853	42.74	2.68	15.95	12855	43.50	2.51	17.33	12854	42.63	2.47	17.26	12856	39.97	2.65	15.08
LM1	95	8	1	4	12997	44.34	2.37	18.71	12999	43.67	2.57	16.99	12998	40.90	2.58	15.85	13000	40.82	2.59	15.76
LM1	95	8	2	4	13001	41.55	2.61	15.92	13003	40.48	2.73	14.83	13002	37.46	2.73	13.72	13004	38.63	2.73	14.15
LM1	95	8	3	4	13005	39.22	2.69	14.58	13007	39.48	2.80	14.10	13006	35.70	2.81	12.70	13008	36.12	2.78	12.99
LM1	95	8	4	4	13009	41.74	2.71	15.40	13011	41.25	2.76	14.95	13010	35.51	2.86	12.42	13012	35.42	2.82	12.56
LM1	95	8	5	4	13013	41.94	2.61	16.07	13015	42.23	2.59	16.31	13014		2.85		13016	41.38	2.82	14.67
LM1	95	13	1	4	15254	42.71	2.19	19.50	15256	41.20	2.23	18.48	15255	38.25	2.63	14.54	15257	40.80	2.69	15.17
LM1	95	13	2	4	15258	40.86	2.41	16.95	15260	43.45	1.98	21.94	15259	37.76	2.61	14.47	15261	38.19	2.65	14.41
LM1	95	13	3	4	15262	42.69	2.33	18.32	15264	42.71	2.10	20.34	15263				15265	41.56	2.32	17.91
LM1	95	13	4	4	15266	44.15	1.66	26.60	15268	44.70	1.91	23.40	15267	41.64	2.11	19.73	15269			
LM1	95	13	5	4	15270	43.28	2.28	18.98	15272	42.48	2.45	17.34	15271	37.92	2.69	14.10	15273	38.87	2.78	13.98
LM1	96	6	1	4	14531	45.05	2.23	20.20	14533	44.26	2.02	21.91	14532	40.32	2.72	14.82	14534	36.45	2.58	14.13
LM1	96	6	2	4	14535	43.08	2.35	18.33	14537	42.57	2.49	17.10	14536	37.49	2.89	12.97	14538	39.33	2.65	14.84
LM1	96	6	3	4	14539	40.89	2.48	16.49	14541	41.03	2.48	16.54	14540	36.25	2.66	13.63	14542	37.55	2.65	14.17
LM1	96	6	4	4	14543	40.22	2.67	15.06	14545	41.62	2.74	15.19	14544	37.61	2.83	13.29	14546	36.98	2.97	12.45
LM1	96	6	5	4	14547	44.73	2.20	20.33	14548	43.46	2.51	17.31	14550	41.54	2.56	16.23	14549	41.84	2.91	14.38
LM1	96	7	1	4	14149	42.93	2.33	18.42	14151	42.86	2.27	18.88	14150	38.85	2.67	14.55	14152	38.14	2.81	13.57
LM1	96	7	2	4	14153	39.32	2.56	15.36	14155	40.82	2.62	15.58	14154	38.64	2.58	14.98	14156	39.91	2.60	15.35
LM1	96	7	3	4	14157	43.22	2.50	17.29	14159	44.70	2.13	20.99	14158	41.13	2.74	15.01	14160	41.65	2.94	14.17
LM1	96	7	4	4	14161	41.63	2.65	15.71	14163	40.63	2.82	14.41	14162	38.08	2.95	12.91	14164	36.87	2.88	12.80
LM1	96	7	5	4	14165	43.37	2.79	15.54	14167	44.27	2.68	16.52	14166	37.51	2.73	13.74	14168	37.92	2.97	12.77
LM1	96	8	1	4	14322	40.29	2.51	16.05	14324	40.58	2.40	16.91	14323	41.19	2.58	15.97	14325	40.28	2.71	14.86
LM1	96	8	2	4	14326	43.26	2.53	17.10	14328	41.50	2.75	15.09	14327	39.22	2.64	14.86	14329	37.25	2.88	12.93
LM1	96	8	3	4	14330	40.18	2.76	14.56	14332	41.07	2.69	15.27	14331	37.05	2.79	13.28	14333	37.46	2.84	13.19
LM1	96	8	4	4	14334	40.61	2.75	14.77	14336	42.00	2.71	15.50	14335	38.46	2.92	13.17	14337	37.36	2.94	12.71
LM1	96	8	5	4	14338	41.60	2.67	15.58	14340	44.33	2.48	17.88	14339	39.98	2.83	14.13	14341	38.09	2.88	13.23

Total Carbon and Nitrogen

					0-4 cm								4-10 cm						
Site	year	month	Core #:	Height	ID#	initial c	initial n	initial c:n	ID#	final c	final n	final c:n	ID#	initial c	initial n	initial c:n	ID#	final c	final n	final c:n
LM1	96	9	1	4	14773	40.93	2.50	16.37	14775	41.39	2.70	15.33	14774	39.90	2.65	15.06	14776	37.76	2.78	13.58
LM1	96	9	2	4	14777	42.79	2.49	17.18	14779	44.13	2.37	18.62	14778	40.79	2.76	14.78	14780	41.89	2.45	17.10
LM1	96	9	3	4	14781	41.57	2.58	16.11	14783	42.47	2.60	16.33	14782	38.51	2.86	13.47	14784	40.46	2.57	15.74
LM1	96	9	4	4	14785	46.21	1.86	24.84	14787	45.45	2.31	19.68	14786	38.30	2.82	13.58	14788	39.81	2.79	14.27
LM1	96	9	5	4	14789	41.53	2.81	14.78	14791	41.28	2.86	14.43	14790	40.07	2.85	14.06	14792	41.57	2.74	15.17
LM1	96	10	1	4	15010	37.41	2.54	14.73	15012	37.04	2.50	14.82	15011	36.18	2.61	13.86	15013	37.66	2.45	15.37
LM1	96	10	2	4	15014	42.43	2.64	16.07	15016	41.44	2.49	16.64	15015	36.78	2.65	13.88	15017	37.06	2.56	14.48
LM1	96	10	3	4	15018	36.32	2.63	13.81	15020	39.55	2.49	15.88	15019	32.62	2.56	12.74	15021	34.35	2.86	12.01
LM1	96	10	4	4	15022	43.96	2.33	18.87	15024	37.62	2.65	14.20	15023	35.19	2.69	13.08	15025	34.67	2.70	12.84
LM1	96	10	5	4	15026	35.25	2.39	14.75	15028	35.82	2.68	13.37	15027	36.78	2.64	13.93	15029	37.21	2.77	13.43
SF	95	6	1	4	12795	36.82	1.85	19.90	12797	34.65	1.45	23.90	12796	41.30	2.23	18.52	12798	41.10	2.23	18.43
SF	95	6	2	4	12799	35.02	1.73	20.24	12801	35.32	1.73	20.42	12800	44.19	2.21	20.00	12802	43.99	2.17	20.27
SF	95	6	3	4	12803	35.01	1.52	23.03	12805	33.60	1.52	22.11	12804	39.47	2.13	18.53	12806	36.47	1.78	20.49
SF	95	6	4	4	12807	27.91	1.43	19.52	12809	38.91	1.27	30.64	12808	35.73	1.99	17.95	12810	34.40	1.87	18.40
SF	95	6	5	4	12811	38.85	1.77	21.95	12813	36.72	1.62	22.67	12812	44.63	1.71	26.10	12814	40.90	2.12	19.29
SF	95	7	1	4	12936	44.39	2.06	21.55	12938	46.72	2.43	19.23	12937	38.52	2.06	18.70	12939	37.97	1.69	22.47
SF	95	7	2	4	12940	39.36	2.08	18.92	12942	43.89	2.11	20.80	12941	37.50	1.85	20.27	12943	41.05	1.74	23.59
SF	95	7	3	4	12944	44.34	2.30	19.28	12946	44.91	2.37	18.95	12945	37.62	1.60	23.51	12947	30.67	1.65	18.59
SF	95	7	4	4	12948	42.38	2.39	17.73	12950	40.39	2.20	18.36	12949	34.88	1.72	20.28	12951	32.56	1.61	20.22
SF	95	7	5	4	12952	41.60	2.20	18.91	12954	42.66	2.32	18.39	12953	31.28	1.30	24.06	12955	40.86	2.23	18.32
SF	95	8	1	4	13056	35.27	2.03	17.37	13058	36.01	1.98	18.19	13057	39.84	2.06	19.34	13059	42.23	2.22	19.02
SF	95	8	2	4	13060	28.33	1.47	19.27	13062	27.44	1.62	16.94	13061	36.96	2.09	17.68	13063	39.07	2.22	17.60
SF	95	8	3	4	13064	32.40	1.90	17.05	13066	31.95	1.76	18.15	13065	43.99	2.66	16.54	13067			
SF	95	8	4	4	13068	36.46	1.68	21.70	13070	33.71	1.89	17.84	13069	42.81	2.40	17.84	13071	45.79	2.30	19.91
SF	95	8	5	4	13072	34.24	1.73	19.79	13074	37.25	1.84	20.24	13073	42.43	2.52	16.84	13075	46.49	2.29	20.30
SF	95	13	1	4	15352	37.39	1.76	21.24	15354	43.96	1.67	26.32	15353	45.58	2.11	21.60	15355	44.97	2.12	21.21
SF	95	13	2	4	15356	38.87	1.49	26.09	15358	35.01	1.64	21.35	15357	32.07	1.77	18.12	15359	36.15	1.84	19.65
SF	95	13	3	4	15360	37.83	1.72	21.99	15362	38.65	1.87	20.67	15361	42.52	2.58	16.48	15363	42.91	2.56	16.76
SF	95	13	4	4	15364	37.27	1.56	23.89	15366	37.81	2.05	18.44	15365	43.19	2.26	19.11	15367	44.86	2.46	18.24
SF	95	13	5	4	15368	31.15	1.86	16.75	15370	31.07	1.47	21.14	15369	40.55	2.17	18.69	15371	44.60	2.44	18.28
SF	96	6	1	4	14713	41.44	1.80	23.02	14715	41.00	1.86	22.04	14714	46.46	1.10	42.24	14716	42.84	1.69	25.35
SF	96	6	2	4	14717	38.83	1.80	21.57	14719	36.24	1.65	21.96	14718	39.20	1.98	19.80	14720	42.43	1.99	21.32
SF	96	6	3	4	14721	32.86	1.60	20.54	14723	34.33	1.92	17.88	14722	45.39	2.06	22.03	14724	44.76	2.44	18.34
SF	96	6	4	4	14725	41.47	1.73	23.97	14727	37.28	1.86	20.04	14726	43.75	2.47	17.71	14728	45.40	2.34	19.40
SF	96	6	5	4	14729	37.86	1.92	19.72	14731	32.19	1.51	21.32	14730	38.84	2.16	17.98	14732	41.60	2.10	19.81
SF	96	7	1	4	14229	45.52	2.30	19.79	14231	43.79	2.23	19.64	14230	32.09	1.87	17.16	14232	47.78	2.06	23.19

Total Carbon and Nitrogen

					0-4 cm								4-10 cm							
Site	year	month	Core #:	Height	ID#	initial c	initial n	initial c:n	ID#	final c	final n	final c:n	ID#	initial c	initial n	initial c:n	ID#	final c	final n	final c:n
SF	96	7	2	4	14233	34.73	2.01	17.28	14235	40.45	1.94	20.85	14234	48.27	2.12	22.77	14236	47.18	2.27	20.78
SF	96	7	3	4	14237	34.01	1.50	22.67	14239	33.77	1.58	21.37	14238	47.94	2.05	23.39	14240	44.69	2.08	21.49
SF	96	7	4	4	14241	39.34	2.15	18.30	14243	33.07	1.81	18.27	14242	47.66	2.25	21.18	14244	39.64	2.34	16.94
SF	96	7	5	4	14245	33.60	1.64	20.49	14247	36.92	2.23	16.56	14246	45.84	2.37	19.34	14248	30.53	2.35	12.99
SF	96	8	1	4	14458	43.07	1.51	28.52	14460	42.83	1.95	21.96	14459	47.18	2.48	19.02	14461	47.97	2.09	22.95
SF	96	8	2	4	14462	40.61	2.35	17.28	14464	40.80	1.80	22.67	14463	44.42	2.38	18.66	14465	46.13	2.30	20.06
SF	96	8	3	4	14466	35.81	1.34	26.72	14468	39.89	1.92	20.78	14467	44.61	2.33	19.15	14469	43.52	2.21	19.69
SF	96	8	4	4	14470	35.14	2.02	17.40	14472	38.52	1.95	19.75	14471	43.53	2.14	20.34	14473	42.57	1.86	22.89
SF	96	8	5	4	14474	35.61	1.67	21.32	14476	36.85	1.90	19.39	14475	43.68	2.56	17.06	14477	37.82	2.45	15.44
SF	96	9	1	4	14929	41.04	2.06	19.92	14931	42.10	2.11	19.95	14930	45.90	2.38	19.29	14932	46.72	2.24	20.86
SF	96	9	2	4	14933	36.23	1.99	18.21	14935	31.55	1.85	17.05	14934	46.88	2.19	21.41	14936	45.45	2.44	18.63
SF	96	9	3	4	14937	42.84	2.23	19.21	14939	42.88	2.13	20.13	14938	46.74	2.33	20.06	14940	46.84	2.51	18.66
SF	96	9	4	4	14941	31.40	1.98	15.86	14943	43.17	2.16	19.99	14942	32.43	2.57	12.62	14944	47.90	2.42	19.79
SF	96	9	5	4	14945	39.67	2.01	19.74	14947	39.97	2.12	18.85	14946	46.52	2.62	17.76	14948	44.77	2.88	15.55
SF	96	10	1	4	15162	42.17	1.71	24.66	15164	40.36	2.23	18.10	15163	42.30	1.98	21.36	15165	43.40	2.08	20.87
SF	96	10	2	4	15166	41.41	2.22	18.65	15168	39.47	2.00	19.74	15167	43.21	2.29	18.87	15169	44.03	2.38	18.50
SF	96	10	3	4	15170	42.50	1.98	21.46	15172	44.07	1.95	22.60	15171	44.63	2.16	20.66	15173	44.12	2.48	17.79
SF	96	10	4	4	15174	40.45	2.22	18.22	15176	38.56	2.11	18.27	15175	44.70	2.61	17.13	15177	43.50	2.56	16.99
SF	96	10	5	4	15178	40.95	1.93	21.22	15180	41.13	2.15	19.13	15179	43.96	2.51	17.51	15181	44.53	2.31	19.28
FSF	95	6	1	4	12816	43.24	1.37	31.56	12818	43.00	1.56	27.56	12817	44.12	1.52	29.03	12819	44.05	1.61	27.36
FSF	95	6	2	4	12820	43.13	1.60	26.96	12822	43.08	1.66	25.95	12821	43.57	2.06	21.15	12823	44.48	1.77	25.13
FSF	95	6	3	4	12824	40.31	1.85	21.79	12826	42.43	1.65	25.72	12825	44.33	1.65	26.87	12827	43.90	1.80	24.39
FSF	95	6	4	4	12828	42.89	1.16	36.97	12830	41.64	1.50	27.76	12829	44.44	1.67	26.61	12831	43.76	1.88	23.28
FSF	95	6	5	4	12832	41.60	1.65	25.21	12834	42.49	1.40	30.35	12833	44.46	2.03	21.90	12835	44.86	1.95	23.01
FSF	95	7	1	4	12957	45.77	1.72	26.61	12959	45.62	1.93	23.64	12958	47.14	1.92	24.55	12960	47.85	1.80	26.58
FSF	95	7	2	4	12961	46.09	1.55	29.74	12963	45.23	1.80	25.13	12962	47.19	1.75	26.97	12964	48.14	1.69	28.49
FSF	95	7	3	4	12965	44.85	1.74	25.78	12967	45.74	1.65	27.72	12966	46.62	1.83	25.48	12968	46.86	1.96	23.91
FSF	95	7	4	4	12969	44.69	1.98	22.57	12971	45.36	1.98	22.91	12970	47.82	1.71	27.96	12972	48.07	1.89	25.43
FSF	95	7	5	4	12973	44.74	1.73	25.86	12975	45.63	1.75	26.07	12974	47.40	1.80	26.33	12976	47.97	1.72	27.89
FSF	95	8	1	4	13077	45.36	1.71	26.53	13079	48.54	1.58	30.72	13078	46.18	1.48	31.20	13080	45.81	1.39	32.96
FSF	95	8	2	4	13081	45.72	1.61	28.40	13083	46.32	1.76	26.32	13082	48.38	1.15	42.07	13084	48.31	1.45	33.32
FSF	95	8	3	4	13085	45.35	1.45	31.28	13087	47.02	1.83	25.69	13086	47.40	1.41	33.62	13088	47.47	1.38	34.40
FSF	95	8	4	4	13089	45.73	1.67	27.38	13091	45.00	2.00	22.50	13090	46.72	1.88	24.85	13092	48.58	1.18	41.17
FSF	95	8	5	4	13093	46.05	1.69	27.25	13095	45.88	1.69	27.15	13094	48.20	1.94	24.85	13096	48.69	1.98	24.59
FSF	95	13	1	4	15373	44.93	1.60	28.08	15375	45.99	1.49	30.87	15374	46.77	1.37	34.14	15376	45.85	1.63	28.13
FSF	95	13	2	4	15377	45.69	1.49	30.66	15379	45.19	1.66	27.22	15378	45.13	1.93	23.38	15380	45.91	2.27	20.22

Total Carbon and Nitrogen

					0-4 cm								4-10 cm							
Site	year	month	Core #:	Height	ID#	initial c	initial n	initial c:n	ID#	final c	final n	final c:n	ID#	initial c	initial n	initial c:n	ID#	final c	final n	final c:n
FSF	95	13	3	4	15381	44.78	2.01	22.28	15383	45.70	1.87	24.44	15382	46.47	1.95	23.83	15384	46.81	2.09	22.40
FSF	95	13	4	4	15385	42.71	2.20	19.41	15387	43.65	1.98	22.05	15386	46.76	2.02	23.15	15388	47.06	2.10	22.41
FSF	95	13	5	4	15389	45.22	1.96	23.07	15391	45.56	1.86	24.49	15390	45.81	2.44	18.77	15392	46.15	2.36	19.56
FSF	96	6	1	4	14752	45.80	1.34	34.18	14754	46.92	1.21	38.78	14753	46.16	1.41	32.74	14755	47.74	1.23	38.81
FSF	96	6	2	4	14756				14758	46.76	0.95	49.22	14757	45.86	1.47	31.20	14759	46.40	1.35	34.37
FSF	96	6	3	4	14760	46.87	1.18	39.72	14762	46.54	1.22	38.15	14761	46.81	2.12	22.08	14763	46.00	1.56	29.49
FSF	96	6	4	4	14764	45.46	1.65	27.55	14766	45.11	1.46	30.90	14765	46.70	1.94	24.07	14767	46.21	1.82	25.39
FSF	96	6	5	4	14768	44.88	1.78	25.21	14770	45.78	1.88	24.35	14769	47.81	2.08	22.99	14771	47.88	2.02	23.70
FSF	96	7	1	4	14268	47.15	1.37	34.42	14270	47.88	1.73	27.68	14269	47.84	1.60	29.90	14271	18.78	1.41	13.32
FSF	96	7	2	4	14272	44.22	1.34	33.00	14274	45.39	1.13	40.17	14273	46.29	1.41	32.83	14275	47.24	1.37	34.48
FSF	96	7	3	4	14276	45.41	1.96	23.17	14279	46.06	1.80	25.59	14278	46.60	1.89	24.66	14280	46.74	2.01	23.25
FSF	96	7	4	4	14281	45.19	1.47	30.74	14283	46.44	1.67	27.81	14282	47.50	1.78	26.69	14284	47.46	1.92	24.72
FSF	96	7	5	4	14285	44.93	1.75	25.67	14287	46.40	2.02	22.97	14286	48.11	2.12	22.69	14288	48.75	1.73	28.18
FSF	96	8	1	4	14494	46.67	1.32	35.36	14496	47.33	1.23	38.48	14495	45.27	1.80	25.15	14497	47.06	1.43	32.91
FSF	96	8	2	4	14498	45.01	0.85	52.95	14500	46.63	1.21	38.54	14499	46.67	1.01	46.21	14501	46.25	1.76	26.28
FSF	96	8	3	4	14502	44.43	1.62	27.43	14504	44.47	1.59	27.97	14503	45.86	1.60	28.66	14505	46.77	1.83	25.56
FSF	96	8	4	4	14506	44.90	1.81	24.81	14508	46.61	1.93	24.15	14507	47.30	2.00	23.65	14509	47.64	1.96	24.31
FSF	96	8	5	4	14510	45.43	1.87	24.29	14512	46.99	1.87	25.13	14511	48.56	1.76	27.59	14513	48.12	2.01	23.94
FSF	96	9	1	4	14974	45.79	1.38	33.18	14976	45.22	1.53	29.56	14975				14977	46.25	1.67	27.69
FSF	96	9	2	4	14978	45.77	1.02	44.87	14980	45.83	1.17	39.17	14979	45.12	1.36	33.18	14981	45.60	1.43	31.89
FSF	96	9	3	4	14982	44.45	2.06	21.58	14984	45.69	1.96	23.31	14983	47.54	2.11	22.53	14985	46.85	2.16	21.69
FSF	96	9	4	4	14986	43.15	1.95	22.13	14988	44.26	2.13	20.78	14987	47.49	1.47	32.31	14989	45.91	2.55	18.00
FSF	96	9	5	4	14990				14992	44.17	2.34	18.88	14991				14993	47.29	2.05	23.07
FSF	96	10	1	4	15221	45.11	1.68	26.85	15223	45.84	1.63	28.12	15222	47.16	1.77	26.64	15224	47.11	1.70	27.71
FSF	96	10	2	4	15225	42.77	1.32	32.40	15227	45.23	1.62	27.92	15226	45.64	1.95	23.41	15228	45.08	2.05	21.99
FSF	96	10	3	4	15229	44.86	1.35	33.23	15231	45.92	1.51	30.41	15230	44.54	1.83	24.34	15232	45.43	1.90	23.91
FSF	96	10	4	4	15233	44.68	1.87	23.89	15235	46.24	1.77	26.12	15234	46.04	2.27	20.28	15236	46.48	1.98	23.47
FSF	96	10	5	4	15237	44.87	1.76	25.49	15239	46.17	1.69	27.32	15238	47.63	1.83	26.03	15240	48.27	1.89	25.54
RM	95	6	1	4	12775	27.35	1.95	14.03	12776	26.38	1.91	13.81	12774	38.17	1.95	19.57	12777	24.95	1.87	13.34
RM	95	6	2	4	12778	34.06	1.99	17.12	12780	33.71	1.99	16.94	12779	28.83	2.01	14.34	12781	29.34	2.10	13.97
RM	95	6	3	4	12782	28.95	2.00	14.48	12784	34.22	2.19	15.63	12783	29.74	2.19	13.58	12785	29.27	2.22	13.18
RM	95	6	4	4	12786	34.29	2.23	15.38	12788	34.47	2.20	15.67	12787	30.58	2.22	13.77	12789	32.70	2.22	14.73
RM	95	6	5	4	12790	40.14	1.92	20.91	12792	35.74	1.98	18.05	12791	32.34	2.38	13.59	12793	33.04	2.25	14.68
RM	95	7	1	4	12915	34.46	1.95	17.67	12917	32.89	1.88	17.49	12916	28.46	1.89	15.06	12918	27.96	1.92	14.56
RM	95	7	2	4	12919	33.18	2.11	15.73	12921	36.06	2.07	17.42	12920	29.55	2.24	13.19	12922	31.61	2.08	15.20
RM	95	7	3	4	12923	36.31	1.90	19.11	12925	37.12	2.29	16.21	12924	31.75	2.24	14.17	12926	30.39	2.14	14.20

Total Carbon and Nitrogen

					0-4 cm								4-10 cm							
Site	year	month	Core #:	Height	ID#	initial c	initial n	initial c:n	ID#	final c	final n	final c:n	ID#	initial c	initial n	initial c:n	ID#	final c	final n	final c:n
RM	95	7	4	4	12927	38.10	1.75	21.77	12929	40.19	2.06	19.51	12928	32.66	2.23	14.65	12930	31.17	2.20	14.17
RM	95	7	5	4	12931	41.76	1.85	22.57	12933	36.76	2.32	15.84	12932	38.13	2.42	15.76	12934	37.38	2.36	15.84
RM	95	8	1	4	13018	32.29	1.94	16.64	13020	27.15	1.99	13.64	13019	28.69	2.01	14.27	13021	25.98	1.89	13.75
RM	95	8	2	4	13022	28.90	1.84	15.71	13024	31.88	1.75	18.22	13023	27.07	1.99	13.60	13025	27.77	2.07	13.42
RM	95	8	3	4	13026	33.72	2.16	15.61	13028	32.11	2.12	15.15	13027	30.43	2.22	13.71	13029	30.37	2.19	13.87
RM	95	8	4	4	13030	36.84	1.83	20.13	13032	35.48	1.92	18.48	13031	31.03	2.12	14.64	13033	32.52	2.15	15.13
RM	95	8	5	4	13034	36.67	2.12	17.30	13036	35.14	2.26	15.55	13035	28.23	2.04	13.84	13037	31.11	2.24	13.89
RM	95	13	1	4	15315	33.15	1.80	18.42	15317	35.08	1.87	18.76	15316	30.64	2.05	14.95	15318	26.88	1.82	14.77
RM	95	13	2	4	15319	38.20	1.60	23.88	15321	37.69	1.70	22.17	15320	29.68	2.02	14.69	15322	26.03	1.91	13.63
RM	95	13	3	4	15323	40.77	1.88	21.69	15325	31.67	2.18	14.53	15324	31.03	2.08	14.92	15326	36.16	1.87	19.34
RM	95	13	4	4	15327	35.84	2.01	17.83	15329	35.64	1.98	18.00	15328	35.26	2.48	14.22	15330	32.12	2.30	13.97
RM	95	13	5	4	15331	33.41	2.12	15.76	15333	38.23	2.02	18.93	15332	29.69	2.20	13.50	15334	32.20	2.27	14.19
RM	96	6	1	4	14646	43.37	1.63	26.61	14648	43.26	1.81	23.90	14647	29.42	2.12	13.88	14649	27.04	1.97	13.73
RM	96	6	2	4	14650	38.00	1.99	19.10	14652	40.05	1.75	22.89	14651	27.74	2.09	13.27	14653	26.78	2.08	12.88
RM	96	6	3	4	14654	42.57	2.13	19.99	14656	40.69	2.00	20.34	14655	29.11	2.06	14.13	14657	31.16	2.21	14.10
RM	96	6	4	4	14658	39.73	2.47	16.09	14660	35.27	2.47	14.28	14659	28.58	2.29	12.48	14661	28.25	2.23	12.67
RM	96	6	5	4	14662	34.95	2.30	15.20	14664	37.63	2.45	15.36	14663	30.78	2.22	13.86	14665	34.93	2.11	16.55
RM	96	7	1	4	14204	35.19	2.01	17.51	14206	26.49	1.90	13.94	14205	27.88	2.17	12.85	14207	25.73	1.86	13.83
RM	96	7	2	4	14208	42.45	1.70	24.97	14210	38.70	2.04	18.97	14209	32.87	2.10	15.65	14211	32.32	2.29	14.11
RM	96	7	3	4	14212	31.68	2.01	15.76	14214	38.90	2.14	18.18	14213	31.08	2.20	14.13	14215	32.12	2.19	14.67
RM	96	7	4	4	14216	36.50	1.95	18.72	14218	32.86	2.24	14.67	14217	30.46	2.27	13.42	14219	28.16	2.17	12.98
RM	96	7	5	4	14220	38.73	2.34	16.55	14222	37.20	2.45	15.18	14221	30.07	2.20	13.67	14223	33.43	2.37	14.11
RM	96	8	1	4	14425	24.10	1.75	13.77	14427	23.12	1.78	12.99	14426	23.71	1.75	13.55	14428	24.18	1.80	13.43
RM	96	8	2	4	14429	31.82	2.11	15.08	14431	34.27	2.17	15.79	14430	29.45	2.02	14.58	14432	28.36	2.03	13.97
RM	96	8	3	4	14433	31.54	2.15	14.67	14435	29.23	2.09	13.99	14434	26.79	2.20	12.18	14436	33.57	2.64	12.72
RM	96	8	4	4	14437	36.75	2.17	16.94	14439	32.11	2.24	14.33	14438	31.77	2.43	13.07	14440	29.02	2.27	12.78
RM	96	8	5	4	14441	33.82	2.32	14.58	14443	41.63	2.11	19.73	14442	33.89	2.34	14.48	14444	31.35	2.44	12.85
RM	96	9	1	4	14896	29.12	1.89	15.41	14898	32.92	2.01	16.38	14897	27.24	2.09	13.03	14899	30.27	2.15	14.08
RM	96	9	2	4	14900	33.68	1.98	17.01	14902	32.78	2.02	16.23	14901	28.62	2.09	13.69	14903	28.68	1.97	14.56
RM	96	9	3	4	14904				14906	36.10	2.18	16.56	14905	30.37	2.26	13.44	14907	27.62	2.13	12.97
RM	96	9	4	4	14908	33.31	2.13	15.64	14910	30.47	2.22	13.73	14909	30.39	2.25	13.51	14911	31.69	2.28	13.90
RM	96	9	5	4	14912	34.34	2.11	16.27	14914	29.28	2.14	13.68	14913	28.33	2.10	13.49	14915	28.98	2.16	13.42
RM	96	10	1	4	15086	28.65	1.91	15.00	15088	28.67	1.95	14.70	15087	26.64	1.90	14.02	15089	30.99	2.25	13.77
RM	96	10	2	4	15090				15092	30.39	1.94	15.66	15091	28.78	2.14	13.45	15093	27.17	1.98	13.72
RM	96	10	3	4	15094	30.77	1.90	16.19	15096	33.13	2.11	15.70	15095	29.66	2.30	12.90	15097	25.52	1.99	12.82
RM	96	10	4	4	15098	29.52	2.05	14.40	15100	29.71	2.02	14.71	15099	31.35	2.29	13.69	15101	29.25	2.14	13.67

Total Carbon and Nitrogen

					0-4 cm								4-10 cm							
Site	year	month	Core #:	Height	ID#	initial c	initial n	initial c:n	ID#	final c	final n	final c:n	ID#	initial c	initial n	initial c:n	ID#	final c	final n	final c:n
RM	96	10	5	4	15102	34.61	1.99	17.39	15104	29.99	2.14	14.01	15103	28.36	1.98	14.32	15105	28.55	2.04	14.00
LM2	96	6	1	4	14572	23.56	1.62	14.54	14574	23.58	1.83	12.89	14573	13.76	1.05	13.10	14575	15.37	1.20	12.81
LM2	96	6	2	4	14576	43.05	2.09	20.60	14578	40.51	2.34	17.31	14577	30.80	2.23	13.81	14579	24.02	1.73	13.88
LM2	96	6	3	4	14580	40.14	2.48	16.19	14582	41.21	2.50	16.48	14581	38.28	2.27	16.86	14583	38.01	2.40	15.84
LM2	96	6	4	4	14584	33.03	1.99	16.60	14586	40.03	2.22	18.03	14585	33.47	2.11	15.86	14587	39.60	2.47	16.03
LM2	96	6	5	4	14588	42.79	2.30	18.60	14590	41.14	2.58	15.95	14589	29.73	1.92	15.48	14591	33.47	2.20	15.21
LM2	96	7	1	4	14170	24.46	1.61	15.19	14172	22.15	1.67	13.26	14171	16.21	1.28	12.66	14173	16.82	1.26	13.35
LM2	96	7	2	4	14174	37.90	2.83	13.39	14176	30.64	2.98	10.28	14175	36.27	2.82	12.86	14177	22.62	1.76	12.85
LM2	96	7	3	4	14178	42.86	2.82	15.20	14180	42.62	2.81	15.17	14179	36.30	2.35	15.45	14181	26.36	1.71	15.42
LM2	96	7	4	4	14182	44.17	2.53	17.46	14184	44.72	2.69	16.62	14183	45.57	2.61	17.46	14185	48.54	2.39	20.31
LM2	96	7	5	4	14186	42.82	2.82	15.18	14188	43.04	2.69	16.00	14187	22.74	1.52	14.96	14189	26.81	1.80	14.89
LM2	96	8	1	4	14382	38.48	2.50	15.39	14384	29.19	2.43	12.01	14383	22.01	1.53	14.39	14385	28.88	2.21	13.07
LM2	96	8	2	4	14386	36.42	2.83	12.87	14388	33.81	2.52	13.42	14387	18.93	1.46	12.97	14389	17.84	1.31	13.62
LM2	96	8	3	4	14390	38.52	2.25	17.12	14392	38.10	2.48	15.36	14391	36.25	2.15	16.86	14393	38.32	2.45	15.64
LM2	96	8	4	4	14394	44.38	2.49	17.82	14396	43.13	2.72	15.86	14395	41.75	2.39	17.47	14397	43.37	2.40	18.07
LM2	96	8	5	4	14398	42.11	2.67	15.77	14400	39.58	2.61	15.16	14399	32.45	2.13	15.23	14401	20.67	1.45	14.26
LM2	96	9	1	4	14846	34.49	2.49	13.85	14848	33.88	2.47	13.72	14847	12.07	0.88	13.72	14849	12.63	0.93	13.58
LM2	96	9	2	4	14850	40.67	2.72	14.95	14852	39.38	2.57	15.32	14851	16.64	1.23	13.53	14853	16.85	1.23	13.70
LM2	96	9	3	4	14854	18.06	1.18	15.31	14856	21.84	1.41	15.49	14855	14.58	0.96	15.19	14857	18.17	1.11	16.37
LM2	96	9	4	4	14858	20.15	1.35	14.93	14860	18.43	1.22	15.11	14859	43.71	2.67	16.37	14861	43.64	2.55	17.11
LM2	96	9	5	4	14862	45.08	2.76	16.33	14864	44.71	2.74	16.32	14863	44.47	2.76	16.11	14865	41.85	2.60	16.10
LM2	96	10	1	4	15054	26.11	1.73	15.09	15056	19.48	1.34	14.54	15055	18.60	1.20	15.50	15057	15.72	1.03	15.26
LM2	96	10	2	4	15058	38.86	2.55	15.24	15060	31.10	2.08	14.95	15059	18.43	1.28	14.40	15061	13.87	0.99	14.01
LM2	96	10	3	4	15062	29.95	1.83	16.37	15064	31.54	1.96	16.09	15063	22.65	1.30	17.42	15065	17.07	1.11	15.38
LM2	96	10	4	4	15066	43.35	2.69	16.12	15068	43.06	2.64	16.31	15067	41.72	2.18	19.14	15069	41.91	2.44	17.18
LM2	96	10	5	4	15070	42.03	2.74	15.34	15072	43.70	2.73	16.01	15071	32.99	2.02	16.33	15073	29.97	1.94	15.45

Note: Site abbreviations are as in production raw data. Carbon and nitrogen are %, C:N are on a weight basis.

Nitrogen, oxygen, methane and diffusive fluxes

Month	Date	Day	Sample	core	O2 Flux	CH4 Flux	Diffusive	N2Flux	adjflux	Month	Date	Day	Sample	core	O2 Flux	CH4 Flux	Diffusive	N2Flux	adjflux
7	96-08-08	4	B#1	1	-34.75	7.86	79.87	1024.82	944.95	9	96-09-19	6	B#1	1	-54.55	37.13	61.69	994.21	932.52
7	96-08-10	6	B#1	1	-39.44	25.24	61.62	1257.74	1196.13	9	96-09-21	8	B#1	1	-86.48	49.01	59.93	604.13	544.20
7	96-08-12	8	B#1	1	-24.41	18.48	52.05	277.97	225.92	9	96-09-23	10	B#1	1	-49.97	46.42	49.03	201.19	152.16
7	96-08-14	10	B#1	1	-31.41	34.67	45.91	575.81	529.90	9	96-09-25	12	B#1	1	-53.93	40.14	49.20	108.19	58.98
7	96-08-16	12	B#1	1	-37.27	35.32	41.53	370.54	329.01	9	96-09-27	14	B#1	1	-57.56	41.80	44.63	273.02	228.39
7	96-08-18	14	B#1	1	-27.48	29.66	38.21	180.62	142.41	9	96-09-19	6	B#2	2	-68.46	24.09	62.79	727.68	664.90
7	96-08-08	4	B#2	2	-49.07	28.64	79.87	1296.57	1216.71	9	96-09-21	8	B#2	2	-82.50	26.75	53.93	498.98	445.06
7	96-08-10	6	B#2	2	-62.62	32.65	61.62	878.49	816.87	9	96-09-23	10	B#2	2	-65.82	31.98	51.46	318.04	266.58
7	96-08-12	8	B#2	2	-56.81	43.15	52.05	432.15	380.10	9	96-09-25	12	B#2	2	-52.14	20.89	38.09	186.50	148.41
7	96-08-14	10	B#2	2	-44.48	30.80	45.91	279.80	233.89	9	96-09-27	14	B#2	2	-81.51	24.62	39.59	207.25	167.66
7	96-08-16	12	B#2	2	-69.67	57.45	41.53	275.78	234.25	9	96-09-19	6	L#1	1	-40.35	2.01	59.13	251.78	192.65
7	96-08-18	14	B#2	2	-44.92	42.59	38.21	175.61	137.40	9	96-09-21	8	L#1	1	-65.58	2.79	45.41	142.35	96.94
7	96-08-08	4	L#1	1	-67.88	16.19	79.87	1161.52	1081.65	9	96-09-23	10	L#1	1	-59.93	1.60	50.93	-10.15	-61.08
7	96-08-10	6	L#1	1	-91.09	17.08	61.62	450.97	389.36	9	96-09-25	12	L#1	1	-64.52	3.16	46.59	72.85	26.26
7	96-08-12	8	L#1	1	-65.32	15.33	52.05	97.23	45.18	9	96-09-27	14	L#1	1	-56.45	1.40	43.82	1156.86	1113.05
7	96-08-14	10	L#1	1	-85.46	11.21	45.91	206.42	160.51	9	96-09-19	6	L#2	2	-64.71	7.92	57.19	540.16	482.97
7	96-08-16	12	L#1	1	-70.15	27.95	41.53	155.27	113.74	9	96-09-21	8	L#2	2	-91.14	6.44	46.81	377.71	330.91
7	96-08-18	14	L#1	1	-78.55	9.84	38.21	249.71	211.50	9	96-09-23	10	L#2	2	-73.71	5.84	43.95	190.95	147.00
7	96-08-08	4	L#2	2	-65.50	2.70	79.87	568.82	488.96	9	96-09-25	12	L#2	2	-48.81	5.21	21.69	175.94	154.25
7	96-08-10	6	L#2	2	-50.87	2.04	61.62	309.99	248.37	9	96-09-27	14	L#2	2	-47.11	5.23	37.69	363.23	325.53
7	96-08-12	8	L#2	2	-59.59	11.54	52.05	393.75	341.70	9	96-09-19	6	M#1	1	-57.51	16.93	62.48	1237.60	1175.12
7	96-08-14	10	L#2	2	-98.60	3.49	45.91	435.94	390.03	9	96-09-21	8	M#1	1	-68.31	15.63	48.52	963.43	914.91
7	96-08-16	12	L#2	2	-63.20	3.24	41.53	67.45	25.92	9	96-09-23	10	M#1	1	-57.17	23.34	43.54	622.38	578.84
7	96-08-18	14	L#2	2	-76.31	9.37	38.21	476.41	438.20	9	96-09-25	12	M#1	1	-53.63	22.57	42.11	549.51	507.40
7	96-08-08	4	M#1	1	-62.96	4.24	79.87	375.62	295.75	9	96-09-27	14	M#1	1	-74.85	24.31	46.24	493.74	447.50
7	96-08-10	6	M#1	1	-26.06	9.04	61.62	626.05	564.43	9	96-09-19	6	M#2	2	-84.41	5.46	61.58	640.11	578.53
7	96-08-12	8	M#1	1	-52.86	17.69	52.05	159.09	107.04	9	96-09-21	8	M#2	2	-82.43	1.42	48.45	152.71	104.26
7	96-08-14	10	M#1	1	-49.30	33.24	45.91	2209.62	2163.71	9	96-09-23	10	M#2	2	-88.34	11.31	42.73	483.63	440.89
7	96-08-16	12	M#1	1	-33.03	4.64	41.53	268.92	227.39	9	96-09-25	12	M#2	2	-79.07	11.31	48.89	604.12	555.23
7	96-08-18	14	M#1	1	-62.11	-0.72	38.21	400.98	362.77	9	96-09-27	14	M#2	2	-117.36	5.36	42.89	698.53	655.64
7	96-08-08	4	M#2	2	-76.42	8.60	79.87	642.56	562.69	9	96-09-19	6	O#1	1	-68.99	7.86	69.38	1160.72	1091.34
7	96-08-10	6	M#2	2	-61.89	5.52	61.62	150.62	89.00	9	96-09-21	8	O#1	1	-92.68	8.99	63.34	796.67	733.33
7	96-08-12	8	M#2	2	-53.80	4.57	52.05	164.83	112.78	9	96-09-23	10	O#1	1	-87.99	19.49	62.53	937.22	874.69
7	96-08-14	10	M#2	2	-71.15	10.42	45.91	277.23	231.32	9	96-09-25	12	O#1	1	-82.28	12.80	58.83	475.63	416.79
7	96-08-16	12	M#2	2	-82.12	3.21	41.53	-7.80		9	96-09-27	14	O#1	1	-82.43	9.94	45.80	518.19	472.39
7	96-08-18	14	M#2	2	-61.91	-0.71	38.21	282.20	243.99	9	96-09-19	6	O#2	2	-56.99	14.75	70.29	796.87	726.58

Month	Date	Day	Sample	core	O2 Flux	CH4 Flux	Diffusive	N2Flux	adjflux	Month	Date	Day	Sample	core	O2 Flux	CH4 Flux	Diffusive	N2Flux	adjflux
7	96-08-08	4	O#1	1	-45.79	11.79	79.87	914.94	835.07	9	96-09-21	8	O#2	2	-93.26	14.72	61.23	461.46	400.23
7	96-08-10	6	O#1	1	-41.97	17.25	61.62	553.48	491.87	9	96-09-23	10	O#2	2	-57.16	5.94	59.74	60.22	0.48
7	96-08-12	8	O#1	1	-51.10	24.04	52.05	377.06	325.01	9	96-09-25	12	O#2	2	-83.11	10.62	58.48	123.24	64.75
7	96-08-14	10	O#1	1	-45.02	20.67	45.91	301.08	255.18	9	96-09-27	14	O#2	2	-74.86	9.70	42.91	376.78	333.87
7	96-08-16	12	O#1	1	-73.09	20.65	41.53	102.45	60.92	9	96-09-19	6	S#1	1	-39.11	0.00	61.68	384.35	322.67
7	96-08-18	14	O#1	1	-55.11	15.75	38.21	267.10	228.89	9	96-09-21	8	S#1	1	-85.35	0.00	56.11	378.52	322.41
7	96-08-08	4	O#2	2	-53.61	15.99	79.87	842.36	762.49	9	96-09-23	10	S#1	1	-80.46	0.00	50.90	105.88	54.97
7	96-08-10	6	O#2	2	-76.22	11.10	61.62	221.48	159.86	9	96-09-25	12	S#1	1	-90.79	0.00	44.77	156.50	111.73
7	96-08-12	8	O#2	2	-64.95	19.87	52.05	149.17	97.12	9	96-09-27	14	S#1	1	-95.78	0.00	44.72	405.32	360.61
7	96-08-14	10	O#2	2	-74.64	23.34	45.91	236.85	190.94	9	96-09-19	6	S#2	2	-42.79	1.12	61.25	272.98	211.73
7	96-08-16	12	O#2	2	-77.73	21.97	41.53	-56.66		9	96-09-21	8	S#2	2	-71.93	5.65	48.51	466.48	417.97
7	96-08-18	14	O#2	2	-58.32	20.03	38.21	208.75	170.54	9	96-09-23	10	S#2	2	-75.66	5.17	42.07	373.27	331.20
7	96-08-08	4	S#1	1	-41.27	2.84	79.87	758.86	678.99	9	96-09-25	12	S#2	2	-57.90	2.31	32.25	233.91	201.65
7	96-08-10	6	S#1	1	-23.33	0.00	61.62	121.09	59.47	9	96-09-27	14	S#2	2	-88.06	5.96	42.73	668.38	625.66
7	96-08-12	8	S#1	1	-55.38	4.79	52.05	446.50	394.45	10	96-10-23	6	B#1	1	-64.30	0.00	67.12	744.72	677.60
7	96-08-14	10	S#1	1	-70.79	11.48	45.91	560.86	514.95	10	96-10-25	8	B#1	1	-66.59	0.00	63.58	414.92	351.35
7	96-08-16	12	S#1	1	-93.71	17.72	41.53	382.69	341.16	10	96-10-27	10	B#1	1	-92.07	0.15	48.50	682.50	634.00
7	96-08-18	14	S#1	1	-71.45	12.39	38.21	339.83	301.62	10	96-10-29	12	B#1	1	-22.71	-0.29	42.51	355.38	312.87
7	96-08-08	4	S#2	2	-30.52	2.30	79.87	181.63	101.76	10	96-10-31	14	B#1	1	-81.26	0.00	42.26	459.40	417.14
7	96-08-10	6	S#2	2	-47.62	6.66	61.62	534.59	472.97	10	96-10-23	6	B#2	2	-70.10	0.08	69.33	810.63	741.29
7	96-08-12	8	S#2	2	-29.72	9.69	52.05	278.34	226.29	10	96-10-25	8	B#2	2	-65.81	-0.67	56.85	717.86	661.01
7	96-08-14	10	S#2	2	-7.13	12.10	45.91	92.08	46.17	10	96-10-27	10	B#2	2	-15.85	0.33	41.03	133.51	92.48
7	96-08-16	12	S#2	2	-75.60	22.06	41.53	307.22	265.69	10	96-10-29	12	B#2	2	-88.38	-0.55	35.74	700.70	664.96
7	96-08-18	14	S#2	2	-35.42	-1.68	38.21	337.86	299.65	10	96-10-31	14	B#2	2	-18.17	0.33	35.41	163.00	127.58
8	96-08-24	6	B#1	1	-76.47	24.41	55.62	1078.53	1022.91	10	96-10-23	6	B#3	3	-24.34	0.00	65.83	305.25	239.42
8	96-08-26	8	B#1	1	-83.35	12.12	44.17	295.97	251.80	10	96-10-25	8	B#3	3	-65.27	-0.42	50.84	541.62	490.77
8	96-08-28	10	B#1	1	-12.65	34.30	50.56	339.30	288.74	10	96-10-27	10	B#3	3	-71.49	0.35	51.85	487.65	435.80
8	96-08-30	12	B#1	1	-72.47	17.70	42.74	170.20	127.45	10	96-10-29	12	B#3	3	-81.37	-0.37	41.20	331.39	290.19
8	96-09-01	14	B#1	1	-47.45	29.48	44.15	124.91	80.76	10	96-10-31	14	B#3	3	-66.49	0.00	40.82	152.91	112.09
8	96-08-24	6	B#2	2	-89.76	6.00	56.00	406.78	350.78	10	96-10-23	6	L#1	1	-83.62	0.84	68.63	465.05	396.42
8	96-08-26	8	B#2	2	-100.33	8.59	49.23	321.92	272.70	10	96-10-25	8	L#1	1	-84.12	0.60	50.52	259.82	209.31
8	96-08-28	10	B#2	2	-97.94	17.75	40.03	402.85	362.82	10	96-10-27	10	L#1	1	-54.45	0.79	46.58	410.36	363.78
8	96-08-30	12	B#2	2	-104.17	7.88	41.83	111.94	70.11	10	96-10-29	12	L#1	1	-67.54	-0.02	31.15	332.16	301.01
8	96-09-01	14	B#2	2	-80.52	5.21	39.89	176.62	136.73	10	96-10-31	14	L#1	1	-46.06	0.53	22.33	404.37	382.04
8	96-08-24	6	L#1	1	-82.42	0.00	50.25	316.88	266.63	10	96-10-23	6	L#2	2	-43.64	1.17	66.65	414.58	347.94
8	96-08-26	8	L#1	1	-68.70	0.00	45.11	57.38	12.27	10	96-10-25	8	L#2	2	-31.92	0.00	50.55	246.47	195.92
8	96-08-28	10	L#1	1	-17.50	1.55	39.32	32.26	-7.06	10	96-10-27	10	L#2	2	-39.60	0.56	38.00	465.70	427.70

Month	Date	Day	Sample	core	O2 Flux	CH4 Flux	Diffusive	N2Flux	adjflux	Month	Date	Day	Sample	core	O2 Flux	CH4 Flux	Diffusive	N2Flux	adjflux
8	96-08-30	12	L#1	1	-45.41	1.84	38.11	10.40	-27.71	10	96-10-29	12	L#2	2	-21.73	0.00	33.00	379.88	346.88
8	96-09-01	14	L#1	1	-45.62	2.47	35.84	145.61	109.77	10	96-10-31	14	L#2	2	-26.00	0.00	44.68	9.44	-35.24
8	96-08-24	6	L#2	2	-71.85	0.88	50.12	257.22	207.10	10	96-10-23	6	L#3	3	-32.53	0.00	64.24	2238.81	2174.58
8	96-08-26	8	L#2	2	-82.55	0.00	52.93	140.57	87.64	10	96-10-25	8	L#3	3	-29.37	-0.71	49.92	1014.25	964.33
8	96-08-28	10	L#2	2	-0.81	0.57	39.35	33.60	-5.75	10	96-10-27	10	L#3	3	-35.42	1.81	41.64	401.14	359.51
8	96-08-30	12	L#2	2	-94.55	5.27	48.87	181.61	132.74	10	96-10-29	12	L#3	3	-64.19	2.16	39.40	882.65	843.26
8	96-09-01	14	L#2	2	-79.30	2.99	41.08	256.01	214.93	10	96-10-31	14	L#3	3	-23.60	0.20	39.03	414.58	375.55
8	96-08-24	6	M#1	1	-30.10	11.12	47.37	634.44	587.07	10	96-10-23	6	M#1	1	-98.30	8.27	49.75	1298.40	1248.65
8	96-08-26	8	M#1	1	-51.25	9.89	35.24	90.69	55.45	10	96-10-25	8	M#1	1	-83.96	4.12	42.04	339.07	297.03
8	96-08-28	10	M#1	1	-17.20	13.41	38.99	207.81	168.82	10	96-10-27	10	M#1	1	-41.45	3.32	46.79	262.18	215.39
8	96-08-30	12	M#1	1	-28.85	11.47	40.52	66.42	25.90	10	96-10-29	12	M#1	1	-56.32	3.36	36.75	403.51	366.77
8	96-09-01	14	M#1	1	-32.90	19.32	27.19	162.33	135.14	10	96-10-31	14	M#1	1	-37.75	6.00	33.07	317.64	284.56
8	96-08-24	6	M#2	2	-104.26	19.47	46.15	476.85	430.70	10	96-10-23	6	M#2	2	-61.23	3.21	54.79	671.64	616.84
8	96-08-26	8	M#2	2	-66.53	15.32	40.62	-13.62	-54.24	10	96-10-25	8	M#2	2	-72.61	2.32	54.57	391.14	336.57
8	96-08-28	10	M#2	2	-70.84	30.35	38.69	2.72	-35.97	10	96-10-27	10	M#2	2	-34.69	0.40	49.59	272.13	222.54
8	96-08-30	12	M#2	2	-83.04	30.07	37.17	-57.92	-95.08	10	96-10-29	12	M#2	2	-77.07	3.42	38.93	432.99	394.06
8	96-09-01	14	M#2	2	-59.37	15.39	42.94	2.86	-40.08	10	96-10-31	14	M#2	2	-31.24	0.00	38.86	85.60	46.74
8	96-08-24	6	O#1	1	-70.17	10.52	62.15	415.14	352.98	10	96-10-23	6	M#3	3	-66.95	0.78	59.27	911.75	852.48
8	96-08-26	8	O#1	1	-106.74	10.72	62.50	190.26	127.76	10	96-10-25	8	M#3	3	-52.11	0.00	65.09	4462.02	4396.93
8	96-08-28	10	O#1	1	-73.59	10.98	62.47	-13.46	-75.93	10	96-10-27	10	M#3	3	-20.63	0.00	51.52	141.67	90.15
8	96-08-30	12	O#1	1	-90.74	14.84	51.85	44.43	-7.42	10	96-10-29	12	M#3	3	-77.07	0.00	42.62	527.00	484.38
8	96-09-01	14	O#1	1	-76.78	11.19	44.01	121.17	77.16	10	96-10-31	14	M#3	3	-74.10	0.00	36.76	415.06	378.30
8	96-08-24	6	O#2	2	-70.94	14.99	61.66	858.44	796.77	10	96-10-23	6	O#1	1	-78.58	2.00	75.15	1186.48	1111.34
8	96-08-26	8	O#2	2	-96.00	12.56	49.11	329.31	280.20	10	96-10-25	8	O#1	1	-53.58	-0.76	70.01	119.63	49.62
8	96-08-28	10	O#2	2	-92.36	13.81	60.38	128.81	68.43	10	96-10-27	10	O#1	1	-22.76	0.00	70.80	284.02	213.22
8	96-08-30	12	O#2	2	-59.56	11.70	43.93	117.13	73.19	10	96-10-29	12	O#1	1	-111.78	6.76	62.56	1063.60	1001.04
8	96-09-01	14	O#2	2	-54.96	15.88	45.88	148.55	102.67	10	96-10-23	14	O#2	1	-80.83	0.00	75.13	379.48	304.35
8	96-08-24	6	S#1	1	-86.07	6.28	56.21	746.42	690.21	10	96-10-25	6	O#2	2	-18.95	0.00	56.21	-93.86	-150.07
8	96-08-26	8	S#1	1	-66.87	0.00	43.41	86.64	43.23	10	96-10-27	8	O#2	2	-26.55	0.00	54.38	218.47	164.09
8	96-08-28	10	S#1	1	-94.48	10.88	46.66	492.16	445.50	10	96-10-29	10	O#2	2	-99.01	2.07	46.30	3648.45	3602.15
8	96-08-30	12	S#1	1	-82.50	16.90	40.58	570.02	529.44	10	96-10-31	12	O#2	2	-71.78	0.00	53.24	577.50	524.26
8	96-09-01	14	S#1	1	-50.03	16.02	35.83	429.67	393.84	10	96-10-23	6	O#3	3	-17.40	0.00	75.67	63.57	-12.10
8	96-08-24	6	S#2	2	-35.61	0.74	55.19	256.29	201.10	10	96-10-25	8	O#3	3	-11.42	0.00	53.26	117.88	64.62
8	96-08-26	8	S#2	2	-62.00	1.98	42.18	203.94	161.76	10	96-10-27	10	O#3	3	-25.86	0.00	50.11	233.03	182.92
8	96-08-28	10	S#2	2	-89.57	4.37	46.99	197.76	150.77	10	96-10-29	12	O#3	3	-24.70	0.00	42.50	127.48	84.98
8	96-08-30	12	S#2	2	-28.06	0.91	43.10	4.57	-38.53	10	96-10-31	14	O#3	3	-16.02	0.00	45.61	213.32	167.71
8	96-09-01	14	S#2	2	-29.68	-0.09	36.40	109.54	73.14	10	96-10-23	6	S#1	1	-97.11	1.91	69.58	1141.85	1072.26

Month	Date	Day	Sample	core	O2 Flux	CH4 Flux	Diffusive	N2Flux	adjflux	Month	Date	Day	Sample	core	O2 Flux	CH4 Flux	Diffusive	N2Flux	adjflux
										10	96-10-25	8	S#1	1	-30.30	0.00	46.48	77.56	31.08
										10	96-10-27	10	S#1	1	-89.44	6.36	43.40	779.60	736.19
										10	96-10-29	12	S#1	1	-61.34	0.63	43.63	311.93	268.30
										10	96-10-31	14	S#1	1	-23.58	0.11	44.66	98.70	54.05
										10	96-10-23	6	S#2	2	-59.12	0.00	69.60	285.92	216.32
										10	96-10-25	8	S#2	2	-41.01	-0.67	46.55	242.53	195.98
										10	96-10-27	10	S#2	2	-56.72	0.00	51.13	324.85	273.72
										10	96-10-29	12	S#2	2	-34.03	0.00	47.56	209.28	161.72
										10	96-10-31	14	S#2	2	-9.53	0.00	53.94	182.69	128.75
										10	96-10-23	6	S#3	3	-21.71	0.00	71.20	243.80	172.60
										10	96-10-25	8	S#3	3	-28.19	0.00	60.15	166.98	106.83
										10	96-10-27	10	S#3	3	-37.02	0.00	44.44	724.58	680.14
										10	96-10-29	12	S#3	3	-33.79	0.00	50.58	194.64	144.06
										10	96-10-31	14	S#3	3	-20.33	0.00	44.15	146.14	102.00

Note: Nitrogen and diffusive fluxes are in µmol N/m^2 hr, while methane is mg CH$_4$/m^2 hr and oxygen is mg O$_2$/m^2 hr. Site abbreviations are as in production raw data.