Development and application of plant macrofossils for paleolimnological reconstructions in the Slave River Delta, N.W.T.

By
Margaret E. Adam

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Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

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Abstract

This thesis combines detailed analyses of living plant communities with paleolimnological methods to develop the use of plant macrofossils as an effective tool to track hydroecological changes in ponds of the Slave River Delta (SRD), N.W.T. Several approaches were used to develop an understanding of the relationships between hydrolimnological conditions, living plant communities, and the composition of sedimentary macrofossil remains across spatial and temporal scales. A spatial survey approach was used to assess the relationships between the composition of plant macrofossil assemblages contained in the surface sediments and the hydrological and limnological conditions of 40 SRD basins that span a broad range of hydrological settings in the delta. Results show that there are strong relationships between the prevailing hydrolimnological conditions in the SRD and the composition of sedimentary macrofossil remains, and subsequently indicator macrofossil taxa were identified to distinguish between sites with high river influence (flood-dominated sites: ostracode shells, *Daphnia* ephippia, *Chara* oospores; exchange-dominated sites: *Myriophyllum* winter-bud scales, *Daphnia* ephippia) and sites with low river influence (evaporation-dominated: *Ceratophyllum* leaves, *Lemna* leaves, *Drepanocladus* leaves).

In light of the strong connection between spring flood events and the hydrolimnological conditions of SRD ponds, and growing concerns that the frequency of spring floods have declined in recent decades, paleolimnological investigations were initiated at a pond (SD2) adjacent to the Slave River to construct a record of flood events in the SRD. Prior to analysis of macrofossil assemblages from sediment cores, a detailed study of the living plant community was conducted at SD2, and results were compared to the distributions of surficial sedimentary plant macrofossil assemblages to assess how representative surficial sediment assemblages are of the living plant community. This study indicates distinct patch-scale (or quadrat-scale) similarity between the living vegetation and sedimentary remains in the central basin, as well as distinct similarity between the living aquatic macrophytes and sedimentary remains at a pond-scale, suggesting there is excellent potential to track changes in the composition and percent cover of aquatic macrophytes in pond sediment cores using plant macrofossil assemblages. Additionally, this study indicates that influence of long-distance transport of macrofossils during the 2005 flood event was minor at this pond, and may not be an important factor affecting paleolimnological reconstructions of plant communities.

With contemporary studies as a framework, an ~90-year record of ice-jam flood frequency was reconstructed from a sediment core collected from pond SD2. Multi-proxy analyses indicated decadal-scale oscillations in flood frequency at this site, with at least three multi-year periods of low river influence. Beginning in ~1943, an 18-year period of particularly low river influence and greatly reduced water levels was indicated by abundant macrofossils of *Sagittaria cuneata* and represents the driest period over the past ~90-years. Similarities between the flood history of SD2 and upstream sites in the Peace-Athabasca

Delta suggest that spring discharge generated from headwaters and major contributing rivers plays a key role in the frequency and magnitude of spring flood events of both deltas.

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Chapter 1: General Introduction

Deltas of the Mackenzie River drainage system encompass some of the most highly productive, environmentally sensitive and economically important habitats of Canada's North (English 1984). These northern floodplain environments include unique, dynamic hotspots for biological productivity and diversity (PADPG 1973, English 1984, English et al. 1996, 1997; Squires et al. 2002b) within which hydrological fluctuation can have widespread ecological consequences for plant communities (Lewis et al. 2000; Jungwirth et al. 2002; Junk 2005), including alteration of community composition (e.g. terrestrial encroachment), primary productivity, species diversity and quality of habitat for wildlife (Cronk and Fenessey 2001). In particular, the physical, geochemical and biological conditions of these floodplain lakes are strongly controlled by the nature of river influence (English et al. 1997; Hay et al. 1997; Lesack et al. 1998; Prowse and Conly 2001, 2002; Squires and Lesack 2001, 2002b, 2003; Spears and Lesack 2006; Brock et al. 2007; Wolfe et al. 2007a; Sokal et al. in press).

There are three major delta ecosystems within the bounds of the Mackenzie River drainage system. From south to north, they are the Peace-Athabasca Delta (PAD), located in northern Alberta at the confluence of the Peace and Athabasca Rivers, the Slave River Delta (SRD), located on the south shore of Great Slave Lake, near Fort Resolution, N.W.T., and the Mackenzie Delta (MD), located in northern N.W.T. where the Mackenzie River drains into the Beaufort Sea. The SRD has been less intensively studied than the PAD and

MD, but concerns over hydrological and ecological conditions of the SRD have increased during recent decades owing to a perceived decline in flood frequency and potential links with river regulation and climate change. Specifically, construction of the W.A.C. Bennett hydroelectric dam in 1968 at the headwaters of the Peace River and the initial filling of Williston Lake reservoir in 1970 has been associated with a decrease of almost 20% in the peak annual flow of the Slave River (Prowse and Conly 1998, 2001; Peters and Prowse 2001; Gibson et al. 2006), and with subsequent effects on the formative processes of the SRD (English et al. 1997). Changes in hydrology and associated vegetation communities have reportedly affected the development of geomorphic features (e.g., formation of levees and subsequent stabilization through colonization by emergent macrophytes; English et al.1997). In the SRD, periodic flooding has formed a landscape with high biological productivity and a diversity of plant species that provides important feeding, staging and breeding habitats for a large number of waterfowl, muskrat and other wildlife (English et al.1997). The natural resources of this ecosystem are of central importance to the livelihood and socio-cultural integrity of the indigenous community of Fort Resolution, N.W.T. (Wolfe et al. 2007a).

Meteorological and climate data are available from January 1953 to current day, for the nearby town of Hay River. These records include temperature, dewpoint, relative humidity, wind direction, wind speed, visibility, standard pressure, humidex, wind chill and qualitative weather conditions (e.g. cloud cover, snow, rain; Environment Canada 2002). In addition, a record of gauged

Slave River discharge from the nearest hydrometric station on the Slave River at Fitzgerald, Alberta is available beginning in 1960 (Water Survey of Canada). These records predate the construction of the W.A.C. Bennett Dam by fifteen and eight years respectively. The absence of longer-term records limits the ability to understand the natural variability of this system, and the ability to develop effective tools to evaluate and predict the effects of human- and climate-induced change on this ecologically sensitive northern delta.

Paleolimnological methods have the potential to provide key insight into hydroecological dynamics of the SRD. In particular the use of plant macrofossil analysis holds promise as a method to reconstruct changes in local aquatic and nearshore vegetation. Plant macrofossils include leaves, shoots, fruit and seeds of the surrounding vegetation. In conjunction with modern vegetation surveys, past plant communities can be reconstructed by analyzing plant macrofossils contained in the sediment record. When preserved in lake or pond sediments, plant macrofossils can be used to reconstruct the local vegetation of wetland and aquatic habitats (Mannion 1986). Plant macrofossils preserved in aquatic sediments have been used in many capacities, such as determining succession patterns and vegetation dynamics in glacial, interglacial and post-glacial deposits (Birks and Ransom 1969; Griffin 1977, Warner 1984b; Terasmae 1959; Birks 2003; Boyd 2007), reconstructing pH level change in peat deposits (Rybnicek 1973), assessing lake level fluctuation (Hannon 1997) and the evolution of tundra ecosystems (Matthews 1974). However, few studies have analyzed plant macrofossils in lake sediment profiles to assess changes in hydrological conditions in delta environments. Most recently, research by Hall et al. (2004) related the composition of macrofossil assemblages in the surface sediments of 57 shallow deltaic water bodies in the PAD to present-day hydrological conditions. Specifically, they found that plant macrofossil assemblages are sensitive indicators of hydroecological conditions in this deltaic environment, and subsequently used these relationships to interpret how changes in macrofossil assemblages observed in sediment cores reflect changes in hydroecological conditions of shallow floodplain basins of the PAD (e.g., Wolfe et al. 2005). The incorporation of plant macrofossil analysis in the PAD studies by Hall et al. (2004) suggests that this approach has the potential to provide robust and reliable information about past hydrological changes in the SRD and their influence on aquatic vegetation dynamics.

Site Description

The Slave River Delta (SRD) is located in the Northwest Territories (centered at approximately 61°15’ N; 113°30’ W) on the south shore of Great Slave Lake (Figure 2-1) The Slave River begins at the confluence of the Peace River and Rivière des Rochers in northern Alberta, and flows north to Great Slave Lake. It provides ~75% of all inflow to Great Slave Lake (Gardner et al. 2006), which is a principal water source for the Mackenzie River. The entire delta extends north-northwest from the Slave River rapids to the south shore of Great Slave Lake and is ~170 km long by ~70 km wide, spanning an area of approximately 8300 km^2, but most of it is no longer active. The active portion of the SRD encompasses ~5% of the entire delta, or an area of ~400 km^2.

Great Slave Lake was formed ~10,000 years BP following the retreat of the Keewatin ice sheet (Vanderburgh and Smith 1988) and the lowering of Glacial Lake McConnell water-levels. The deposition of alluvial material from the Slave River into the southern arm of Great Slave Lake began the formation of the SRD (English 1984). The present-day soils of the SRD have developed on this sandy calcareous alluvium and are discontinuously frozen under forest cover (Day 1972).

The SRD climate is strongly seasonal, with an average January temperature of -23.1 ºC, and an average July temperature of 15.9 ºC. The average yearly temperature and average yearly relative humidity are -2.9 ºC and 76.3% respectively, based on 1971-2000 climate normals measured in Hay River, N.W.T. (Environment Canada 2002). Annual precipitation in the SRD is approximately 320mm, with approximately half falling as rain during thaw season.

The modern SRD is a large wetland complex consisting of numerous river channels, marshes, fens, bogs, swamps and forests. Scattered throughout this landscape are a multitude of small, shallow (<4m) ponds spanning a wide hydrological gradient. These shallow ponds are macrophyte-dominated systems (Sokal et al. in press) with productive shoreline communities that provide diverse habitats for a variety of plant and animal communities (English et al. 1997).

Using water stable isotope tracers ($\delta^{18}O$, $\delta^{2}H$), Brock et al. (2007) identified three distinct hydrological types of aquatic basins in the SRD based on differences in the relative roles of precipitation, snowmelt runoff, river flooding, evaporation, and Great Slave Lake seiche events on the water balances following spring thaw. Subsequently, Sokal et al. (in press) used water chemistry and sediment diatom assemblages within the framework of this classification scheme to show that limnological conditions in SRD basins and the composition of sediment diatom communities differ among the three hydrological categories. Flood-dominated basins, located in the active delta, have water balances most strongly influenced by Slave River flood water during the spring melt and are characterized by low concentrations of nutrients (TP, TN) and ions (Cl^-, SO_4^{-2}). Evaporation-dominated basins, located in the non-active delta, have a water balance most strongly influenced by spring snowmelt and summer rainfall, with evaporation as the overriding process controlling lake water balances during the ice-free season. Evaporation-dominated sites are characterized by high concentrations of nutrients and ions, and high alkalinity. Exchange-dominated basins, located along the Slave River and delta front adjacent to Great Slave Lake, receive inputs from channel connections with the Slave River and/or Great Slave Lake through seiche events, resulting in variable water balances depending on the relative magnitude and frequency of their hydrologic connections. Exchange-dominated sites have the lowest alkalinity the lowest concentrations of nutrients, ions and chlorophyll-a of all three categories.

The major vegetation patterns in the SRD have been described by English et al. (1997) as part of a delta classification scheme using both vegetation and geomorphological characteristics. The outer, active delta is dominated by semi-aquatic emergent vegetation such as *Equisetum fluviatile* and various species of sedge (*Carex* spp.) and willow (*Salix* spp.). The mid-delta is a transitional area between the active and non-active delta, and is characterized by the dominance of *Equisetum arvense*, *Alnus tenufolia*, *Cornus stolonifera* and *Populus tremuloides* (English 1984). The apex is located primarily within the non-active delta, where bryophytes form thick ground cover and mature forests support stands of *Picea glauca* and *Populus tremuloides*, with shrubs consisting largely of *Rosa acicularis*, *Alnus tenufolia*, *Cornus stolonifera* and *Vibernum edule* (English 1984). *Equisetum arvense* dominates the herb layer, with *Pryola secunda var. secunda* and *Linnaea borealis* as major subdominant species (English 1984).

Research Objectives

This thesis consists of three distinct studies, written in journal manuscript style, focused on developing and testing the use of sedimentary plant macrofossil assemblages as indicators of hydroecological conditions in basins of the SRD. This approach is then used in conjunction with other paleolimnological proxies to assess past changes in the hydroecological conditions at a flood-prone pond adjacent to the Slave River. The aim of the first study (presented in Chapter 2) is to assess the relationships between the compositions of plant macrofossil assemblages contained in the surface sediments of 40 SRD basins, spanning a range of hydrological and limnological conditions, and the prevailing hydrolimnological conditions that exist in the delta. Multivariate numerical methods are used to determine whether the composition of sedimentary macrofossil assemblages discriminate among the three hydrological categories (Flood-, exchange- and evaporation-dominated) and to identify the indicator macrofossil taxa that contribute to the differences among hydrological lake categories. The aim of the second study (presented in Chapter 3) is to assess the patch- and pond-scale relationships between spatial distributions of plant macrofossils in surficial sediments from one flood-prone delta pond (SD2) and the contemporary living plant community within and adjacent to that pond. The third study (presented in Chapter 4) constructs a record of ice-jam flood events based on geochemical and biological proxy analyses, including plant macrofossils. These analyses are conducted on a sediment core collected from flood-prone pond SD2, and aim to identify the relative roles of geomorphology, river regulation and climate on flood frequency and magnitude at this site.

Chapter 2: A spatial analysis of relationships between plant macrofossils and hydrolimnological conditions in ponds of the Slave River Delta, N.W.T.

INTRODUCTION

Hydrological fluctuations can have widespread ecological consequences for plant communities of floodplain environments (Lewis et al. 2000; Jungwirth et al. 2002; Junk 2005), including alteration of community composition of submerged aquatic plants to emergent plants, primary productivity, species diversity and quality of habitat for wildlife (Cronk and Fenessey 2001). In the Slave River Delta (SRD), periodic flooding has formed a landscape with high biological productivity and diversity of plant species that provides important feeding, staging and breeding habitats for a large number of waterfowl, muskrat and other wildlife (English et al. 1997). The natural resources of this ecosystem are also of central importance to the livelihood and socio-cultural integrity of the indigenous community of Fort Resolution, N.W.T. (Wolfe et al. 2007a). Examination of historical aerial photographs dating back to 1954 suggests that changes in hydrology and the subsequent changes to vegetation communities have affected the development of deltaic landforms (e.g., stabilization of levees via colonization by emergent macrophytes) in the SRD, which has raised concerns that river regulation has reduced flood frequency (English et al.1997). Long-term monitoring records of climate and river discharge extend back 54 and 47 years, respectively, and are too short to assess the range of natural variation or to detect directional changes and their causes. Tracking changes in vegetation over longer time scales using paleolimnological methods may provide one of the few approaches to assess hydroecological dynamics of the SRD and to evaluate the mechanisms responsible for the changes.

Plant macrofossils preserved in lake or pond sediments can often be used to reconstruct the local vegetation of wetland and aquatic habitats (Mannion 1986). They have been used in many capacities, such to improve understanding of successional patterns and vegetation dynamics in glacial, interglacial and post-glacial deposits (Birks and Ransom 1969; Griffin 1977; Warner 1984; Terasmae 1959; Birks 2003; Boyd 2007), to reconstructing pH changes in peat deposits (Rybnicek 1973), assessing lake-level fluctuations (Hannon 1998) and the evolution of tundra ecosystems (Matthews 1974). However, few studies have analyzed plant macrofossils in lake sediment profiles to assess changes in hydrological conditions from deltaic environments. Most recently, research by Hall et al. (2004) has used the composition of macrofossil assemblages in surface sediments, with associated present-day hydrological conditions, to develop interpretations of changes in macrofossil assemblages observed in sediment cores from the Peace-Athabasca Delta (PAD). For example, reconstruction of plant communities from a perched basin in the PAD revealed strong variability in hydroecological conditions over the past ~300 years, consistent with other proxy indicators (Wolfe et al. 2005).

To assess the response of local aquatic and near-shore vegetation to changes in hydrological conditions in the SRD through time, the contemporary relationships between plant macrofossil assemblages in the surface-sediments and the hydrological and limnological gradients in the SRD must first be identified. Using water isotope tracers, Brock et al. (2007) identified three distinct hydrological basin types based on differences in the relative roles of precipitation, snowmelt runoff, river flooding, evaporation, and Great Slave Lake seiche events on basin water balance following the 2003 spring thaw. Subsequently, Sokal et al. (in press) used water chemistry and sedimentary diatom assemblages within the framework of this classification scheme to show that limnological conditions in basins of the SRD are strongly regulated by their hydrology. To summarize these studies briefly, *flood-dominated* basins, located in the active portion of the delta, have a water balance that is most strongly influenced by Slave River flood water during the spring melt. These flood-dominated systems are characterized by low concentrations of nutrients with high concentrations of Cl^- and SO_4^{2-}. In the older, non-active part of the delta, the water balance of *evaporation-dominated* basins is most strongly influenced by spring snowmelt and summer rainfall, and subsequently evaporation becomes the overriding process controlling lake water balances during the remainder of the thaw season. Evaporation-dominated sites are characterized by high nutrient concentrations (TP, TN), alkalinity and ionic content. *Exchange-dominated* basins, located along the Slave River and delta front adjacent to Great Slave Lake, received periodic inputs from channel connections with the Slave River and/or Great Slave Lake water through seiche events, resulting in variable water balances depending on the relative magnitude and frequency of the hydrologic connections. The water chemistry of exchange-dominated sites is characterized by low but variable concentrations of nutrients, ions, chlorophyll-*a* and alkalinity.

It is important to note that Slave River discharge during spring thaw in 2003 was average when compared to 46 years of gauge data from the nearest hydrometric station. This feature is key to the hydrological classification developed from samples collected in 2003 because both the water balances and water chemistries of SRD basins are strongly influenced by Slave River spring discharge (Brock et al. 2007; Sokal et al. in press). The surface-sediments used in this study (collected in September 2002) contain plant macrofossils deposited in the top 1 cm of sediment over the past several years and thus are likely to reflect the average contemporary vegetation communities of the delta ponds.

The previous studies by Brock et al. (2007) and Sokal et al. (in press) in the SRD indicate that limnological conditions are strongly regulated by their hydrology, which is consistent with findings from the Mackenzie Delta (MD) (Squires and Lesack 2002) and PAD (Wolfe et al. 2007b), that have identified flood frequency and the degree of hydrological connection between floodplain lakes and their associated rivers as the strongest regulator of limnological conditions. Additionally, Sokal et al. (in press) identified diatom indicator taxa that distinguish among the different hydrological categories of basins in the SRD. The integration of water chemistry and isotope tracers to characterize the present hydrolimnological and ecological conditions in the Slave Delta, combined with the utility of plant macrofossils in reconstructing changes in hydroecological conditions in the PAD (Hall et al. 2004; Wolfe et al. 2005) suggest excellent potential for the development and application of plant macrofossils to assess the influence of hydrological change on aquatic vegetation communities in the SRD.

This study assesses the relationships between the composition of plant macrofossil assemblages contained in the surface sediments and hydrological and limnological conditions of 40 basins in the SRD that span a broad range of hydrological conditions that exist in the delta. Multivariate analyses are used to determine whether macrofossil assemblages differ among the three hydrological basin categories, and to identify the macrofossil taxa which best discriminate among hydrological lake categories.

METHODOLOGY

Sampling and laboratory procedures

The water bodies, surface-sediment samples and water chemistry samples used in this study are the same as those sampled and analyzed by Brock et al. (2007) and Sokal et al. (in press). These water bodies and sampling locations are shown in Figure 2-1. Samples were collected in September 2002 from 40 ponds spanning the three hydrological categories as described by Brock et al. (2007), including flood-dominated (n = 10), exchange-dominated (n = 4) and evaporation-dominated (n = 26) basins, the Slave River (R3 (Resdelta channel)), two distributaries of the Slave River (R1 (East Channel) and R2 (Jean River)) and Great Slave Lake (SD42) (Table 2-1). Briefly, water samples were collected from ~10 cm below the water surface, near the deepest or central portion of each of the 40 ponds and from the mid-channel at river sites. Water from Great Slave Lake was collected from ~100 m from the delta front in Great Slave Lake, to determine the chemical composition of input waters from seiche events at exchange-dominated sites. Limnological variables (pH, conductivity, temperature and water depth) were measured and recorded at each sampling site, and water samples were collected for chlorophyll-a and chemical analyses (concentrations of dissolved organic carbon (DOC), colour, total nitrogen (TKN), nitrate + nitrite (NO_3^-+NO_2^-), dissolved phosphorus (dP), total phosphorus (TP), dissolved silica (SiO_2) major ions (Ca^{2+}, Mg^{2+}, K^+, Na^+, Cl^-, $SO4^2$) and alkalinity). All water samples were first filtered using a 650µm screen to remove large particulates. Water samples were then filtered through 0.7µm pore-size Gf/C filters for chlorophyll-a (chl-a) measurements. Filters were frozen until analysis (Jeffery et al. 1997). Water samples for chemical analysis were stored at 4°C and analyzed within 3-5 days of collection, at the Water Chemistry Laboratory, at the University of Montréal.

Surface-sediment samples (0-1 cm) were collected at the same time as water samples using a Mini-Glew gravity corer (Glew 1991), at or near the deepest central part of the same 40 ponds, and stored in Whirl-pak® bags at 4^{o}C. Macrofossil samples were prepared following standard techniques as outlined by Birks and Birks (1980). Briefly, macrofossil samples were prepared by washing 10 cm^3 of wet sediment samples through a 125-µm mesh screen with lukewarm tap water. Material retained on the sieve was sorted in water using a binocular dissecting microscope at 8-40x magnification and all identifiable macrofossils were enumerated. Data were recorded as concentrations of macrofossils per volume of sediment. Analyses focused on the identification and enumeration of plant macrofossils, however animal macrofossils present in the samples were also counted. All identifications were made to the finest taxonomic resolution possible, with the aid of the modern reference samples (collected as part of Chapter 3, this thesis), as well as with the use of keys by Martin and Barkley (2000), Berggren (1969), Montgomery (1977), Schoch et al. (1988), Artjuschenko (1990) and Delorme (1970a-c). Original sediment samples and identified specimens are stored at the University of Waterloo Environmental Change Research Lab, Department of Biology, University of Waterloo, Waterloo, ON, Canada. Raw data are available in Table 1 of Appendix I.

Data analysis

Data analyses followed methods associated with the spatial-survey (or training-set) approach that is commonly used by paleolimnologists (e.g. Hall and Smol 1996) to assess relationships between biotic assemblages in surficial sediments and contemporary environmental conditions. Here, the approach was used to explore relationships between hydrolimnological conditions of SRD ponds and macrofossil assemblages in surface sediments. Prior to numerical analyses, macrofossil data were log (x+1) transformed in order to reduce the influence of dominant taxa. Rare taxa (i.e. taxa encountered at < 3 sites and with maximum abundance ≤1%) were omitted from numerical analyses to avoid the influence of taxa whose distributions were poorly characterized by the selected sites. A total of 15 taxa were used. All ordinations were performed using CANOCO version 4.5 (ter Braak and Šmilauer 2002), on inter-species differences, with bi-plot scaling and rare species down-weighted.

Detrended Correspondence Analysis (DCA) of the macrofossil data was used to assess the gradient length of the first axis to determine whether unimodal- or linear-based ordination techniques would be most appropriate to analyze the macrofossil data. All gradient lengths were >2 standard deviation units, and thus unimodal ordination methods were used (Birks 1995). Correspondence Analysis (CA) was used to assess the distribution of macrofossil assemblages among basins, and basins were coded by their hydrological categories to visualize relationships between macrofossil assemblages and hydrological basin type. Canonical Correspondence Analysis (CCA) was used to investigate relationships between surface sediment macrofossil assemblages and limnological gradients. Significantly correlated environmental variables (Pearson correlation, $p \leq 0.1$) were identified and one variable from each grouping was retained. Specifically, DOC (correlated to colour) was chosen because it encompasses measurements of both coloured and non-coloured forms of DOC, which are present in high concentrations in SRD ponds. Alkalinity (correlated to Mg^+ and Ca^{2+}) includes measurements of ions. Na^+ was correlated with Cl^- and so captures variation in Cl^- among basins. $\delta^{18}O$ was correlated with $\delta\,^2H$, and was chosen over $\delta\,^2H$ because $\delta^{18}O$ measurements have lower error. In addition, four of five environmental variables with high multi-collinearity (inflation factor of greater that 20) were removed to avoid unstable canonical coefficients (ter Braak 1986). CCA was performed using forward selection to identify a minimum subset of environmental variables which explained significant ($p \leq 0.1$) and independent amounts of the variation in the macrofossil data using Monte Carlo tests with 999 random permutations (ter Braak and Šmilauer 2002). Surface-sediment macrofossil assemblages (sample scores) in ordination diagrams were coded *a priori* according to hydrological category to visualize how the relationships between macrofossil assemblages and limnological conditions relate to the hydrological categories. All ordinations were performed using CANOCO version 4.5 (ter Braak and Šmilauer 2002).

Analysis of Similarities (ANOSIM) was used to test whether macrofossil assemblages differ among the three hydrological basin categories. ANOSIM is a non-parametric test analogous to multivariate one-factor Analysis of Variance (ANOVA; Clarke and Warwick 1994) where within- and across-group rank Bray-Curtis dissimilarities are computed and permuted (5000 times), and the distributions are compared to the initial rank dissimilarity and reported as the R-statistic (Clarke and Warwick 1994). An R-statistic significantly greater than zero ($p < 0.1$) indicates that differences in assemblage composition between hydrological categories are greater than the variability within each hydrological category (Clarke and Warwick 2006). The R-statistic is generated for both comparisons among all hydrological categories (global R) as well as for comparisons between pairs of categories (pairwise R; Clarke and Warwick 2006).

Similarity Percentages tests (SIMPER; Clarke and Warwick 2006) were used to identify macrofossil taxa contributing to the similarity of samples within a category. Taxa contributing to >1% of the average Bray-Curtis similarity within a hydrological category are considered '*indicator taxa*' of that hydrological category, and can be used to inform paleolimnological studies within the region. Following methods developed by Hall et al. (2004) and Sokal et al. (in press), ANOSIM tests and analyses using SIMPER were performed using the statistical package PRIMER, version 6.1.5 (Clarke and Warwick, 2006).

RESULTS AND INTERPRETATIONS

Sokal et al. (in press) performed a Principal Components Analysis (PCA) of the water chemistry measurements made on the 40 SRD lakes to assess patterns of limnological conditions among the hydrological lake categories. This analysis provides an important starting point for the assessment of relationships between plant macrofossil assemblages and hydroecological conditions and so is presented here. The PCA ordination indicates that the basins differed primarily along gradients of concentrations of nutrients (N, P, DOC), ions, chl-a and alkalinity (Figure 1of Appendix I). The main separation between sites occurs along axis 1, where sites that have direct exchange of water with either Great Slave Lake or the Slave River (flood- and exchange-dominated basins) are positioned mainly on the right-hand side (Figure 1, Appendix I) and plot separately from sites that have no river influence (evaporation-dominated lakes, positioned mainly along the left-hand side of Figure 1, Appendix I). In general, ionic concentrations are highest in evaporation-dominated lakes when compared to flood-dominated basins, while exchange-dominated basins have the lowest values and are most similar to river sites. There are a few exceptions to these trends. Pond SD32, classified as evaporation-dominated by Brock et al. (2007) based on stable isotope composition (δ^2H, δ^{18}O), had water chemistry more typical of flood-dominated lakes. Sites SD28 and SD17 were classified as exchange-dominated sites but had water chemistry more typical of evaporation-dominated sites. Additionally, the exchange-dominated site SD10 had water chemistry more similar to that of flood-dominated sites.

Macrofossil remains included 28 specimen types (e.g., stems, leaves, seeds, shells) from 22 plant and animal taxa. However, only 20 types from 15 taxa were present in at least 3 ponds and retained for statistical analysis. When multiple types of remains were present from a single taxa, the most abundant type was used in numerical analyses. While the focus of this study was to identify the contemporary relationships between the remains of vegetation communities and hydrolimnological gradients in the SRD, animal macrofossil taxa were also included for additional information. Overall, surface sediment macrofossil assemblages included remains of emergent, wetland and terrestrial plants that occupied shoreline habitats as well as remains of submerged and floating-leaved macrophytes that were restricted to aquatic habitats (Figure 2-2).

Distributions of several macrofossil taxa showed preferences for river-influenced sites (flood- and exchange-dominated) and evaporation-dominated sites, but there was some overlap of the distribution of submerged macrophytes and aquatic animals among the hydrological basin categories (Figure 2-2). Evaporation-dominated basins tended to have greater abundance of seeds from the emergent plant taxa *Carex* lenticular-type, *Carex* trigonas-type and *Scirpus*, seeds of the deciduous trees *Salix* and *Betula,* stems of *Drepanocladus* moss, leaves from the floating leaved *Lemna* and leaves from the submerged macrophyte *Ceratophyllum* compared to the other hydrological categories. However, many of the submerged aquatic plants and aquatic animals, such as *Potamogeton*, *Myriophyllum,* filamentous algae, *Chara*, *Daphnia*, and ostracodes, had no clear affinity for basin type and were widely distributed in ponds of all three hydrological categories. On average, total abundance of plant macrofossils tends to be highest in evaporation-dominated ponds and lowest in exchange-dominated ponds (Figure 2-2)

Ordination by CA indicates that surface-sediment macrofossil assemblages differed among hydrological categories, despite considerable overlap in community composition (Figure 2-3). Eigenvalues for the first and second axis were 0.351 and 0.248 respectively, and explained 37.1% of the variation in the data set. The main gradient of variation separated primarily river-influenced sites (flood- and exchange-dominated basins) from evaporation-dominated basins, although there was substantial overlap of macrofossil assemblages among all hydrological categories. Flood-dominated ponds clustered together to the left of the ordination, with the exception of SD4. There was a high abundance of macrofossil remains in the SD4 surface-sediment sample, a feature more typical of evaporation-dominated sites. These remains were predominantly the leaves of *Ceratophyllum*, and the unusually high number suggests the presence of a dense mat of this genus at the location where cores were collected. Evaporation-dominated sites were spread along the second axis, but tended to plot to the right of flood-dominated basins. SD8 plotted away from other evaporation-dominated sites, having particularly low diversity and abundance of macrofossil remains. Evaporation-dominated sites typically had high abundances of *Ceratophyllum*, *Lemna, Carex* l-type and *Drepanocladus* in their surface-sediments. Remains of *Salix*, *Betula*, *Carex* t-type were not strongly associated with evaporation-dominated sites, which may be a reflection of low concentrations and limited distributions of these taxa.

Ordination using CCA identified water balance (as $\delta^{18}O$) and concentrations of DOC, TP, and SO_4^{2-} as environmental variables which explained significant and independent amounts of the variation in macrofossil assemblages among sites (Figure 2-4). Eigenvalues of the first two CCA axes ($\lambda_1 = 0.08$, $\lambda_2 = 0.06$) were significant ($p \leq 0.1$) and explained 19.4% of the variation in the macrofossil data. CCA axis 1 was most strongly associated with DOC and axis 2 with $\delta^{18}O$.

The first CCA axis separated flood-dominated ponds with high abundances of *Myriophyllum, Chara, Potamogeton, Daphnia, Sparganium* and ostracodes, characterized by low values of $\delta^{18}O$, high ion concentrations and low nutrient concentrations, from evaporation-dominated ponds with high abundances of *Drepanocladus, Ceratophyllum, Lemna, Betula, Salix* and *Carex,* characterized by moderate to high nutrient concentrations, low ion concentrations, and high values of $\delta^{18}O$ (Figure 2-4). Exchange-dominated ponds were distributed more broadly along the first axis, but were generally more closely associated with assemblages and environmental conditions more typical of flood-dominated ponds.

In the CA and CCA ordinations, the relationship between water chemistry and macrofossil assemblages from pond SD32 (identified as evaporation-dominated by Brock et al. (2007)) was more similar to that of flood-dominated basins (Figure 2-4). This deviation is supported by results from by Sokal et al. (in press) which indicated that the diatom assemblage composition of SD32 also shared greater affinity with flood-dominated rather than evaporation-dominated basins. Consequently, SD32 was classified as a flood-dominated basin in all subsequent analyses.

Macrofossil assemblage composition differed significantly ($p \leq 0.1$) among hydrological basin categories for the Slave River Delta, as assessed by ANOSIM tests (global $R = 0.198$, $p = 0.005$) (Table 2-2), and between all three groups (flood vs. evaporation, $p = 0.005$; flood vs. exchange, $p = 0.073$; exchange vs. evaporation, $p = 0.093$). Analysis using SIMPER identified 'indicator' taxa that discriminate between ponds of differing hydrological categories (Table 2-3). Sediment remains from flood-dominated ponds were characterized by high abundances of ostracode shells, *Daphnia* ephippia and *Chara* oospores relative to ponds in the other hydrological categories. Exchange-dominated ponds were characterized by *Myriophyllum* winter-bud scales and *Daphnia* ephippia, and evaporation-dominated ponds were characterized by *Ceratophyllum* leaves and *Lemna* leaves. Several taxa were identified as indicators of more than one hydrological category, which likely reflects overlap in habitat availability. This overlap is evident in Figure 2-2, where the remains of aquatic animals and submerged macrophytes were present in the sediment macrofossil assemblages from all three hydrological categories.

DISCUSSION

Distinct assemblages of plant and animal macrofossils in the surface sediments of SRD ponds were associated with established gradients of hydrolimnological conditions. The hydrological classification system developed by Brock et al. (2007), and the relationships to limnological conditions of SRD ponds spanning the three hydrological categories developed by Sokal et al. (in press) were associated with distinctly different plant and animal macrofossil assemblages in surface sediments, as summarized in Table 2-3.

Flood-dominated basins were characterized by low values of $\delta^{18}O$, high pH, high ion concentrations, low nutrient concentrations and macrofossil assemblages in the surface sediments which were dominated by ostracode shells, *Daphnia* ephippia, *Chara* oospores, *Potamogeton* leaves and *Myriophyllum* winter-bud scales. In spite of high minerogenic turbidity during spring flood events, these ponds support dense growth of aquatic macrophytes (Sokal et al. in press). Field observations also indicated extensive submerged aquatic communities in these basins, dominated by *Myriophyllum* and

Potamogeton. *Equisetum fluviatile* and *Typha latifolia* typically fringed these ponds, along with several species of *Carex*. Animal macrofossils were particularly abundant in the sediments of flood-dominated basins, specifically ostracodes and *Daphnia*, which dominated the sediment remains and contributed to more than 60% of the similarity within flood-dominated macrofossil assemblages. Higher abundances of ostracode shells in the surface-sediments of flood-dominated basins of the SRD may be reflective of lower ion concentrations and higher pH when compared to evaporation-dominated basins, resulting in greater relative availability of $CaCO_3$ for shell formation as well as preservation within the surface sediments. In lakes of the Yukon, Burnbury (2005) found that high ion concentration, low pH and low availability of dissolved $CaCO_3$ were the most important factors limiting ostracode distributions.

Evaporation-dominated ponds were characterized limnologically by high concentrations of nutrients, ions and high values of $\delta^{18}O$. The surface-sediment macrofossil assemblages were dominated by aquatic macrophyte remains, with high abundances of *Ceratophyllum*, *Lemna, Salix* and *Betula* relative to the other hydrological categories. These assemblages reflect relatively low-energy conditions and a clear water column, results which are consistent with high relative abundances of epiphytic diatom taxa in the surface sediments (Sokal et al. in press). Field observations of vegetation indicated thick beds of submerged aquatics such as *Ceratophyllum*, *Myriophyllum*, and several species of *Potamogeton* at these sites, fringed by an emergent macrophyte community dominated by several species of *Carex.* A diverse herbaceous community in the catchment was often surrounded by extensive stands of *Salix* and *Betula* shrubs and mature trees. In addition, extensive beds of *Drepanocladus* moss were often present in the shallow margins of particularly low-energy ponds. The remains of herbaceous species were not present in sufficient abundance (<2% total) to be included in this analysis.

Evaporation-dominated sites exhibited the largest degree of variation in plant macrofossil assemblages between sites, and had the highest concentrations of nutrients and several ions compared to the other hydrological categories. The variation in plant macrofossil communities among sites in the evaporation-dominated category may reflect differing periods of time elapsed since flooding at individual sites. For example, field observations of spring thaw conditions in 2005 indicated that wide-spread flooding inundated several evaporation-dominated ponds (SD8, SD18, SD19, SD29) that did not flood in 2003 or 2004 (Brock et al. in preparation). These sites have macrofossil assemblages more closely associated with flood-dominated sites in CA and CCA ordinations (Figures 2-3, 2-4), and account for at least some of the overlap between surface-sediment macrofossil assemblages of the three hydrological categories. The differences observed in the composition of macrofossil assemblages in surface sediments from SD8, SD18, SD19 and SD29 may reflect differences in the vegetation communities at these sites which have resulted from susceptibility to infrequent, high-magnitude ice-jam induced flood events.

In surface sediment samples from exchange-dominated sites macrofossil concentrations were generally low, likely a result of frequent connection to the Slave River or Great Slave Lake and the associated high rates of allochthonous inorganic sedimentation that dilute macrofossil remains relative to other hydrological settings. Additionally, these sites were more turbid and the resulting low light environment likely reduces macrophyte production (Sokal 2007). For example, exchange-dominated sites periodically re-connected to the river or, as in the case of SD41, located at the outer fringe of the active delta, were periodically inundated with water from Great Slave Lake during seiche events during the open-water season (Brock et al. 2007). Consequently there were insufficient remains in the surface sediment samples of SD41 to include in analyses. At SD39 and SD30 (also exchange-dominated basins) remains were generally sparser than in sediments from either flood- or evaporation-dominated sites. The macrofossil assemblages from SD17 and SD28 plot with evaporation-dominated sites in CCA ordination. This suggests that while point-in-time water samples (collected in spring 2003) indicated water balances with strong river influence (exchange-dominated basin) over the open-water season, channel connections at these sites likely became restricted and eventually closed. Thus, ponds SD17 and SD28 behaved predominantly as evaporation-dominated basins, a feature captured over the time-scale represented by surface-sediment samples. Field observations indicated that exchange-dominated sites were dominated by dense stands of the emergent macrophytes *Equisetum fluviatile* and *E. palustre*, but these taxa were not well represented in the sediments. This, in conjunction with high sedimentation rates, suggests that analysing a larger volume of sample might allow for a more representative quantification of abundances. Also, there were few exchange-dominated sites (n = 4) relative to flood-(n= 10) and evaporation-dominated sites (n = 26) in this study. Increasing the number of exchange-dominated sample sites may have generated less overlap in the indicator taxa for flood- and exchange-dominated sites.

The statistically significant relationship between macrofossil assemblages in surface sediments of SRD basins and differences in hydrolimnological conditions between hydrological categories allowed the identification of indicator taxa to distinguish between sites with high river influence (flood-dominated sites: ostracode shells, *Daphnia* ephippia, *Chara* oospores; exchange-dominated sites: *Myriophyllum* winter-bud scales, *Daphnia* ephippia) and sites with low river influence (evaporation-dominated: *Ceratophyllum* leaves, *Lemna* leaves, *Drepanocladus* leaves). While overlap between taxa indicative of each of the three hydrological categories may limit the utility of macrofossil data in discriminating between each hydrological category, these results suggest a potential for macrofossils to provide key information for multi-proxy paleolimnological analyses. Previous work by Sokal et al (in press) using sediment diatoms assemblages to discriminate between evaporation-dominated and river-influenced hydrological states depends strongly on the presence of planktonic centric diatoms (*Stephanodiscus minutulus* and *Cyclostephanos spp.*) which are supplied by river flood waters and do not thrive in the absence of flooding (Sokal et al. in press). Since these taxa tend to occur at low relative abundance in sedimentary assemblages, diatom analyses may not always detect shifts in hydrological conditions that do not cross major hydrological thresholds. Incorporating plant macrofossil analysis may allow for the detection of changes in the ecology of a site that might occur in the absence of river flooding. The absence of river flooding over many consecutive years could be detected through changes in plant communities resulting from, for example declining water levels due to evaporative drawdown. Determining changes in the plant communities during periods with low river influence would likely provide more detailed paleolimnological reconstructions, and thus enhance the ability to anticipate the response of this ecologically sensitive northern delta to climate change and human modifications of upstream river systems.

CONCLUSIONS

This study has used a spatial survey of surficial sediment macrofossil assemblages to demonstrate that distinct assemblages of plant and animal macrofossils in the surface sediments of 40 SRD ponds are associated with hydrolimnological categories of the SRD ecosystem as described by Brock et al. (2007) and Sokal et al. (in press). The statistically significant differences of macrofossil assemblages among hydrolimnological basin categories allowed the identification of indicator taxa to discriminate among flood-dominated (ostracode shells, *Daphnia* ephippia, *Chara* oospores), evaporation-dominated (*Ceratophyllum* leaves, *Lemna* leaves, *Drepanocladus* leaves) and exchange-dominated sites (*Myriophyllum* winter-bud scales, *Daphnia* ephippia; Table 2-3). The relationships established here will be used to inform paleolimnological analyses of sediment cores from the basins throughout the SRD. Macrofossil analyses have the potential to identify key ecological responses of plant communities to the hydrological changes observed in the analyses of other proxies, such as diatoms and elemental and stable isotope composition, and may be able to refine interpretations and hydroecological classifications based on analyses of stable isotopes and diatoms. Analyses of surficial sediment macrofossil assemblages suggest that there are some differences in the ecological conditions at evaporation-dominated ponds susceptible to high-magnitude flood events when compared to other ponds that were classified as evaporation-dominated based on use of water stable isotopes. Evaporation-dominated ponds that flood during high-magnitude ice-jam flood events, such as occurred in 2005 (SD8, SD18, SD19 and SD29) had macrofossil assemblage compositions that differed somewhat from evaporation-dominated ponds that did not flood in 2005 and also exhibited greater similarity with assemblages of flood-dominated lakes. Additionally, plant macrofossils can provide information about hydroecological change when other proxies, such as diatoms, are uninformative (e.g., in the absence of river flooding). This study complements previous studies aimed at understanding the complex interactions amoung hydrology, limnology and aquatic ecology in this freshwater ecosystem, which in conjunction with ongoing contemporary work in the SRD, will be necessary for anticipating responses to climate change and human modifications of upstream river systems.

Table 2-1. Slave River Delta sampling sites by hydrological category, with UTM zone 12 coordinates. *SD32 was re-located to the flood-dominated category following PCA analysis by Sokal et al. (in press) because limnological conditions are more characteristic of flood-dominated basins.

Flood-dominated			**Exchange-dominated**			**Evaporation-dominated**		
	UTM Coordinates			UTM Coordinates			UTM Coordinates	
pond	*Northing*	*Easting*	*pond*	*Northing*	*Easting*	*pond*	*Northing*	*Easting*
SD1	6796450	360900	SD10	6800325	363078	SD8	6792549	358400
SD2	6796800	361650	SD17	6791348	368063	SD11	6798140	369545
SD3	6797350	363250	SD28	6791339	372046	SD12	6796301	371053
SD4	6796760	362150	SD30	6787657	387222	SD13	6798099	371918
SD5	6795888	365177	SD39	6800378	357341	SD14	6799258	373304
SD6	6798670	363650	SD41	6798317	355966	SD15	6802209	372375
SD7	6802929	363807				SD16	6801021	372195
SD9	6797369	359764				SD18	6795593	370045
SD38	6800416	359957				SD19	6796500	375250
SD40	6795784	356331				SD20	6800033	375441
*SD32	6783643	385619				SD21	6797868	378831
						SD22	6798855	380493
						SD23	6795825	381409
						SD24	6795230	377971
						SD25	6793846	378186
						SD26	6786563	370914
						SD27	6789184	372615
						SD29	6790800	381718
						SD31	6786252	385316
						SD33	6779992	381208
						SD34	6787134	362162
						SD35	6779578	380385
						SD36	6771359	380103
						SD37	6770753	381762

Table 2-2. Summary of analysis of similarities (ANOSIM) test results used to compare composition of surface sediment macrofossil assemblages from flood-dominated, exchange-dominated and evaporation-dominated ponds in the Slave River Delta.

	Lake Category	**R-statistic**	**p-value**
Global Test:	All hydrological categories	0.198	0.005
Pairwise Tests:	Flood vs. Exchange	0.215	0.073
	Flood vs. Evaporation	0.219	0.005
	Exchange vs. Evaporation	0.166	0.093

Table 2-3. Summary of Slave River Delta basin hydrology, limnology, diatom and macrofossil ‘indicator’ taxa, adapted from Sokal et al, (in press). Hydrological inputs and outputs are based on data from Brock et al. (2007), where R = river inputs during elevated (spring flood) flow conditions (R_F) and normal summer flow (R_N), S = catchment-sourced snowmelt inputs, P = thaw season precipitation, O = surface outflow during elevated (spring flood) flow conditions (O_F) and normal summer flow conditions (O_N), and E = surface water evaporation. Dominant processes are shown in bold. Limnological conditions and diatom ‘Indicator’ taxa are based on data from Sokal et al. (in press). * *Drepanocladus* leaves did not the meet criteria set out for SIMPER identified indicators of evaporation-dominated ponds, however extensive field observations indicated that this taxa was highly abundant at these ponds.

	Slave River Delta Hydrological Categories		
	Flood-dominated	Exchange-dominated	Evaporation-dominated
Hydrological Inputs	$\mathbf{R_F}$ + S + P	$\mathbf{R_F}$ + $\mathbf{R_N}$ + S + P	S + **P**
Hydrological Outputs	O_F + **E**	$\mathbf{O_F}$ + $\mathbf{O_N}$ + E	**E**
Limnological Characteristics	↓ nutrients	↓↓ nutrients	↑ nutrients
	↓ ions	↓↓ ions	↑ ions
	↓ chl-*a*	↓↓ chl-*a*	↑ chl-*a*
	↓ alkalinity	↓↓ alkalinity	↑ alkalinity
Diatom 'Indicator taxa'	*Navicula libonensis*	*Eunotia bilunaris*	*Navicula minima*
	Gyrosigma attenuatum	*Fragilaria capucina* var. *gracilis*	*Nitzschia amphibia*
	Rhopalodia gibba	*Nitzschia perminuta*	
	Cyclostephanos PAD sp.2	*Cyclostephanos* cf. *tholiformis*	
		Stephanodiscus minutulus	
Macrofossil 'Indicator' taxa	ostracode shells	*Myriophyllum* winter buds	*Ceratophyllum* leaves
	Daphnia ephippia	*Daphnia* ephippia	*Lemna* spp. leaves
	Chara oospores		*Drepanocladus* leaves*

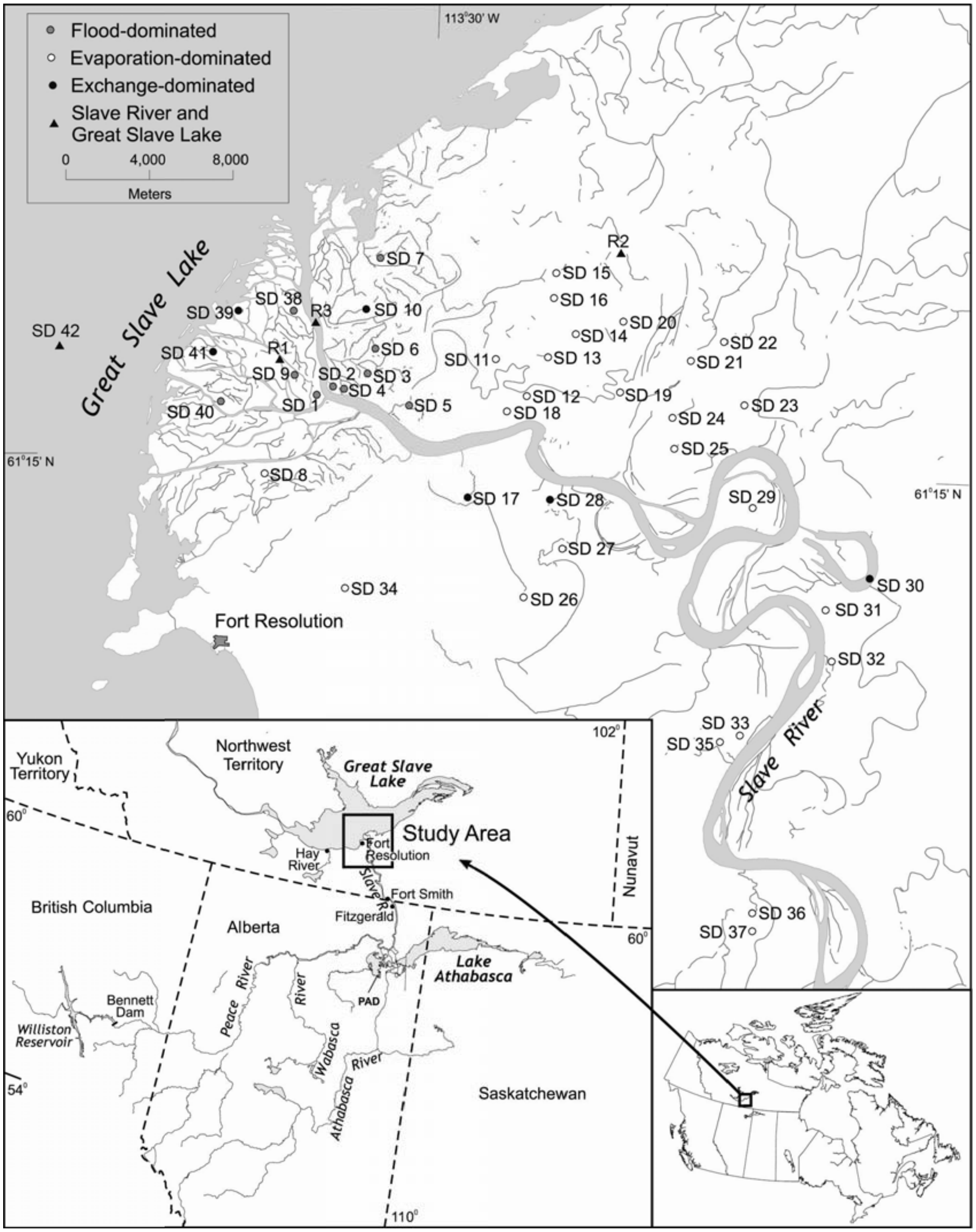

Figure 2-1 Locations of Slave River Delta sampling sites with hydrological classification. These sites are the same as those sampled in Brock et al. (2007) and Sokal et al. (in press). Flood-dominated sites are indicated by closed grey circles, evaporation-dominated sites are indicated by closed black circles, exchange-dominated sites are indicated by open circles and Slave River and Great Slave Lake sites are indicated by black triangles (figure adapted from Sokal et al. in press)

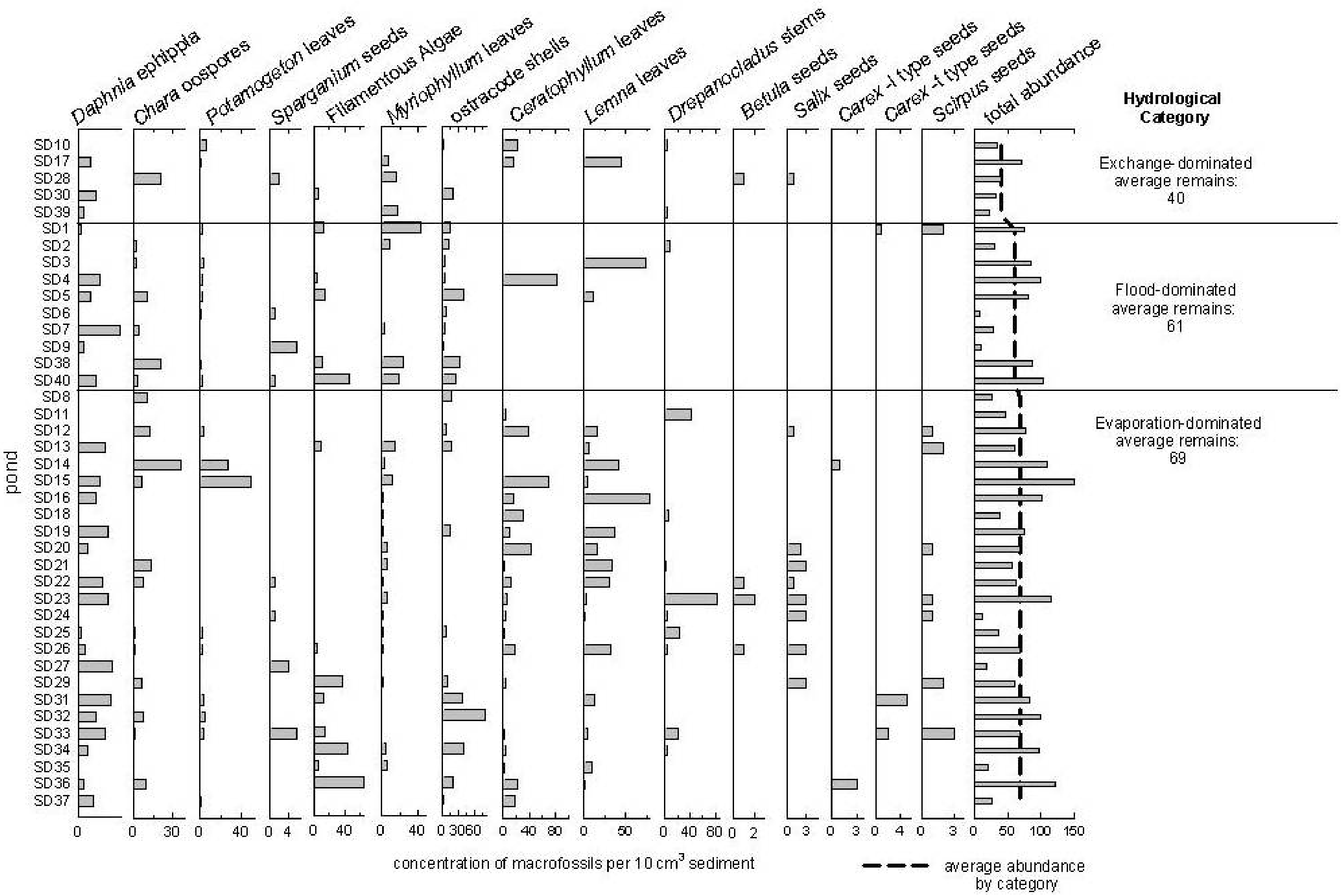

Figure 2-2 Composition of macrofossil taxa in surficial (0-1 cm) sediment samples of 40 basins of the Slave River Delta. The basins are grouped by hydrological category, as identified by Brock et al. (2007).

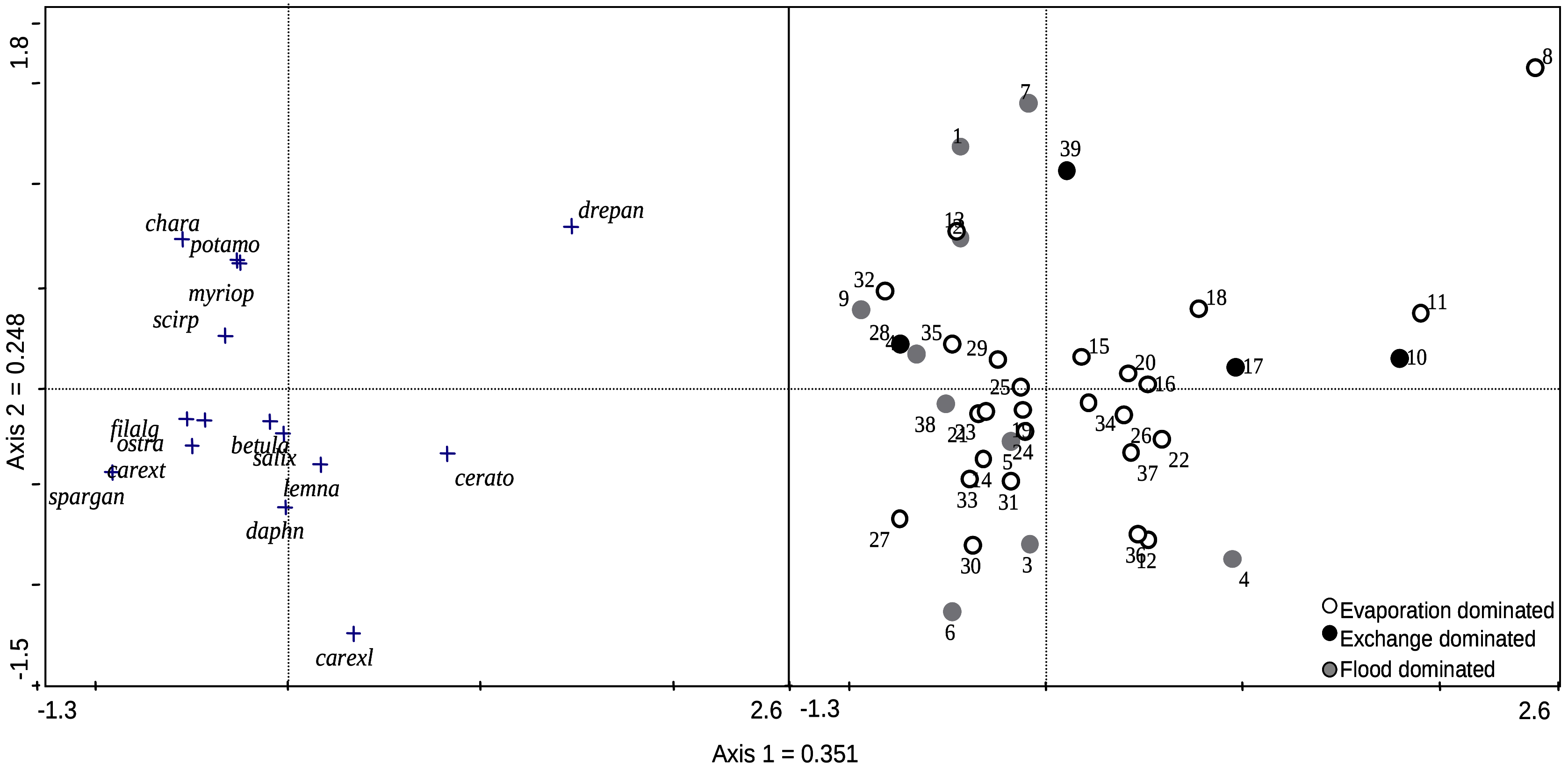

Figure 2-3 Correspondence Analysis (CA) of sedimentary macrofossil taxa (n=15) from surface sediments of ponds (n=40) situated along hydrological gradients in the Slave River Delta, N.W.T. Macrofossil taxa scores are shown in the left panel, while site scores, coded by hydrological category, are shown in the right panel. Full taxon names are listed in Table 2 Appendix I.

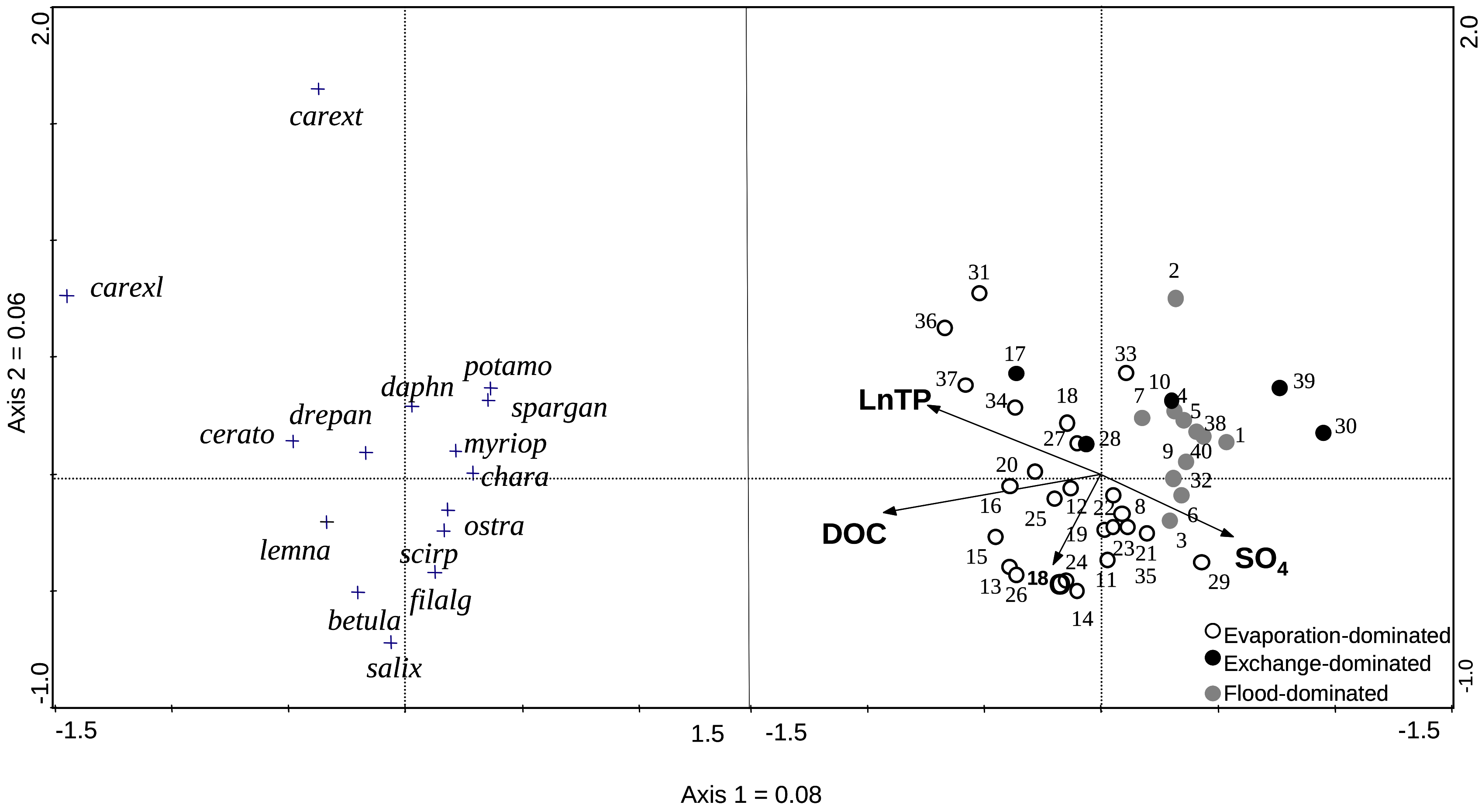

Figure 2-4 Canonical Correspondence Analysis (CCA) of sedimentary macrofossil taxa (n=15) and forward selected environmental variables from ponds of the Slave River Delta, N.W.T.. Macrofossil taxa scores are shown in left panel, site scores are shown in the right panel, coded by hydrological category. Full taxa names are listed in Table 2 Appendix I.

Chapter 3: Patch- and pond-scale relationships between sedimentary plant macrofossil assemblages and living vegetation from a flood-prone pond in the Slave River Delta, N.W.T.

INTRODUCTION

The reconstruction of past plant communities through analysis of plant macrofossil remains, for the purpose of identifying environmental change, requires an understanding of the contemporary spatial relationship between aquatic vegetation and macrofossil remains in surficial sediments. This understanding of the distributions of contemporary vegetation is rarely addressed, yet it is commonly recommended to improve interpretations of sediment core plant macrofossil assemblages (e.g., Birks and Birks 1980). Additionally, to fully realize the potential of plant macrofossil data from a particular core, it is essential to consider the processes influencing the accumulation of macro-remains at the coring site (Warner 1990). Understanding both the contemporary vegetation and the processes governing plant macrofossil deposition has the potential to greatly enhance the understanding of both the limitations of and accuracy with which living vegetation is represented by the remains preserved in the sediments. Plant macrofossils are the end product of processes that lead to their incorporation and preservation in the sediments and these sediment assemblages represent only a fraction of the total flora that lived at the time of deposition (Warner 1990). A detailed comparison of living plant taxa and their macrofossils in surficial sediments of lakes by Birks and Deacon (1973) demonstrated that the number of macrofossils of a given taxon in a sample generally increases with an increased percent coverage of that taxon. A number of recent studies have highlighted the potential of plant macrofossil analysis to assess long-term vegetation dynamics and succession of the proximal plant community (Sayer et al. 1999; Odgaard and Rasmussen 2001; Dieffenbacher-Krall and Nurse 2005; Davidson et al. 2005; Rasmussen and Anderson 2005). Most recently, Zhao et al. (2006), determined that the abundance and composition of macrofossils in aquatic sediments adequately represented the local living plant community within 20-30 m in a productive, shallow, closed-basin lake in eastern England, and supported the existence of a patch-scale (or quadrat-scale) relationship between plant macrofossils and parent vegetation. Previous studies by Hall et al. (2004) used plant macrofossil records in conjunction with diatom, stable isotope and pigment records to track changes in hydrological conditions of the Peace-Athabasca Delta (PAD) through time. The PAD study demonstrated that plant macrofossil analysis is a reliable indicator of hydrological changes in a delta system. However, there remains an inadequate understanding of processes governing the supply, distribution and preservation of plant macrofossils in sediments of floodplain basins, and associations between the living community and plant macrofossil assemblages in the sediments.

The aim of this study was to assess the relationship between the spatial distributions of plant macrofossils in surficial sediments of a small flood-prone pond in the Slave River Delta (SRD), SD2, and the contemporary plant community within and adjacent to this pond. The processes contributing to production, transport and preservation of macrofossils at pond SD2 likely include the dispersal mechanisms and seed productivity of the local flora, seed germination rates, palatability of macro-remains by local organisms (e.g., ducks and invertebrates), microbial activity, oxygen availability, limnological properties and perhaps most importantly, hydrology (specifically flooding).

The first objective of this study was to assess the patch- or quadrat-scale association between contemporary plant communities and sedimentary macrofossil assemblages in pond SD2. A detailed quadrat-based survey of the living vegetation throughout the catchment was conducted, and compared to surface-sediment macrofossil assemblages collected at the same sites to assess the distribution and dispersal of plant macrofossils relative to their source. The percent cover of living vegetation at each quadrat was then compared to the relative abundance of taxa in the surficial remains to determine if valid inferences concerning community composition are possible. In addition, this study aimed to address how important the effect of long-distance transportation of macrofossil remains was on sediment macrofossil assemblages at SD2 by comparing taxa presence in surficial sediments to presence within the living plant community at SD2. The second objective of this study was to address how well any one of the surficial sediment assemblages collected from the transect of quadrats represents the presence and percent cover of the overall living plant community at pond SD2. The patch- and pond-scale relationships established between sedimentary macrofossils and the living vegetation communities at

SD2 will provide key information to inform paleolimnological analysis of macrofossil assemblages from sediment cores retrieved from the basin (Chapter 4).

METHODOLOGY

Site description

Pond SD2 is a site of focus for ongoing studies in the Slave River Delta intended to address the range of natural variability and understand the causes and effects of changes in river regime on the hydroecology of the delta, as well as the consequences for the residents of nearby Fort Resolution (Wolfe et al. 2007a). SD2 was identified as a site of interest for constructing a record of Slave River Delta ice-jam flood events (Chapter 4) because it is relatively susceptible to flooding due to its proximity to the Slave River, has a low sill separating the basin from the river, and because regional hydrolimnological studies indicate that this site is representative of flood-dominated ponds located in the active delta (Chapter 2). Pond SD2 is a shallow (maximum depth 1.5 m), flood-dominated pond (Brock et al. 2007) located at the mouth of the Resdelta channel (61°16’ N; 113°34’ W; Figure 2-1). Prior to sampling in July 2005, a major ice-jam flood event in the Slave River inundated pond SD2 with flood waters in the spring of 2005.

Sampling and laboratory procedures

A detailed vegetation survey, using a transect consisting of 13 ~1 m^2 quadrats, was completed at SD2 to record presence/absence and percent cover of taxa based on visual estimates. Quadrats were spaced ~10 m apart, across the aquatic basin (Figure 3-1A) and extended into the terrestrial catchment at ~4 m intervals. Sampling extended into the catchment to the first quadrat with greater than 50% cover by *Salix* spp. (14 m to 75 m from start of *Equisetum* fringe). The orientation of the transect was parallel to the channel of Slave River flood water entry (Q1 proximal, Q13 distal). The starting quadrat (Q1) and finishing quadrat (Q13) were flagged using a physical marker to assist in visual determination of the transect. A vegetation map depicting spatial organization of the taxon types at pond SD2 was constructed, and zones, or areas of similar vegetation were identified (Figure 3-1B). This vegetation map serves to provide insight into the structure of vegetation and to allow comparison of the spatial distributions of living plants with the sedimentary macrofossil assemblages. Since the acquisition of modern specimens is essential to taxonomic identification of sedimentary plant remains (Warner 1990), two or three individuals of each taxon encountered were collected, preserved, catalogued and are stored at the WAT Herbarium (Holmgren et al. 1990) and the Waterloo Environmental Change Research Lab, Department of Biology, University of Waterloo, Waterloo, ON, Canada. Care was taken to select samples of taxa possessing the attributes, such as seeds, nuts or fruits, which are typically represented in the sediments. Plant identifications were made to the finest taxonomic resolution possible, using Flora North America (2000-2007), volumes 22-25 and collections in the WAT Herbarium (Holmgren et al. 1990).

Surface sediments (0-2 cm) were retrieved in September 2005, using a Mini-Glew gravity corer (Glew 1991) at the same quadrats where living vegetation presence and percent cover were previously recorded in July 2005 (Fig. 3-l). GPS was used to locate coring sites near quadrats with reasonable accuracy (+/- 6m). Plant macrofossil samples were prepared by washing 20 cm^3 wet sediment samples through a 125-μm mesh screen with warm tap water. Material retained on the sieve was sorted in water using a binocular dissecting microscope at 8-40x magnification and all identifiable macrofossils were enumerated. Data are recorded as number of macrofossils per volume of sediment. Macrofossil identifications were made to the highest taxonomic resolution possible, with the aid of the aforementioned modern reference samples, as well as with the use of keys such as Martin and Barkley (2000), Berggren (1969,1981), Montgomery (1977), Schoch et al. (1988) and Artjuschenko (1990). Original sediment samples and identified specimens are stored at the Waterloo Environmental-Change Research Lab, University of Waterloo, Waterloo, ON, Canada.

Data analysis for patch-scale relationships between living vegetation and sediment macrofossils

To address patch- or quadrat-scale relationships based on taxa presence between sedimentary plant macrofossils and living vegetation, two approaches were used. First, the presence of living taxa recorded at each quadrat was compared to surface-sediment plant macrofossil assemblages (Figure 3-3). To avoid over-representing taxa represented by several types of remains, relative abundances were calculated using the most abundant type (e.g. *Myriophyllum* winter-bud scales instead of seeds). To address whether the composition of surface-sediment plant macrofossil assemblages in each quadrat reflects the percent cover of living vegetation in each quadrat, the relative abundance of each taxon within the surface-sediment macrofossil assemblages was compared to the percent cover of each taxon in the living vegetation. Correspondence Analysis (CA) was then used to explore patterns of change (co-variation among quadrats along the transect in pond SD2) in sedimentary relative abundances of plant macrofossils and vegetation percent cover data. CA, a direct gradient multivariate ordination method that assumes unimodal distribution of biota, was used because Detrended Correspondence Analysis (DCA) of the macrofossil data indicated that gradient lengths were sufficient (>2 standard deviation units) to model taxon responses as unimodal (Birks 1995). Analyses were performed on inter-species distances in a CA run with bi-plot scaling where both data sets were log (x+1)-transformed in order to stabilize variances. Sample scores on axes one and two were plotted spatially to identify correlations between patterns of vegetation community composition and sedimentary macrofossil assemblage composition along the transect in SD2. Pearson correlations were assessed between sample scores for living vegetation and sediment assemblages on both axis one and two to ascertain whether statistically significant relationships exist between the sample scores for axis one and two of the sediment remains and the living vegetation.

Data analysis for pond-scale relationships between living vegetation and sediment macrofossils

To assess the representitiveness of sedimentary macrofossil assemblages with respect to presence and percent cover of the overall living vegetation at SD2, a value for the overall vegetation community at SD2 was calculated. Each taxon present in the living vegetation was combined into one list, to form a "whole-pond presence of living vegetation" to be used in calculation of Sorensen's index of similarity. Sorensen's index of similarity (Sorensen 1948), a measure of likeness between biological communities, is commonly used in analyses comparing plant communities based on taxon presence and absence (Wolda 1981). For example, Sorensen's index has been used to compare seed bank composition to contemporary vegetation (Anderson and Van Devener 1991; Soloman et al. 2006; Osem et al. 2006), to assess changes in the plant community composition of manufactured wetlands through time (Jahr and Crow 2005), and to compare differences in the biodiversity and floristic composition of floodplain marshes between differing hydrological conditions (Liu et al. 2006). Sorensen's coefficient was calculated (Wolda 1981) between this "whole pond presence of living vegetation" and each quadrat. Sorensen's index of similarity is defined by $[2a/ (2a+b+c)]*100\%$, where 'a' is the number of taxa in both samples 'a' and 'b' (joint occurrences), 'b' is the number of taxa in sample 'b' but not 'a', and 'c' is the number of taxa in sample 'a' but not 'b'. Sorensen's index weights matches in taxon presence between two samples more heavily than mismatches, which is useful when many taxa are present within a community as a whole, but not necessarily in every sample. Values of Sorensen's index can range from 0% (not similar) to 100% (identical) (Wolda 1981). The percentage reported for each quadrat represents the similarity between the plant macrofossil remains of that quadrat to the "whole-pond presence of living vegetation" community at pond SD2. Two values were determined for each quadrat. The first compared the quadrat sample to all vegetation identified in and around pond SD2 in July 2005 (zones 1-4 from Figure 3-2B) and the second compared the quadrat sample to only those taxa present in the open-water portion of the pond (zones 1 and 2 from Figure 3-2B). These were differentiated to determine if the macrofossil assemblages have a greater ability to specifically capture the submerged macrophyte community rather than the terrestrial vegetation.

The percent cover of each taxon was averaged across the 13 quadrats to estimate the "average percent cover of living vegetation" at the pond-scale, to evaluate whether there was a relationship between the relative abundance of sedimentary macrofossils in a sample (quadrat) and the percent cover of that taxon in the living vegetation at the pond-scale. Renkonen's index (Renkonen 1938) compares how similar two biological communities are with respect to relative proportions, and was used to determine whether there is a quantitative relationship between the relative abundance of taxa in sediment remains and their contemporary percent cover at pond SD2. Renkonen's index uses quantitative taxon values (in this case relative abundance of macrofossils) and contemporary percent cover, where the sum of each sample is equal to 100%.

Renkonen's index is defined by $\Sigma[\text{Minimum}(P_{1i},P_{2i})]$, where P_{1i} is the percentage of taxon in 'i' community of sample 1 and P_{2i} is the percentage of taxon in 'i' community of sample 2. This index is considered one of the best quantitative measures of similarity available because it is relatively unaffected by sample size and taxon diversity, and is preferable for this data set because it allows for the use of percent cover data (Wolda 1981; Krebs 2001). Renkonen's index of similarity can range from 0% (not similar) to 100% (identical).

RESULTS AND INTERPRETATIONS

Living vegetation community

Vegetation zones at pond SD2 consisted of an open-water area dominated by submerged macrophytes, a shoreline community dominated by emergent macrophytes, a sedge meadow with numerous grasses and herbs and low shrubs transitioning to mature trees in the surrounding catchment (Figure 3-1B). There were five major vegetation zones at pond SD2. The open-water submerged macrophyte zone (zone 1) was distinguished by extensive stands of *Myriophyllum exalbescens*, *Potamogeton pusillus, P. freisii, P. richardsonii and P. zosteriformis*, and isolated patches of *Ceratophyllum demersum* and the macroalga *Chara* sp. The fringing emergent macrophyte zone (zone 2), was dominated by *Equisitum fluviale* and then *E. fluviale* mixed with *Typha latifolia*. This was followed by a sedge meadow (zone 3) consisting of predominantly *Carex* spp. and *Calamagrostis canadensis*. With increasing distance from the pond, there was shift to *Salix* spp. (willow thicket (zone 4)) and a gradual transition into mature forest (zone 5), denoted by the presence of *Betula spp.*, *Populus tremuloides* and *Picea glauca.* Field observations indicated a notable absence of mature forest along the south east arm of the SD2 catchment. Instead, vegetation in this region was dominated by *Salix*, a genera more typical of floodplain soils (Johnson et al. 1995). This area is of low topographic relief and is the path through which Slave River spring flood waters inundate pond SD2.

Patch-scale relationships between living vegetation and sediment macrofossils

The spatial distribution of plant remains in the sediments of pond SD2 differed widely between taxa, with cases of both over-and under-representation of remains when compared to the distribution of living counterparts (Figure 3-2). Macrofossil remains of *Potamogeton* spp. (leaves) and *Myriophyllum exalbescens* (winter-bud scales) showed strong correspondence of presence/absence at the patch-scale between sediments and the living plant community. These taxa were also the most widely distributed. Macrofossil remains of *M. exalbescens* corresponded to presence of this taxon in the living plant community at eight of the thirteen quadrats, and macrofossil remains of *Potamogeton* (leaves) and living plants corresponded at twelve of the thirteen quadrats. The seeds of *Potamogeton* corresponded to living vegetation presence at only two of thirteen quadrats (data not shown), suggesting that the seeds would not be present in sufficient abundance to be a useful tool for paleolimnological studies at this site. Living *Chara* sp. plants occurred at only one quadrat, yet macrofossil remains (oospores) were identified in the surface sediments of nine of the thirteen quadrats. This indicates wide dispersal of *Chara* oospores from parent plants, which is consistent with previously established dispersal patterns for this taxon (Dieffenbacher-Krall and Haltman 2000; Davis 1985; Zhao et al. 2006), and suggests that the presence of oospores in sediment macrofossil assemblages does not necessarily indicate a patch-scale presence of *Chara*. *Equisetum* macrofossil remains (vegetative shoots) were present at seven of thirteen quadrats, but living plants were identified at only four quadrats. *Equisetum* macrofossils and plants coincided at only one quadrat, suggesting that macrofossil remains of *Equisetum* also do not necessarily indicate a patch-scale presence. In contrast, macrofossil remains of *Lemna* spp. (leaves) were present in sediment assemblages at only one quadrat, while it was part of the living plant community at five quadrats. This is likely a reflection of poor preservation, since all three species of *Lemna* identified in the vegetation survey had only soft vegetative remains, which often translates into poor preservation within the sediments (Birks and Birks 1980). Macrofossil remains of *Salix* spp. (seeds) were found in two of the thirteen sediment samples, primarily in the outermost quadrats. A handful of herbs, sedges and grasses (including *Calamagrostis canadensis* var. *canadensis*, *Sium sauve, Sagittaria latifolia, Sagittaria cuneata, Potentilla palustris, Epilobium palustre* and all *Carex* species) that were recorded in the quadrats of the living plant community were not present in any macrofossil sediment samples.

A similar pattern of over- and under-representation of certain taxa was also evident in comparisons of the percent cover of living vegetation to the relative abundance of a taxon's sedimentary remains (Figure 3-3). The percent cover of living plant taxa, along with both plant macrofossil concentrations and calculated percent abundance are presented (by quadrat) in Table 1, Appendix II. The relative abundances of *Myriophyllum* and *Potamogeton* macrofossil remains corresponded well to the living percent cover of these taxa, while *Chara* and *Equisetum* had higher relative abundances in sediment macrofossil assemblages than percent cover of living plants. The percent cover of *Ceratophyllum demersum* and *Sagittaria* spp. did not correspond well to the relative abundance of sedimentary macrofossils. In fact, no macrofossil remains from these taxa were found in any of the quadrats samples.

Correspondence Analysis (CA) of the percent cover of living plants and the relative abundances of plant macrofossils in surface sediments indicated an association between the living vegetation and sedimentary macrofossil remains. The eigenvalues for axis 1 (0.427 for vegetation, and 0.460 for sediments) and axis 2 (0.366 for vegetation and 0.381 for sediments) were similar. Axis 1 sample scores for each data set were significantly correlated ($p \leq 0.05$, df =12). When the axis 1 sample scores were compared graphically by quadrat, the similarity was striking (Figure 3-4) and suggests that sediment macrofossil assemblages vary directly in response to the contemporary vegetation. When axis 2 sample scores were compared (Figure 3-4) the direction of change showed a similar trend, however Pearson correlation did not indicate a significant relationship ($p > 0.05$, df = 12). The covariation observed between axis 1 sample scores for living vegetation and sedimentary macrofossils indicates that, at the patch- or quadrat-scale, the percent abundances of macrofossil remains in surficial sediments were representative of the percent cover of taxa in the living plant community at SD2. This is consistent with studies from non-floodplain lakes, which indicate that plant macrofossils (with the exception of *Characeae*) tend to best represent the local (quadrat) or patch-scale vegetation (Davis 1985; Diefenbacher-Krall and Halteman 2000; Combroux et al. 2001).

Despite the absence of some taxa in the sediment record that are known to have been growing in or around the pond, it is important to note that sedimentary macrofossil assemblages did not contain remains from plant taxa that were not growing in or around pond SD2. In the spring of 2005, a major flood event inundated pond SD2 with Slave River water and sediments. The absence of remains from foreign plant taxa in sediments collected in the fall of 2005 suggests that even though this pond experienced major inputs of river flood waters, the composition of sedimentary macrofossil assemblages retrieved from pond SD2 did not appear to be strongly affected by long-distance transport by the river, and macrofossil assemblages were representative of the local vegetation.

Pond-scale relationships between living vegetation and sediment macrofossils

Sorensen's index of similarity (Table 3-1) indicated greater similarity between taxa present in sediment macrofossil remains and taxa present in the living vegetation found within the pond (zones 1 and 2) than from both the pond and catchment (zones 1 to 5). This indicates that sediment macrofossil assemblages likely captured a local signal of living vegetation, consisting predominantly of the submerged macrophytes growing near each quadrat at pond SD2. Additionally, Sorensen's index indicated that at least five quadrats along the transect capture a realistic picture of living vegetation composition. Specifically, quadrats two, three, seven, nine and ten had at least a 73% similarity between the presence of taxa within the sediment macrofossil assemblages and living pond vegetation. Renkonen's similarity analysis (Table 3-1) showed that five quadrats (eleven, ten, six, five and one) had at least an 85% similarity between the relative abundance of sediment macrofossil remains and average percent cover of living vegetation.

DISCUSSION

A small number of studies have previously sought to understand the spatial relationships between sedimentary plant macrofossil assemblages and the distributions of living plant communities, and all of them have found significant patch-scale relationships between aquatic macrophytes and their associated sediment remains (Davis 1985; Warner and Barnett 1986; Diefenbacher-Krall and Halterman 2000; Zhao et al. 2006). However, in a deltaic environment, water level fluctuations, transport processes, and diagenetic processes may differ markedly from lakes where these other studies have been conducted. This study suggests that spring flood events occurring at pond SD2 (including the year in which this study was conducted) do not appear to have obscured the patch-scale associations between contemporary vegetation and sedimentary remains. In fact, there is a statistically significant pattern of inter-quadrat variability between living communities and surface-sediment macrofossil assemblages across pond SD2 (Figure 3-4). There are taxa that are over-represented (*Chara* and *Equisetum*) and under-represented (*Lemna* and *Salix)*, and taxa that are well-represented in terms of both distribution and abundance in the sediments of pond SD2 (*Myriophyllum* and *Potamogeton*). Understanding these patterns of distribution will have important implications for interpreting assemblages of plant macrofossils in sediment cores from this site. For example, well-represented taxa, such as *Myriophyllum*, have the potential to more accurately indicate shifts in community composition because presence and relative abundance of sediment remains reflect the contemporary presence and percent cover, respectively. Further, the absence of remains from catchment plants (e.g., sedge marsh vegetation) such as *Carex*, *Sagittaria*, *Typha*, *Potentilla*, *Epilobium*, *Sium* and *Calamagrostis* suggest that taxa found within the sedge marsh at pond SD2 have very limited dispersal. This observation is consistent with dispersal patterns identified by Greatrex (1983) in the catchments of several small deep lakes, which demonstrated that seeds tend to originate from plants within one metre of sampling points. It is plausible then, that the presence of remains from these catchment taxa in sediment core samples from pond SD2 may indicate a very local presence of these taxa (within just a few metres of the sampling site) such as might occur at a central location with water-level drawdown due to evaporation in to the absence of flooding.

To construct a useful record of past changes in vegetation at pond SD2, it is essential to understand how the plant macrofossil assemblages in the sediments of pond SD2 represent the overall composition and percent cover of the contemporary vegetation at the time of sampling. Similarity analyses comparing presence/absence data of plant macrofossil assemblages to the living plant community indicates that plant macrofossil assemblages capture 73% of the living taxa at five quadrats (2, 3, 7, 9, 10) 21 m (Q2) to 42 m (Q7) from shore. These five most similar quadrats are located on both the proximal (Q2) and distal (Q10) ends of the pond with respect to the river flood entry point, suggesting that major inundation of this pond with flood waters has had little impact on the distributions of plant macrofossils. Further, similarity analysis using percent cover data indicates that the relative abundances of plant macrofossils in sediment assemblages have at least 85% similarity to the percent cover of contemporary counterparts at five quadrats (1, 5, 6, 10, 11). Two quadrats in particular (10 and 6), both near the deepest part of pond SD2, have very high degrees of similarity (88.4% and 87.4% respectively). Quadrats 4 and 8 have particularly low similarity between surface sediment macrofossil relative abundances and the percent cover of living vegetation (19% and 20% respectively). This is due to the presence of mats of *Potamogeton* spp., noted at the time of sampling as forming dense beds in the area, which prevented a representative sample of surface sediments from being obtained. From the raw count data, these surface sediment samples had disproportionate amounts of thick, unidentifiable vegetation, and relatively few plant macrofossil remains.

Renkonen’s index of similarity suggests a strong relationship between the relative abundance of sedimentary plant macrofossils and percent cover of living vegetation and excellent potential for the use of plant macrofossils as a tool in tracking not only changes in taxa presence, but also changes in the percent cover of submerged aquatic macrophytes at pond SD2.

Analysis of surface sediments retrieved from pond SD2 in September 2005 indicate that all remains identified represented local vegetation, while remains of non-local (foreign) plant taxa were not present in the samples. Previous studies have identified long-distance transport of plant macrofossils as a significant contributor to the process of deposition in the sediments of montane lakes, specifically where streams flow into these lakes from high elevations (Drake and Burrows 1980; Holyoak 1984). In addition, Warner and Barnett (1986) found that accounting for processes such as long-distance transport can aid in the interpretation of plant macrofossil assemblages in late Quaternary deltaic sequences in southern Ontario, and concluded that long-distance transport was a contributing factor to the presence of plant macrofossil assemblages of taxa that do not co-exist in the same contemporary vegetation zone. However, none of these studies delved into the consequences of long-distance transport in modern sediment remains but rather made inferences based on the presence of unusual plant macrofossil assemblages in sediment core samples. While previous studies suggest that propensity for long-distance transport may be elevated in a deltaic environment, the absence of remains from foriegn plant taxa in sediment samples from pond SD2 following inundation by

Slave River floodwaters in spring 2005 as well as good correspondence between living vegetation and sedimentary assemblages suggests that long-distance transport did not strongly alter sedimentary macrofossil assemblage composition.

CONCLUSIONS

This study has improved understanding of the processes involved in plant macrofossil deposition in a dynamic deltaic pond, and increases the ability to produce meaningful interpretations of past plant communities from sediment core analysis and the identification of past environmental and ecological changes. This study has assessed the spatial patterns of plant macrofossil deposition in a small flood-prone delta pond (SD2) through the study of surficial sediment remains and their relationship to the surrounding living vegetation community. The absence of foreign plant macrofossils in the sediment assemblages recovered from pond SD2 suggests that the possible influence of possible recent long-distance transport by river flooding in 2005 or other vectors did not strongly affect macrofossil assemblages in surficial sediments. Consequently, the plant macrofossil composition of sediment samples appears to vary directly in response to changes in contemporary vegetation located at each respective quadrat. Further, the relative abundance of plant macrofossils retrieved from surface sediments at the centre of pond SD2 demonstrates a notable level of correspondence (~73-87%) with the overall autochthonous vegetation community. Correspondence between the presence and relative abundance of sedimentary plant macrofossils and the presence and percent cover of living vegetation at multiple locations at SD2 indicate that macrofossil assemblages in sediment cores collected from the central, deepest portion of a basin will likely be representative of the local aquatic vegetation. While the scope of this study is limited to assessing the distributions of living plants and their respective sediment remains from one flood-prone pond in the Slave River Delta during the 2005 ice-free season, it provides important insight into the potential influence of river flooding on plant macrofossil deposition. This study suggests there is excellent potential for the use of plant macrofossils as a tool in tracking changes in the composition and percent cover of submerged aquatic macrophytes at pond SD2.

Table 3-1. Sorensen's and Renkonen's Similarity Indices to compare sedimentary plant macrofossils to living vegetation at SD2 based on presence/absence and percent cover data respectively. Values for each index can range from 0% (no similarity) to 100% (identical).

Quadrant	**Sorensen's Index**		**Renkonen's Index**
	Catchment vegetation	*Within pond vegetation*	
Q1	21%	44%	85.10%
Q2	38%	73%	46.90%
Q3	38%	73%	41.40%
Q4	30%	60%	19.20%
Q5	30%	60%	85.90%
Q6	30%	60%	87.40%
Q7	38%	73%	73.50%
Q8	21%	44%	20.30%
Q9	38%	73%	73.70%
Q10	38%	73%	88.40%
Q11	21%	44%	85.10%
Q12	21%	44%	54.00%
Q13	21%	44%	34.90%

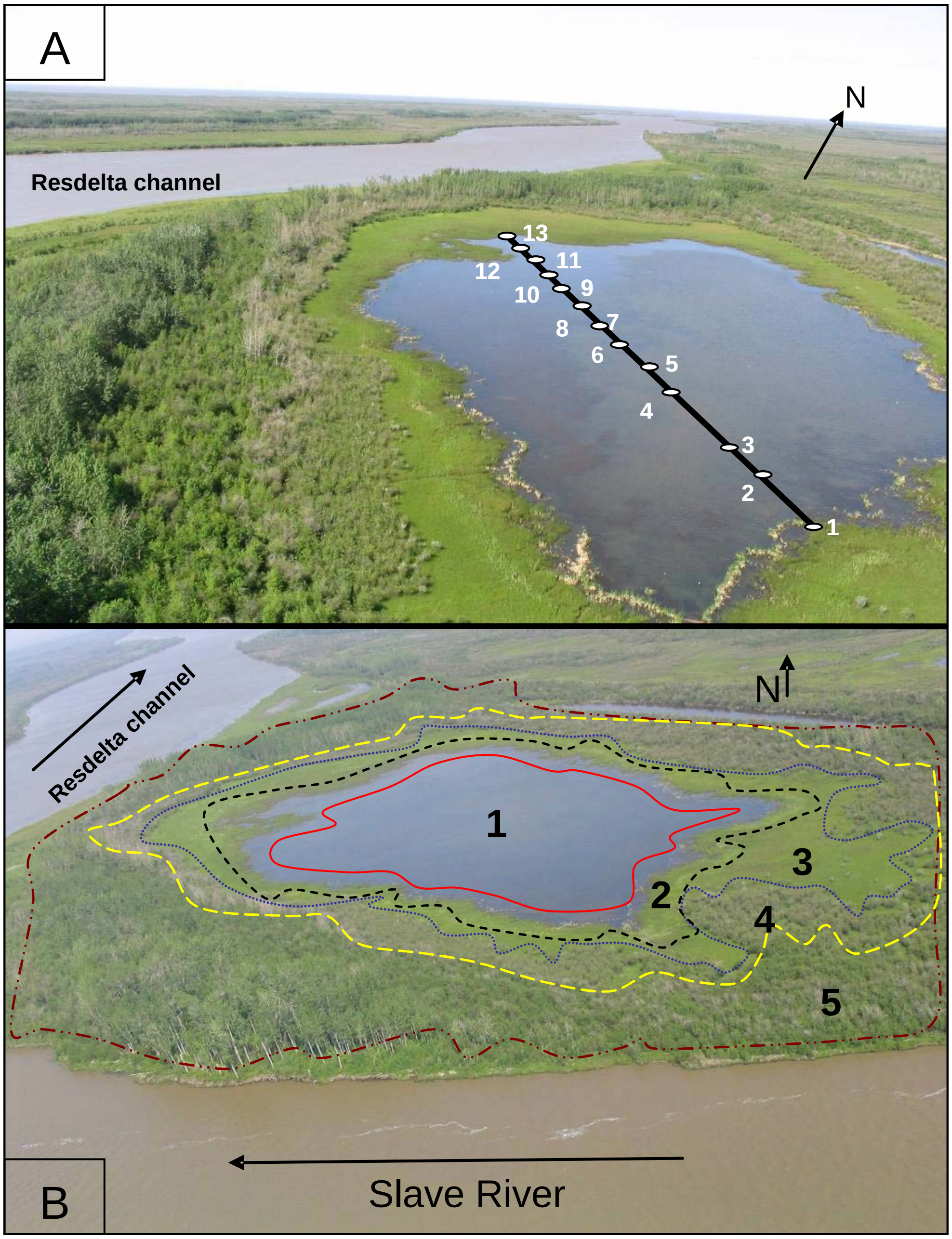

Figure 3-1A Aerial photograph of pond SD2, indicating the location of quadrat sampling sites (see Figure 2-1 for location). The solid line denotes the approximate transect location, and numbered ellipses represent quadrats sampled. Living vegetation percent cover was estimated in July 2005, and surficial sediments were collected in September 2005.

Figure 3-1B. Aerial Photograph of Pond SD2 with vegetation zones. Each line drawn on this photograph represents an area of gradation from one community type to another. Taxa distributions are as follows: 1) open-water zone, dominated by submerged macrophytes, 2) fringing emergent macrophytes, 3) sedge meadow, 4) *Salix* thicket, 5) mature vegetation (aspen and spruce forest).

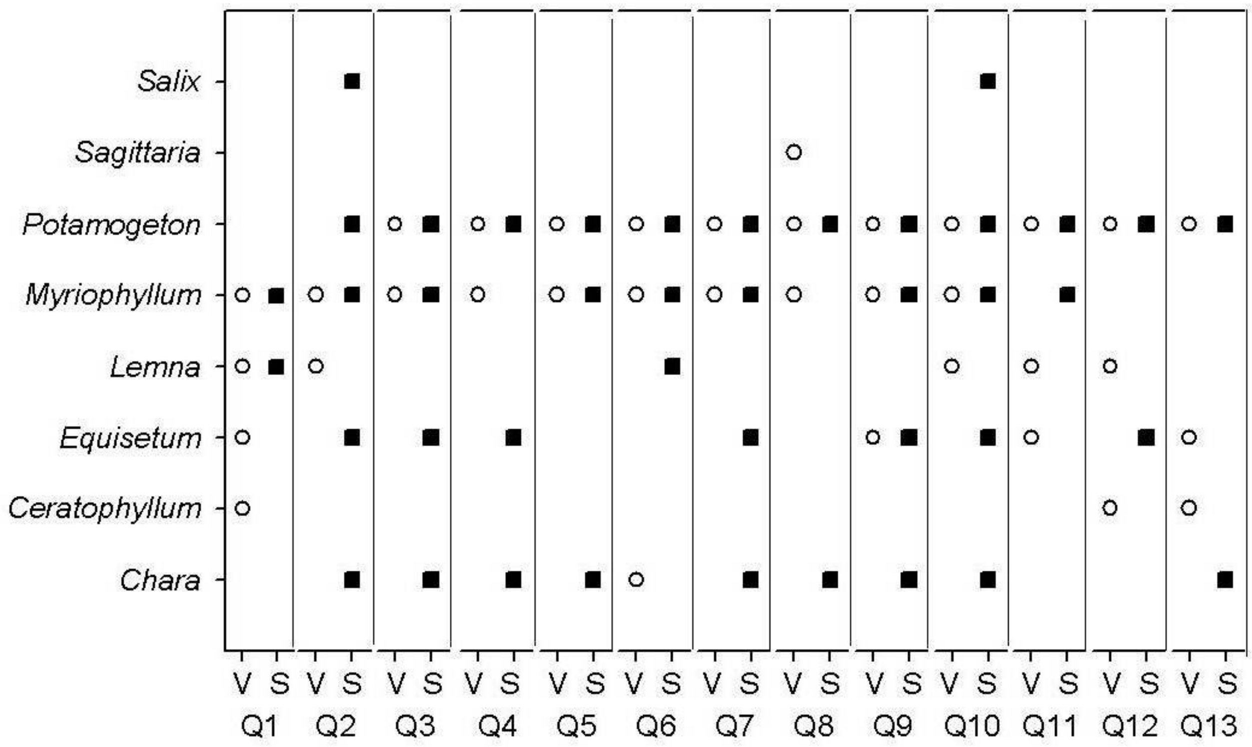

Figure 3-2 Comparison of the presence of taxa in living vegetation (open circles) and surface sediment samples (closed squares) (0-2cm) along a transect of 13 quadrats (Q1 SE to Q13 NW) across pond SD2 of the Slave River Delta, N.W.T. Sediment remains compared are as follows: *Salix* seeds, *Sagittaria* seeds, *Potamogeton* leaves, *Myriophyllum* winter bud scales, *Lemna* leaves, *Equisetum* stems, *Ceratophyllum* leaves, *Chara* oospores. Several herbs, sedges and grasses (including *Calamagrostis canadensis* var. *canadensis*, *Sium sauve*, *Sagittaria latifolia*, *Sagittaria cuneata*, *Potentilla palustris*, *Epilobium palustre* and all *Carex* species) were recorded in the quadrats of the living plant community were not present in any macrofossil sediment samples.

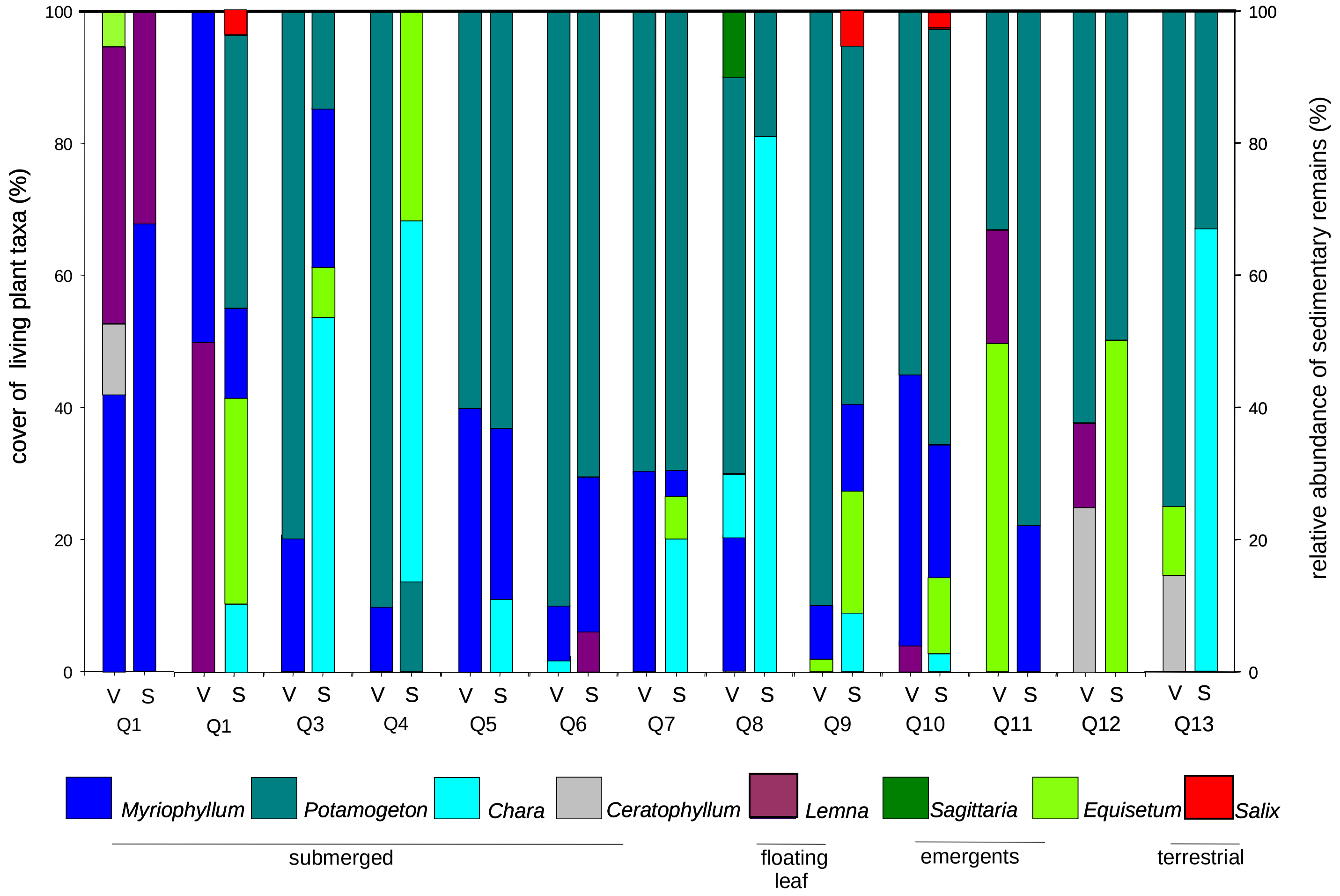

Figure 3-3 Relative abundance of plant macrofossils (S) in the surface-sediments from pond SD2 of the Slave River Delta, N.W.T., plotted alongside the percent cover of living vegetation (V) along a transect of 13 quadrants (Q1 SE to Q13 NW) across SD2.

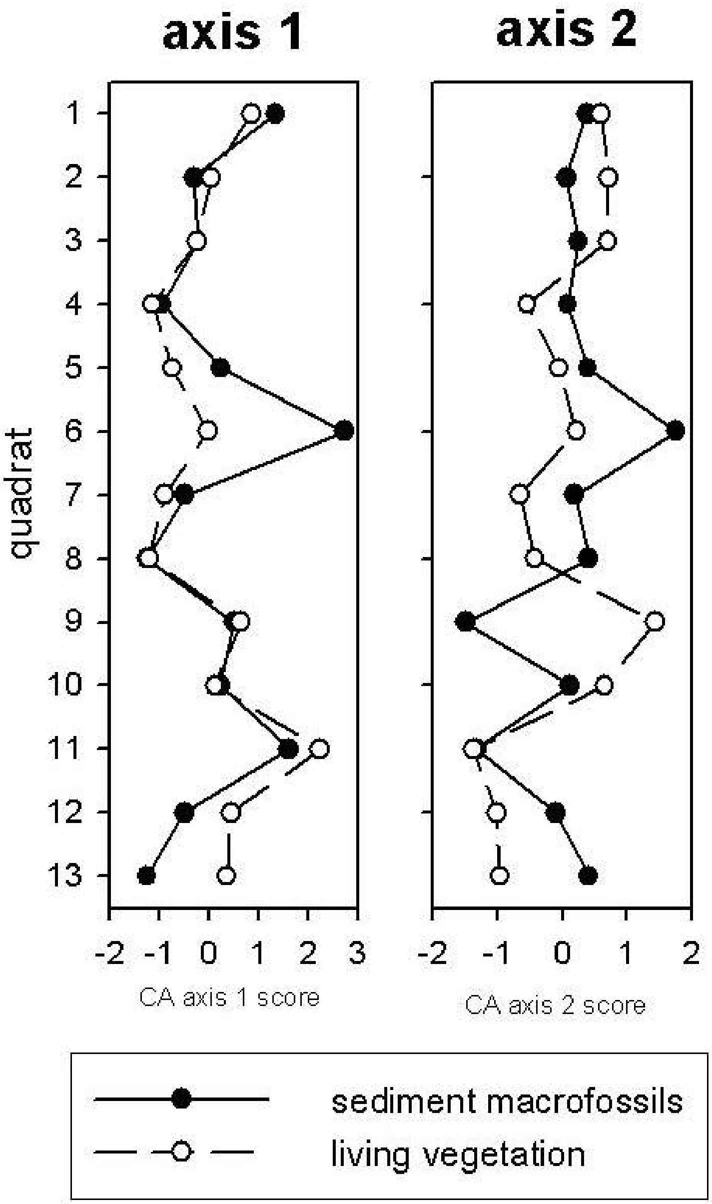

Figure 3-4 Sample scores for axis 1 and axis 2 from Correspondence Analysis (CA) of sediment macrofossils (solid line, solid circle) and living vegetation (dashed line, open circle), plotted by quadrat at pond SD2 of the Slave River Delta, N.W.T.

Chapter 4: Decadal-scale oscillations in Slave River flood frequency: a 90-year record from a shallow pond in the Slave River Delta, N.W.T

INTRODUCTION

Concerns over changes in the hydrological and ecological conditions of the Slave River Delta (SRD), N.W.T., have increased over recent decades owing to a perceived decline in flood frequency and potential links with river regulation and climate change. Specifically, construction of the W.A.C. Bennett hydroelectric dam at the headwaters of the Peace River has resulted in a decrease of almost 20% in the peak annual flow of the Slave River (Prowse and Conly 1998, 2002; Peters and Prowse 2001; Gibson et al. 2006), This change in flow regime is thought to have subsequently altered the formative processes of the SRD (English 1997). A series of aerial photographs (Figure 4-1, modified from Gardner et al. (2006)) indicate a marked shift in distributary flow, as a result of geomorphic change between 1954 and 1966, which pre-date construction of the dam and resulted in redirection of ~90% of Slave River flow through the mouth of the Resdelta channel (English et al. 1997). This geomorphic change begins prior to river regulation, and is attributed to natural deltaic processes (Gardner et al. 2006), but may have influenced changes in flood frequency and hydroecological conditions of the Slave River Delta (SRD).

Existing records of climate and Slave River discharge extend to just fifteen and eight years prior to river regulation, and are insufficient to understand the natural variability of this system. In the absence of long-term monitoring, paleolimnological investigations of basins within the SRD were initiated in 2002 to assess the range of natural variability, and understand the causes and effects of changes in river regime on the hydroecology of the delta and on the residents of nearby Fort Resolution (Wolfe et al. 2007a). Contemporary regional studies on a subset of SRD ponds have identified differences in basin hydrology (Brock et al. 2007), which correspond to statistically significant differences in limnological conditions and the compositions of diatom (Sokal et al. in press) and macrofossil assemblages (Chapter 2) in the surficial sediments. With these contemporary studies as a framework, carbon and nitrogen geochemistry, diatom and plant macrofossil assemblages were analyzed to construct a flood history of pond SD2 and relate aquatic and near shore biotic communities to the past and present hydrological conditions. Pond SD2 was identified as a site of interest because it is relatively susceptible to flooding due to its proximity to the Slave River and a sill of low topographic relief separating the basin from the river. In addition, SD2 was selected because regional hydrolimnological studies indicate that this site is representative of flood-dominated ponds located in the active delta. Recent work by Brock et al. (in preparation) to map the spatial extent of flooding as a result of ice-jam flood events found that moderate ice-jam induced flooding in 2003 occurred primarily in the active delta, but in 2005, significant ice-jam flooding with a much greater spatial extent resulted in flooding in not only the active delta, but also at upstream sites along the river. In 2004 the spatial extent of ice-jam induced flooding was low, and SD2 did not flood. Water supplied by river flooding is likely important to sustain water levels and aquatic habitat, particularly in the active delta (English et al. 1997; Brock et al. 2007). Given the importance of river flooding to the delta, understanding the frequency of high-magnitude flood events, such as the one in 2005, and their relationship with geomorphological change, river discharge and climate is key to anticipating and managing future changes to the ecosystem.

Here, an approximately 90-year record of flood events was constructed based on geochemical and biological proxy analyses of pond sediments from a sediment core collected from pond SD2 to address three key research questions:

1. How has flood frequency varied over the past century in the Slave River Delta?
2. What are the potential drivers of high-magnitude ice-jam flood events in the Slave River Delta?
3. What are the relative roles of geomorphology, river regulation and climate to flood frequency and magnitude in the Slave River Delta?

METHODS

Site description

Pond SD2 is located at the mouth of the Resdelta channel, in the active SRD (Brock et al. 2007) (61°16’ N; 113°34’ W). It is a shallow pond (maximum depth 1.5 m) with *flood-dominated* hydrology (Brock et al. 2007). Vegetation at pond SD2 consists of an open-water area dominated by submerged macrophytes (*Myriophyllum exalbescens*, *Potamogeton pusillus, P. freisii, P. richardsonii and P. zosteriformis*, and isolated patches of *Ceratophyllum demersum* and the macroalgae *Chara* sp.), emergents, grasses and herbs along the lake margin (*Equisetum fluviale, Typha latifolia, Carex* spp. and *Calamagrostis canadensis, Sagittaria cuneata, Potentilla palustre*), and low shrubs (*Salix* spp., *Betula* spp., *Alder* spp.) transitioning to mature trees (*Betula spp.*, *Populus tremuloides* and *Picea glauca*) in the surrounding catchment.

Sampling procedures

A 49.5 cm sediment core (SD2-KB5) was collected from the northwest region of SD2 in July 2004 using a gravity corer (Glew 1989). This site is distal to the known point of entry of flood waters, and was chosen to maximize the length of time captured because lower sediment accumulation rates are expected compared to a site proximal to the point of flood water entry. The core was sectioned into 0.5 cm intervals at the field station, transported to the University of Waterloo Environmental Change Research Lab (WaterLab), Department of Biology , University of Waterloo, Waterloo, ON, Canada., and stored at 4ºC.

Chronology

Sediments were analyzed for radioactive isotopes (^{210}Pb and ^{137}Cs) using an Ortec GWL Series HPGe coaxial well gamma spectroscopy system maintained at the WaterLab, University of Waterloo, Waterloo ON, Canada. The analysis of ^{210}Pb in the sediments is based on the measure of total ^{210}Pb activity, which is made up of supported and unsupported sources of ^{210}Pb. Supported ^{210}Pb is formed in the sediments through the in-situ decay of ^{226}Ra. Unsupported atmospheric ^{210}Pb fallout, which is deposited and incorporated into aquatic sediments, decays to ^{210}Bi with a half life of 22.26 years. The result is a decreasing total ^{210}Pb activity with sediment depth. Supported activity is subtracted from the total ^{210}Pb to provide a measure of the unsupported ^{210}Pb. Generally, the point at which unsupported activity intersects supported activity denotes a period of 150 years or less (Oldfield and Appleby 1978). The chronology developed was based on the ^{210}Pb activity profile using the Constant Rate of Supply model, which assumes a constant rate of ^{210}Pb supply to the sediments, but is able to account for fluctuations in the sedimentation rate (Oldfield and Appleby 1984). The ^{210}Pb chronology was constrained using ^{137}Cs, where the peak activity of ^{137}Cs (half-life of 33 years) is linked to the 1963 peak in global nuclear activity, and is captured as a peak concentration in sediments at depth throughout the world (Oldfield and Appleby 1978).

Macrofossils

Macrofossil samples were prepared following standard techniques as outlined by Birks and Birks (1980). Briefly, macrofossil samples were prepared by washing 10 cm^3 wet sediment samples through a 125 µm mesh screen with lukewarm tap water. Material retained on the sieve was sorted in water using a binocular dissecting microscope at 8-40x magnification and all identifiable macrofossils were enumerated. Data are recorded as concentrations of macrofossils per volume of sediment. Identifications were made to the finest taxonomic resolution possible, with the aid of the modern reference samples (from Chapter 3), as well as with the use of keys such as Martin and Barkley (2000), Berggren (1969,1981), Montgomery (1977), Schoch et al. (1988), Artjuschenko (1990) and Delorme (1970a-c). Original sediment samples and identified specimens are stored at the University of Waterloo Environmental Change Research Lab (WaterLab), Department of Biology, University of Waterloo, Waterloo ON, Canada.

As part of parallel graduate theses, corresponding sediment samples were also analyzed for organic carbon and nitrogen elemental and stable isotope geochemistry (Mongeon, MES thesis in progress, Wilfrid Laurier University) as well as diatom assemblage composition (Sokal, Ph.D. thesis in progress, University of Waterloo).

RESULTS AND INTERPRETATIONS

Chronology

Radiometric analysis of core SD2-KB5 indicated a distinct activity maximum for ^{137}Cs at a depth of 25.5 cm, which is interpreted to represent peak atmospheric fallout in 1963 (Figure 3-2). The rise in ^{137}Cs at 30 cm likely corresponds to the onset of nuclear weapons testing in ~1955 (Appleby 2001). A lower peak in ^{137}Cs activity at 28 cm likely corresponds to a secondary peak in atmospheric fallout in 1958, with the subsequent depression at 26 cm possibly corresponding to brief moratorium on weapons testing (Appleby 2001). Alternately, the rapid decline in ^{137}Cs at this horizon may be attributed to a known flood event in 1965 (Timoney et al. 1997). The ^{137}Cs peak at 25.5 cm is well defined and the absence of substantial levels of activity above 22 cm indicates that upward mobility of this radioisotope and/or mixing of the sediments of SD2 is minor, and the ^{137}Cs profile is considered to provide reliable stratigraphic markers. Peak ^{137}Cs concentrations of 0.02 Bq/g in the SD2 sediment core are consistent with levels observed in hydrologically similar lakes of the PAD (Wolfe et al. 2006), and have ^{137}Cs activity profiles very similar to the profile from SD2.

The chronology of the core from SD2 was developed using the CRS model for ^{210}Pb activity, which assumes a constant rate of unsupported ^{210}Pb supply to the sediment, and constrained to fit the 1963 ^{137}Cs peak. The CRS model was chosen because of the propensity for flooding at SD2, and evidence of flood deposits in the sediments that suggest sedimentation rates are likely to be highly variable. Fluctuations in the total ^{210}Pb activity profile likely reflect dilution by rapid sedimentation during flood events. For example, depressed total ^{210}Pb activity in the intervals 2.0-3.5 cm, 10.5-12 cm, 15.5-17 cm, 18.5-19.5 cm, 20.5-21.0 cm and 26-27 cm is suggestive of flood deposits in these sediment sections and so these are excluded from the CRS model.

To circumvent the limitations of an atypical ^{210}Pb decay curve, the definitive 1963 peak in ^{137}Cs activity was used to constrain the CRS modelled age-depth profile. Unsupported ^{210}Pb does not reach background values (defined by ^{214}Bi). ^{210}Pb dates were determined down-core to 36.75 cm, providing a modelled date of 1935 at this depth. Calculation of the inventory below 36.75 cm (by extrapolation based on the regression line of CRS modelled ^{210}Pb dates and cumulative dry mass (not shown)) continued until the age-depth curve passed through the 1963 ^{137}Cs peak. The resulting chronology spans 90 years in 50 cm, with a basal date of *c*. 1913. This chronology is indicative of particularly high sedimentation rates, which is expected of a pond that experiences high-frequency and variable-intensity flooding. Results from the CRS model indicate that the average sedimentation rate at SD2 (0.653cm yr^{-1}) is slower than sedimentation rates in frequently flooded oxbow lakes in the PAD (2.0cm yr^{-1} and 1.39cm yr^{-1}; Wolfe et al. 2006).

Macrofossil record from SD2

Macrofossil remains were abundant and well preserved within the sediments of core SD2-KB5. A total of 23 taxa were identified (Table 2, Appendix III) and 19 of these taxa were present in at least 3 samples. Specimens included both vegetative and reproductive remains of submerged and emergent aquatic macrophytes (i.e. *Potamogeton*, *Myriophyllum*, *Equisetum*, *Carex* spp., *Sagittaria cuneata*), aquatic moss leaves (e.g., *Drepanocladus*). Deciduous tree remains (*Salix* spp. and *Betula* spp. seeds) and the remains of several invertebrate fauna (ostracode and mollusk shells, cladoceran carapaces) were also present. Generally, macrofossil remains in the sediments of pond SD2 were dominated by *Myriophyllum* winter-bud scales, *Chara* oospores, *Potamogeton* leaves, *Equisetum* stems, *Sagittaria* seeds and ostracode shells.

Oscillations in each of the macrofossil taxa through this record indicate dynamic vegetation responses to fluctuating hydrological conditions over the past ~90-years (Figure 4-3). These oscillations imply shifts in vegetation and aquatic animal communities and abundance, likely in response to fluctuations in nutrient inputs, light environment and water levels as a result of fluctuations in the intensity and duration of spring flood events. Several intervals of low macrophyte and aquatic animal abundance (~1918-1921, 1930-1944, 1967-1973, and 1977-1982) are evident through the record. The declines in abundance may be a result of elevated rates of inorganic sediment supply from flood events, which have diluted macrofossil abundance in the sediments during these periods. Recent work by Sokal et al. (2007) indicated that changes in light environment, as a result of high energy conditions generated in some ponds by ice-jam induced flood events during spring thaw, have lead to differences in the biomass of submerged macrophytes in flooded versus non-flooded ponds. Specifically, high sediment turbidity decreased available light and delayed the onset of macrophyte growth in ponds that received spring flooding. The decreased biomass may be reflected in the sediments as a decline in the abundance of sedimentary macrofossil remains.

At least one interval of sustained low-flood influence and water-level drawdown is evident in the macrofossil record. The consistent presence of *Sagittaria cuneata* seeds between ~1940 and 1956 suggests substantially lower water levels at the coring site during this period, likely in response to many consecutive years of low-flood influence at pond SD2 and strong evaporative drawdown. There are two key details that support this interpretation. *S. cuneata* is typically found in ankle-deep water, but is capable of growing in up to one metre, where it produces floating leaves (Borman et al. 1997). Modern vegetation assessments at pond SD2 indicate that *S. cuneata* is concentrated on the edge of the sedge marsh zone, where the water level is between five and fifteen cm above the sediment surface. Typically, wetland plants respond to water levels as a control on sexual reproduction (seed production). Water regime can act as a seasonal signal, such that high water levels are typical of spring conditions and so taxa growing in water levels at the upper maximum of their ecological tolerance do not receive the appropriate seasonal signals to induce sexual reproductive strategies, and instead will reproduce vegetatively (Cronk and Fenessy 2001). Three consecutive years of field observations at pond SD2 (2003, 2004, 2005) confirmed that *S. cuneata* growing in the open-water zone (zone 1) of SD2 (depth ~0.5 m – 1 m) did not flower, despite extensive stands of flowering *S. cuneata* growing in the sedge marsh zone (zone

3). The presence of *S. cuneata* seeds in sediments from SD2-KB5 suggests that water levels at this site were between five and fifteen cm at the time of deposition. This peak in seeds could alternately be interpreted as representing an interval of higher water with extended shallows around SD2. However, modern studies indicate that despite an abundance of *S. cuneata* surrounding SD2 when water levels are high, seeds are found neither in the surface-sediments (13 transect samples, Chapter 3) nor at the top of this sediment core. Additionally, *S. cuneata* is widespread throughout the SRD, yet seeds from this taxa are absent from each of 40 surface-sediment samples analyzed as part of regional sampling (Chapter 2), which is further evidence for very local seed dispersal. This combination of seasonal controls on sexual reproduction, field observations and modern assessments of seed dispersal patterns of *S. cuneata* is taken as evidence of substantially lowered water levels at pond SD2 between ~1940 and 1956 as a result of an extended period of low flood influence from the Slave River.

Multi-proxy summary of hydrolimnological change at pond SD2

This section summarizes the geochemical and diatom sediment records from pond SD2, which are further refined by macrofossil analysis. Zones were determined visually based on areas of change and agreement between proxies that distinguish intervals of different hydrological conditions. Figure 4-4 summarizes these profiles.

Carbon and nitrogen geochemistry (Mongeon, MES thesis in progress, Wilfrid Laurier University)

Following the spring ice-jam flood event in May 2005, a sample of the flood deposit was collected from the catchment of SD2 and analyzed for mineral content, organic carbon and nitrogen elemental and stable isotope composition. This Slave River flood deposit sample is indicated by the dashed line included with each profile (Figure 4-4). It is characterized by high mineral matter (>90%), elevated $\delta^{15}N$ values (~2‰), low carbon (0-2% dry mass) and nitrogen (0-0.2% dry mass) and relatively high C/N weight ratios. Conversely, periods of low-flood influence are characterized by low mineral matter (<90%), low $\delta^{15}N$ values, high organic carbon and nitrogen content, and low C/N ratios relative to periods of high flood influence. Intervals of high-flood frequency have been identified based primarily on where geochemical profiles approach the measured flood deposit of 2005.

Diatoms (Sokal, Ph.D. thesis in progress, University of Waterloo)

Diatoms indicative of high river-influence span a wide range of habitat types including epiphytic, planktonic, tychoplanktonic and motile benthic taxa. Planktonic or high river 'indicator' taxa (*Cyclostephanos* cf. *tholiformis*, *Stephanodiscus minutulus* and *Cyclostephanos* PAD sp.2) are not found in evaporation-dominated lakes and are important indicators of high river influence from the Slave River (Sokal et al. 2007). These taxa have also been associated with high river connectivity in the Peace-Athabasca Delta (Hall et al. 2004).

Macrofossils

Indicator plant and animal macrofossil taxa were used to asses the response of local vegetation and aquatic animal communities to periods of high and low river influence on SD2. Specifically, the remains of the submerged aquatic macrophyte *Myriophyllum exalbescens* and the benthic invertebrate Ostracoda are present at highest abundance among all macrofossils identified in the sediments. These taxa have been associated with ponds strongly influenced by river flooding (Chapter 2). Plant macrofossils are also used to characterize the effects of intervals of particularly low river influence on the catchment vegetation community.

Zone 1 (~AD 1913-1927)

Between ~1913 and 1927 a period of generally low river influence is indicated by low $\delta^{15}N$ signatures (0.1‰), low C/N ratios (from ~14 - 9), with abundant low river-influence diatoms (from 10% - 15%), and low relative abundance of high river-influence diatoms (from 25% - 12%). However, beginning at about 1918, there were two or three years of high river influence on the basin, as indicated by the geochemical proxies characterized by values closer to the Slave River flood deposit of 2005. From 1921 to 1927 there was a notable period of low river influence reflected by relatively low $\delta^{15}N$ signatures (0.1‰), declining C/N ratios (from ~14 - 9) and reduced inorganic content. *Myriophyllum* winter-bud scales and ostracode shells were generally abundant during this period, indicating moderate to low turbidity and low inorganic sediment deposition as a result of low Slave River influence.

Zone 2 (~AD 1928 – 1942)

Beginning at about 1928 there was a 14-year period of high river influence, as indicated by an abrupt increase (from 10% - 20%) in abundance of high river-influence diatoms and notable shifts in each of the geochemical profiles to values comparable to those of the Slave River flood deposit. Macrofossil remains were sparse during this period, with *Myriophyllum* absent from the record in all but two samples, likely reflecting dilution due to increased inorganic sediment flux and higher turbidity during spring flood events which may have delayed the start of the growing season.

Zone 3 (~AD 1943 – 1961)

Between 1943 and 1961 each profile suggests a period of particularly low river influence on pond SD2. There is a decrease in the high river-influence diatoms from 20% in 1944 to less than 7% between 1950 and 1961. The $\delta^{15}N$ signature gradually shifts from ~1‰ in 1944 to -1‰, weight C/N decreases from 16 to 9 and mineral matter decreases by ~10%. The presence of *Sagittaria cuneata* seeds between 1940 and 1955 suggests substantially lower water levels at the coring site during this period, likely in response to many consecutive years of low flood influence at pond SD2 and strong evaporative drawdown (as discussed above). This interval of low river influence is characterized by geochemical proxy values that show the least similarity to Slave River flood deposits in the entire 90-year profile.

Zone 4 (~AD 1962 – 1982)

Pronounced shifts in each geochemical profile and diatom relative abundances in ~1962 mark the beginning of Zone 4. Specifically, the $\delta^{15}N$ signature increased by 2‰, C/N increased from 9 to 16, the mineral matter increased by ~10%, and the relative abundance of high river-influence diatoms increased from ~7% to 25% while diatoms associated with low river-influence decreased from ~7% to less than 2%. The abrupt end to the preceding 18-year period of low river influence on SD2 was marked by a major flood event in ~1962, after which the profiles indicate somewhat variable but generally high river influence until 1982. The abundances of macrofossil remains were consistently low during through this period, but between ~1971 and 1974 there was a peak in ostracode abundance which suggests two to three years of low river influence within this interval.

Zone 5 (~AD 1983 – 1990)

From 1983 to 1990 oscillations in each of the geochemical proxies indicate increased variability of river influence. There is a trend toward low river influence, with each of $\delta^{15}N$, C/N, mineral matter and high river-influence diatom abundance approaching levels previously observed in the profile during the low water levels of the 1950s. Macrofossil remains were abundant during this interval, with a peak in ostracode abundance around 1988.

Zone 6 (~1991-2004)

Between 1991 and 2004 the diatom record indicates a period of generally high river influence. Geochemical proxies suggest a 5-year period of high river influence from 1996 to 2000, indicated by increased mineral matter and weight C/N. There is a greater diversity and abundance of both plant and animal macrofossils between 1991 and 2004, which suggests higher productivity when compared to other periods of high river influence (e.g., zone 2: 1928-1942), perhaps due to lower intensity flood events than in the past.

DISCUSSION

The use of multiple proxies in the analysis of this sediment core has provided a comprehensive ~90-year record of hydroecological variability at pond SD2 (Figure 4-4). This high resolution record indicates that since ~1913, pond SD2 has been subject to high-frequency, variable-intensity flooding. Five stratigraphic zones can be distinguished in this record. Between 1913 to 1927 (zone 1) the geochemical and diatom records indicate variable-frequency flooding, as evidenced by variation in $\delta^{15}N$ values, percent mineral matter, C/N, C and N, as well as oscillations in the abundance of both low and high river-influence diatoms, and variation in the abundance of plant and animal macrofossils. From 1928 to 1942 (zone 2) there was a 14-year period of high flood frequency, indicated by elevated relative abundance of high river-influence diatom taxa, and notable shifts in each of the geochemical profiles to values comparable to those of the Slave River flood deposit of 2005. Beginning in ~1943 (zone 3) there was a distinctive interval of low Slave River influence. This shift in the geochemical and diatoms profiles is reflected in the appearance and rise in abundance of one species in particular that suggests a great impact on the vegetation dynamics at SD2. *Sagittaria cuneata* is a species common in the Slave Delta, but remains are relatively rare in regionally and locally derived surface sediment samples (see Chapters 2 and 3). Three years of field observations, extensive contemporary assessments of seed dispersal patterns and literature suggesting the importance of seasonal controls on sexual reproduction indicates the rise in abundance of *S. cuneata* in the sediments during this ~18-year period is due to substantially lowered water levels at pond SD2, as a result of an extended period of low flood influence from the Slave River. Zone 4 (1962-1982) began with an abrupt shift in each of the proxies from a sustained period of low river influence to values and abundances reflective of substantially higher river influence. Between 1981 and 1990 (Zone 5) there is strong evidence for low river influence reminiscent of conditions in Zone 3, although not to the same extent. From 1991-2004 (Zone 6) oscillations in diatom and macrofossil profiles were mirrored in geochemical fluctuations that suggest a period of low-intensity, variable-frequency flooding.

Comparison of the SD2 sediment record of flood events and gauged Slave River discharge over the past 46 years (1960-2005, Water Survey of Canada gauging station at Fitzgerald, AB) shows marked correspondence between elevated Slave River discharge during spring thaw and periods of high river influence at SD2 (Figure 4-5). In 2005, ice-jam-induced backwater flooding and ice-jam release flooding in the SRD resulted in massive, widespread flooding across the delta (Brock et al. in preparation). This flood event is associated with greater than average discharge during spring thaw (see figure 4-5). In contrast, thermal melt conditions in the spring 2004 thaw season and the absence of a delta-wide spring flood event coincide with below-average Slave River discharge when compared to the past 46 years of gauge data. Moreover, in spring 2003, moderate flooding corresponds with roughly average discharge levels when compared to the past 46 years. Using 2003, 2004 and 2005 as a framework, a relationship between elevated Slave River discharge during spring thaw and periods of high river influence (Figure 4-5) over the past 46 years becomes apparent. For example, between 1962 and 1982 geochemical and diatom profiles indicate a period of high river influence on pond SD2, denoted by high levels of mineral matter, high C/N, high $\delta^{15}N$ values and the prevalence of river diatoms. During this period, Slave River discharge matched or exceeded 2003 levels for thirteen of twenty years, and in 1974 the magnitude was two-fold greater than 2005. Furthermore, from 1983 to 1990 a period of low river influence, denoted by low mineral matter, low C/N, high C and N, and low $\delta^{15}N$ values coincides with a period where Slave River discharge is at or below 2004 levels in six of eight years. Finally, between 1996 and 1999 four consecutive years of discharge at or above 2003 levels, are mirrored by high C/N ratios, increased mineral matter content and greater abundance of high river-influence diatoms.

Strong correspondence between the flood history of pond SD2 and upstream sites located in the northern part of the Peace-Athabasca Delta (PAD) suggest that the current hydrological regime at SD2 is relatively unrelated to local geomorphological change, and that spring discharge generated from headwaters and major contributing rivers play an important role in the frequency and magnitude of spring flooding of the SRD and PAD (Figure 4-5). For example, sediment records that reflect organic carbon and nitrogen geochemical signals show pronounced similarity between SD2 and PAD15 (Figure 4-5). PAD 15 is a flood-prone oxbow lake located in the Peace sector of the PAD that was formed by a meander cutoff of a major distributary of the Peace River. It is currently hydrologically isolated from the Peace River, except during high-water events, evidenced by sediment core records which capture a high resolution record of Peace River flood frequency. (Wolfe et al. 2006). Between 1928 and 1942, the PAD 15 C/N record indicates low values, consistent with low C/N values and flood events at SD2. Beginning at ~1943, low C/N ratios at PAD 15 coincide with an ~18-year period of low water levels that have been identified as the driest period in the SD2 sediment record in the past 90 years. From 1962 to 1982 high C/N ratios in the PAD15 record are consistent with an interval of high river influence (high C/N ratios) in the SD2 record. Finally, between ~1983 and 1990 evidence for increasingly lower C/N values in both sediment records suggest a period of low river influence, and the correspondence between SD2 and PAD 15 persists in recent years, with relatively high C/N values indicating higher river influence at both sites after 1991.

CONCLUSIONS

The high-resolution paleolimnological record from SD2 provides a comprehensive ~90-year record of hydroecological variability which indicates decadal-scale oscillations in Slave River influence on the active delta, with periods of high-frequency, variable-intensity flooding as well as at least three intervals of low river influence lasting a decade or longer. Beginning in ~1943, an ~18-year period of particularly low river influence is reflected by low C/N ratios, low abundance of river influence diatoms, low mineral matter and high δ^{15}N values. Further analysis of this sediment core for plant macrofossil remains revealed a distinct response of the vegetation at SD2 to this period of low river influence. The presence of a relatively unique macrofossil assemblage, dominated by *Sagittaria cuneata,* suggests greatly reduced water levels at SD2 between 1943 and 1961, likely in response to evaporative draw-down associated with many consecutive years of low Slave River influence. Despite potential limitations in our ^{210}Pb activity profile, the distinctive 1963 peak in ^{137} Cs at 26.5 cm clearly indicates that this period, which represents the driest period recorded in the sediments over the past ~90 years, ends ~5 years prior to regulation of the Peace River upstream. This record indicates that the onset of river regulation by the W.A.C. Bennett Dam was not the most important factor contributing to flood frequency in the SRD. There is no evidence of a post-regulation directional change toward reduced flood frequency in the sediment record from SD2.

Pronounced correspondence between elevated Slave River discharge during spring thaw and periods of high river influence at SD2 verifies the important role of river discharge in regulating spring flood events. Furthermore, similarities between the flood history in the SRD and upstream sites located in the northern part of the Peace-Athabasca Delta (PAD) suggest that the current hydrological regime at SD2 is relatively unrelated to local geomorphological change, and that spring discharge generated from headwaters and major contributing rivers play an important role in the frequency and magnitude of spring flooding of the SRD and PAD.

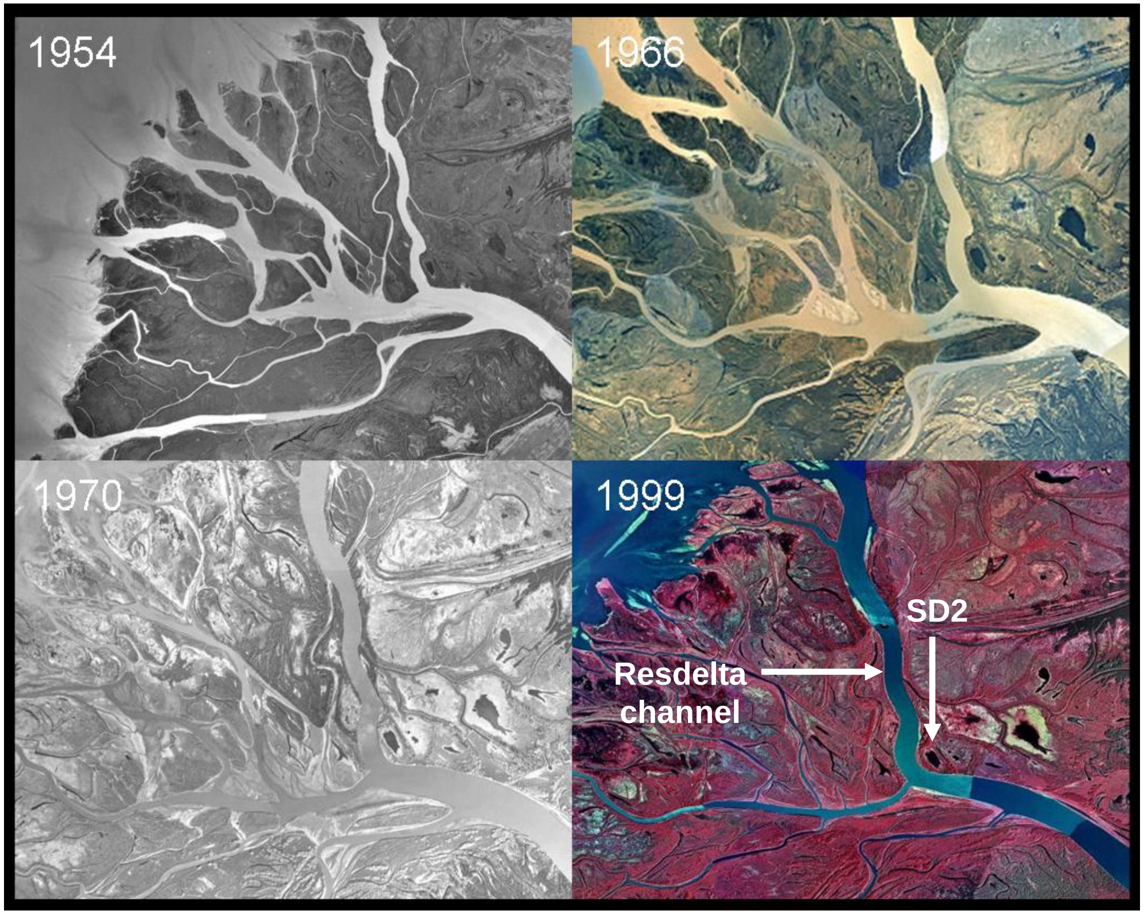

Figure 4-1 Time series of composite aerial photographs and satellite images of the Slave River Delta (1954-1999), showing the location of pond SD2 at the mouth of the Resdelta channel, and indicating a shift in distributary flow between 1954 and 1966. (Adapted from Gardner et al. 2006).

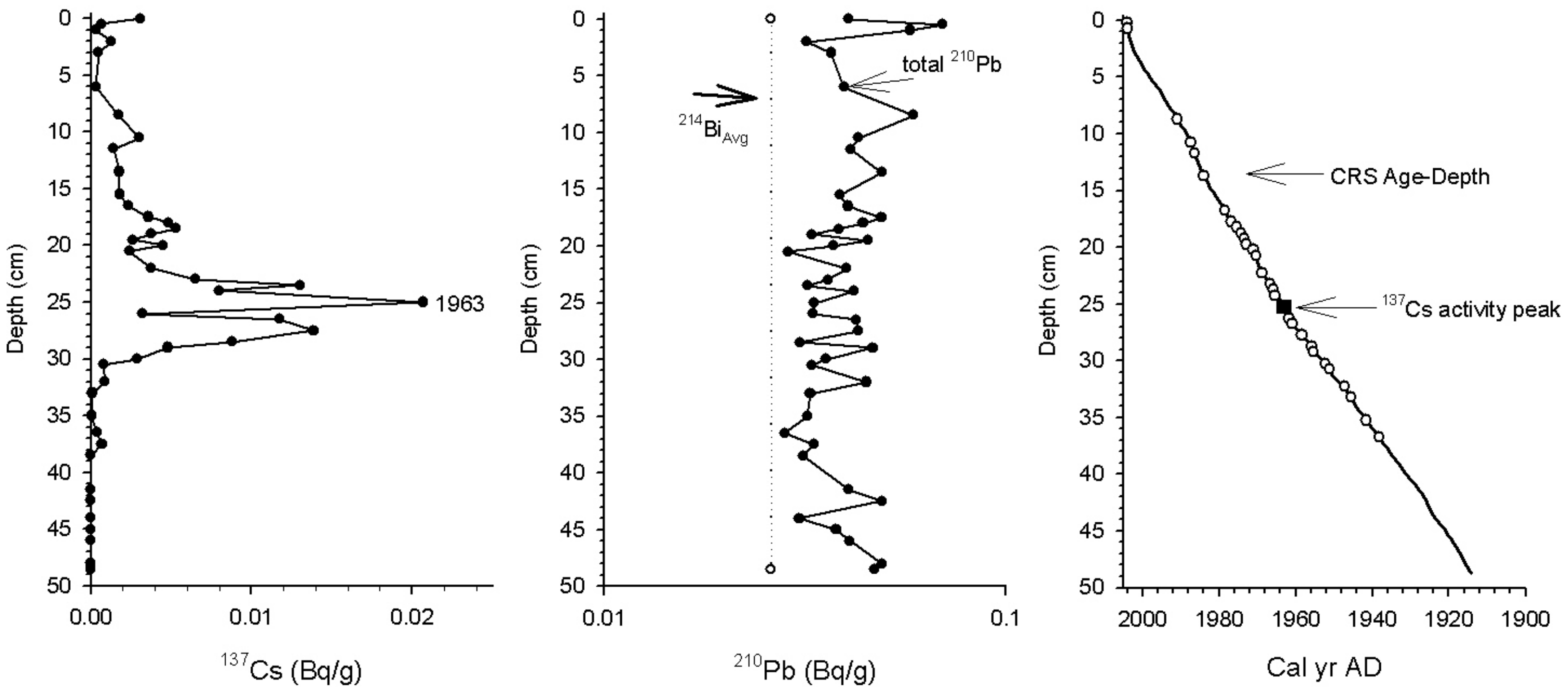

Figure 4-2 ^{137}Cs and ^{210}Pb activity profiles for sediment core KB5 from pond SD2 of the Slave River Delta, N.W.T., including chronology developed using the key 1963 peak in ^{137}Cs activity to constrain a CRS modelled age-depth profile.

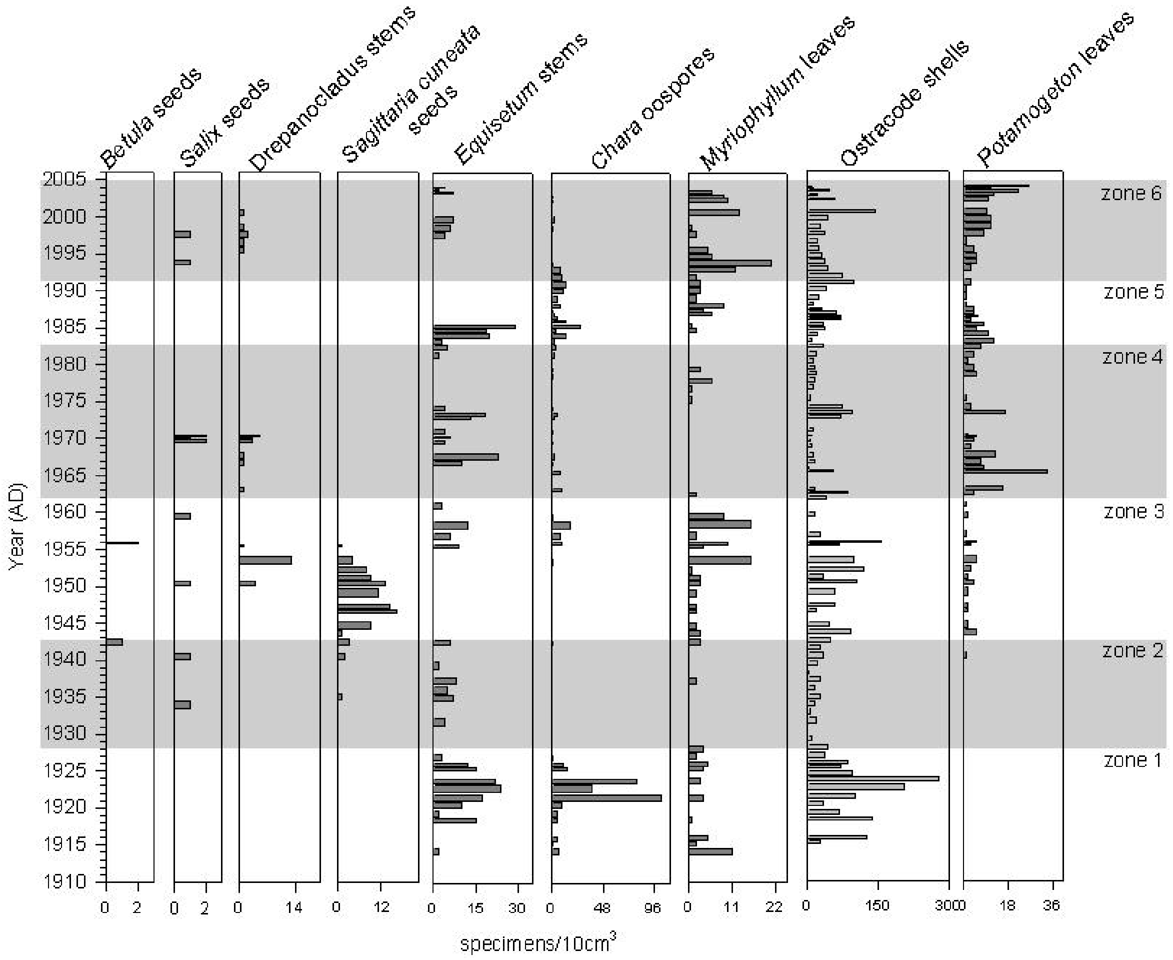

Figure 4-3 Abundance of macrofossil taxa (per 10cm^3 wet sediment) in sediments of core KB5 from pond SD2 in the Slave River Delta, N.W.T. Grey bands represent intervals of high-frequency flooding, and white intervals represent intervals of low-frequency flooding as determined by multi-proxy analysis (Figure 4-4).

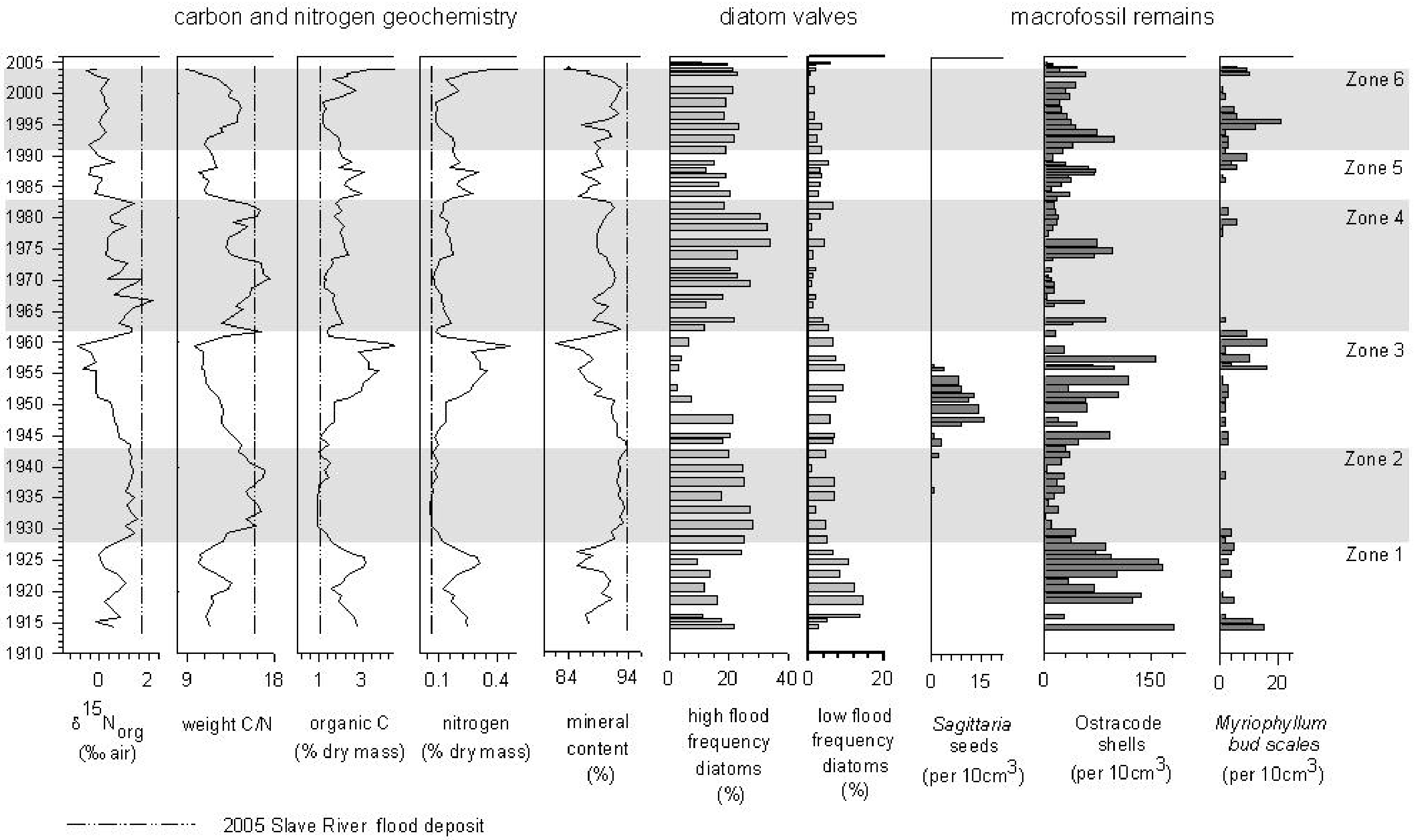

Figure 4-4 Summary of key proxy indicator data in core KB5 from pond SD2 of the Slave River Delta, NWT, including macrofossil assemblage compositions, geochemistry data (provided by C. Mongeon) and diatom assemblage compositions (provided by M. Sokal). Grey bands represent intervals of high-frequency flooding, and white bands represent intervals of low-frequency flooding.

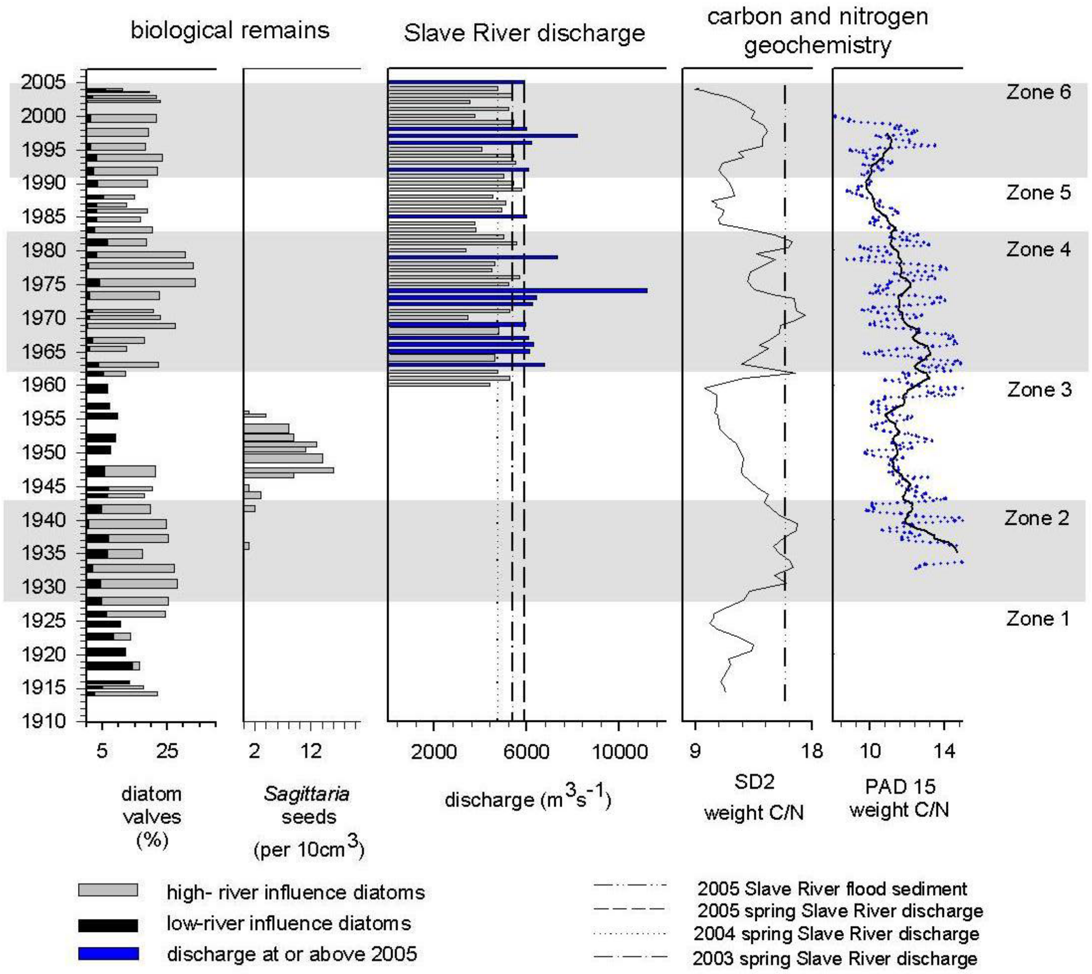

Figure 4-5 Key proxy records from core KB5 of pond SD2 in the Slave River Delta, N.W.T., plotted alongside the C/N values from sediments at PAD15, an upstream flood prone oxbow lake in the Peace-Athabasca Delta (dotted blue line represents measured values, solid black line represents a 5-year running mean) (Wolfe et al. 2006) and Slave River discharge data from the Water Survey of Canada gauging station at Fitzgerald, Alberta.

Chapter 5: Concluding Summary

This project addresses growing concerns over changes in the hydrological and ecological conditions of the SRD, which have increased over recent decades owing to a perceived decline in flood frequency and a potential link with river regulation and climate change. This project is part of a multi-disciplinary research program initiated in 2002 to assess the range of natural variability, and understand the causes and effects of changes in river regime on the hydroecology of the delta, as well as consequences of the changes on the residents of Fort Resolution (Wolfe et al. 2007a).

This thesis has combined detailed analysis of contemporary plant communities with paleolimnological methods to improve our understanding of the relationships between hydrolimnological conditions, living plant communities, and the distribution of sedimentary macrofossil remains across spatial and temporal scales. First, methods associated with a spatial survey of surficial pond sediments, as developed and applied by paleolimnologists (e.g., Hall and Smol 1996), were used to relate the composition of sediment macrofossil assemblages to differences in the hydrolimnological conditions of a subset of 40 basins in the SRD. Results show that there are strong relationships between the prevailing hydrolimnological conditions in the SRD and the composition of sedimentary macrofossil remains, and subsequently indicator macrofossil taxa were identified to distinguish between sites with high river influence (flood-dominated sites: ostracode shells, *Daphnia* ephippia, *Chara* oospores; exchange-dominated sites: *Myriophyllum* winter-bud scales, *Daphnia* ephippia) and sites with low river influence (evaporation-dominated: *Ceratophyllum* leaves, *Lemna* leaves, *Drepanocladus* leaves; Table 2-3). Macrofossil analysis allowed for a refinement of the ecological conditions at evaporation-dominated ponds susceptible to high-magnitude flood events. Several ponds that were initially classified as evaporation-dominated based on water stable isotope samples collected following moderate ice-jam induced flooding in the spring of 2003 and that flooded in 2005 (SD8, SD18, SD19 and SD29) during a high-magnitude ice-jam induced flood event had macrofossil assemblage compositions that showed some affinity to assemblages from flood-dominated ponds and they differed from evaporation-dominated ponds that did not flood in 2005.

Secondly, this study assessed how well sedimentary macrofossils reflected the living vegetation community at pond SD2 of the Slave River Delta. This study demonstrated that at patch-scale, there is a 60-73% similarity between the living vegetation and sedimentary remains in the central basin of SD2 (Sorensen's Index). In addition there is at least an 85% similarity between the living aquatic macrophytes and several sedimentary samples at pond-scale, suggesting an excellent potential for the use of plant macrofossils as a tool to track changes in the composition and percent cover of aquatic macrophytes in sediment cores from pond SD2. The absence of remains of foreign taxa in the sedimentary remains despite a major flood event at this site prior to sampling, combined with strong correspondence between sedimentary macrofossil assemblages and living vegetation, indicates that long-distance transportation of macrofossils did not exert strong influence on composition of macrofossil assemblages. Overall, the macrofossil remains collected from the surface sediments of pond SD2 in the fall of 2005 are representative of the local contemporary vegetation that lived within and around the pond in July 2005.

In light of the connection between spring flood events and the limnological and ecological conditions of SRD ponds, and growing concerns over the potential ramifications of a perceived decline in flood frequency, paleolimnological investigations were initiated to construct a record of ice-jam flood events in the SRD. Pond SD2 was identified as a site of interest due to proximity to the Slave River, low relief of the sill separating the basin from the river, the presence of an apparent flood path, and series of aerial photographs which indicate marked changes in river distributaries during the past several decades. Pond SD2 is a shallow, flood-dominated basin located in a key position that is ecologically, limnologically and hydrologically representative of flood-dominated ponds located within the active delta.

Using contemporary studies as a framework, a ~90 year record of flood frequency was reconstructed from a sediment core from this shallow, flood-dominated pond in the active Slave River Delta. Multi-proxy analyses indicate decadal-scale oscillations in flood frequency at this site, with at least three intervals of low river influence lasting a decade or longer. Beginning in ~1943, an 18-year period of particularly low river influence is reflected by low C/N ratios, low abundance of river influence diatoms, low mineral matter and high $\delta^{15}N$ values. Macrofossil analysis identified greatly reduced water levels at SD2 between ~1943 and 1961, as evidenced by abundant *Sagittaria cuneata* seeds, likely in response to evaporative draw-down associated with many consecutive years of low Slave River flood influence. This period ended five years prior to river regulation and represents the driest period recorded in the sediments over the past ~90 years. The sediment record from SD2 indicates that the onset of river regulation by the W.A.C. Bennett Dam was not the most important factor contributing to flood frequency in the SRD, and there is no evidence of a post-regulation directional change toward reduced flood frequency. A comparison of this sediment record of flood events to the past 45 years of gauged Slave River discharge shows pronounced correspondence between elevated Slave River discharge during spring thaw and periods of high river influence at SD2, which verifies the important role of river discharge in spring flood events at the SRD. Furthermore, similarities between the flood history of SD2 and upstream sites located in the northern Peace-Athabasca Delta suggest that spring discharge generated from headwaters and major contributing rivers play a key role in the frequency and magnitude of spring flooding of the SRD and PAD.

FUTURE DIRECTIONS

This study has developed plant macrofossils as a useful and important tool in multi-proxy reconstructions of paleoecological conditions in the SRD. It has highlighted clear differences between hydroecological conditions in the Slave River Delta prior to the initiation of Slave River discharge monitoring (between 1913 and 1960) and the years following (1961-2004). The sediment record from pond SD2 indicates that since ~1970, flood frequency at this site has been well within natural variability of the 20th century. This ~90 year record however, may be a brief illustration the true natural variability of this system. As such, the following recommendations for future work are suggested:

- Extend the sediment record at SD2 in order to identify multi-century patterns of change in flood history in the SRD, so that the response of this sensitive northern delta to climate change as well as human and natural modifications of upstream river systems can be better anticipated (P. Harms, M.Sc. thesis in progress, Department of Earth Sciences, University of Waterloo).
- Compare this record of flood history with records of climate-sensitive sites situated at higher elevations and further from distributaries of the Slave River, to better understand the relative roles of climate, flooding and geomorphic change on the hydroecological dynamics on a delta-wide scale in the SRD. (C. Mongeon, MES thesis in progress, Department of Geography, Wilfrid Laurier University).
- Compare an extended SD2 record to extended records from PAD 15 (Jarvis, MES thesis in progress, Department of Geography, Wilfrid Laurier University) and ongoing tree ring analysis from the PAD (Bailey, M.Sc. thesis in progress, Department of Earth Sciences, University of Waterloo), to identify the relationship between Slave and Peace River hydrology, as well as to assess the

response of Peace and Slave River hydrology to climatic variability.

- Development of an advanced level of understanding about contemporary vegetation dynamics at study sites is highly recommended for future paleolimnological investigations involving macrofossil analysis. The macrofossil record from SD2 has shown macrofossil analysis to be an effective tool in tracking changes in vegetation, and provided key insight into hydroecological dynamics of the SRD. The interpretation of the macrofossil record was based on regional studies and statistical analysis, but the robust understanding of the contemporary vegetation was developed through experience and knowledge collected during three field seasons in the delta.
- It would be wise to increase the volume of sediment collected in the spatial survey studies, such that there is always adequate sediment available for plant and animal macrofossil analysis.
- Develop a key to *Potamogeton* leaves for plant macrofossil analysis and identification in the SRD. At SD2, the concentrations of *Potamogeton* seeds are low, likely reflecting high palatability by waterfowl at this site. However, the leaves of this taxon are plentiful in the sediment remains and observations during sample identifications suggest that differences in morphology may allow

for the development of species-level identifications with the aid of a modern reference collection.

- Develop long-term monitoring programs that incorporate paleolimnological analyses of surface sediments and sediment cores to improve the ability to detect change, and in so doing, recognize the SRD as a dynamic system that responds sensitively to changes in river discharge and thus can not be managed as a static system.

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Appendix I

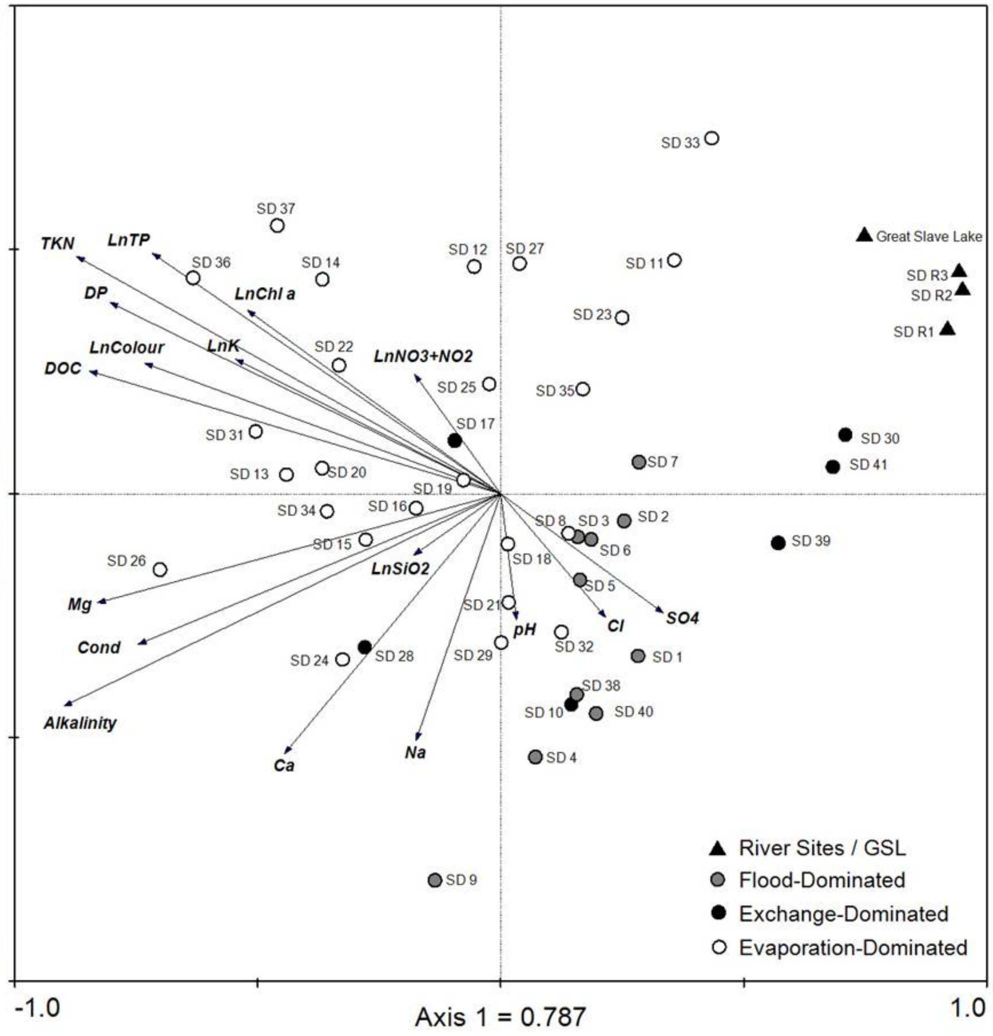

Figure 1. Principal Components Analysis (PCA) showing the relative positions of 41 Slave River Delta ponds with respect to 17 chemical and physical water variables and three hydrological categories (Sokal et al. in press).

Table 1. Slave River Delta study sites, with UTM zone 12 coordinates, by hydrological category. *SD32, initially classified as evaporation-dominated by Brock et al. (2007) based on stable isotope composition (δ^{2}H, δ^{18}O), has water chemistry more typical of flood-dominated lakes, it was relocated to the flood-dominated category for all numerical analyses.

Flood-dominated			**Exchange-dominated**			**Evaporation-dominated**		
	UTM Coordinates			UTM Coordinates			UTM Coordinates	
pond	*Northing*	*Easting*	*pond*	*Northing*	*Easting*	*pond*	*Northing*	*Easting*
SD1	6796450	360900	SD10	6800325	363078	SD8	6792549	358400
SD2	6796800	361650	SD17	6791348	368063	SD11	6798140	369545
SD3	6797350	363250	SD28	6791339	372046	SD12	6796301	371053
SD4	6796760	362150	SD30	6787657	387222	SD13	6798099	371918
SD5	6795888	365177	SD39	6800378	357341	SD14	6799258	373304
SD6	6798670	363650	SD41	6798317	355966	SD15	6802209	372375
SD7	6802929	363807				SD16	6801021	372195
SD9	6797369	359764				SD18	6795593	370045
SD38	6800416	359957				SD19	6796500	375250
SD40	6795784	356331				SD20	6800033	375441
*SD32	6783643	385619				SD21	6797868	378831
						SD22	6798855	380493
						SD23	6795825	381409
						SD24	6795230	377971
						SD25	6793846	378186
						SD26	6786563	370914
						SD27	6789184	372615
						SD29	6790800	381718
						SD31	6786252	385316
						SD33	6779992	381208
						SD34	6787134	362162
						SD35	6779578	380385
						SD36	6771359	380103
						SD37	6770753	381762

Table 2. Full taxa names for abbreviations used in analyses and plots, along with type of remains representing each taxa.

Abbreviation	Taxa	Remains
geum	*Geum*	seeds
salix	*Salix*	seeds
betula	*Betula*	seeds
poaceae	*Poaceae*	seeds
carxlent	*Carex*	Lenticular-type seeds
carextrig	*Carex*	Trigonas-type seeds
carexaqu	*Carex*	aquatilis-type seeds
equisstm	*Equisetum*	stems
eleosds	*Eleocharis*	seeds
scirpsds	*Scirpus*	seeds
spargsds	*Sparganium*	seeds
rumarsd	*Rumarex*	seeds
potepalusds	*Potentilla palustrus*	seeds
ceraplnt	*Ceratophyllum demersum*	leaves
ceratsds	*Ceratophyllum demersum*	seeds
lemna	*Lemna minor*	leaves
myriplnt	*Myriophyllum exalbescens*	leaves
myriseed	*Myriophyllum*	seeds
potsds	*Potamogeton* spp.	seeds
potwbud	*Potamogeton* spp.	winter buds
potaleav	*Potamogeton* spp.	leaves
charaplt	*Chara* sp.	leaf like branchlets
charaoos	*Chara* sp	oospores
filalgae	Filamentous Algae	strands
drepstem	*Drepanocladus* spp.	stems
draplvs	*Drepanocladus* spp.	leaves
aqmsstem	other aquatic moss	leaves
gastero	Gastropoda	shells
daphepp	Daphnia	ephippia
ostra	Ostracoda	shells
orbmts	Orbid Mite	carapace
crista	*Cristatella sp*	statoblasts
othstato	unidentifiable bryophytes	statoblasts
fwspgems	Fresh Water Sponge	gemules
fltwrmegs	Flatworm	eggs
rhizo	Rhizopoda	shells

Table 3. Concentrations of macrofossil taxa (number per 20 cm^3 sediment) identified in surficial sediment samples collected from 40 Slave River Delta ponds.

	SD 1	SD 2	SD 3	SD 4	SD 5	SD 6	SD 7	SD 8	SD 9	SD 10
Geum seeds	0	0	0	0	0	0	0	0	0	0
Salix seeds	0	0	0	0	0	0	0	0	0	0
Betula seeds	0	0	0	0	0	0	0	0	0	0
Poaceae seeds	0	0	0	0	0	0	0	0	0	0
Carex lenticular-type seeds	0	0	0	0	0	0	0	0	0	0
Carex trigonas-type seeds	1	0	0	0	0	0	0	0	0	0
Carex aquatilis-type seeds	0	0	0	0	0	0	0	0	0	0
Equisetum stems	0	0	0	0	0	0	0	0	0	0
Eleocharis seeds	0	0	0	0	0	0	0	0	0	0
Scirpus seeds	2	0	0	0	0	0	0	0	0	0
Sparganium seeds	0	0	0	0	0	1	0	0	6	0
Rumex seeds	0	0	0	0	0	0	0	0	0	0
Potentilla seeds	0	0	0	0	0	0	0	0	0	0
Ceratophyllum leaves	0	0	0	82	0	0	0	0	0	22
Ceratophyllum seeds	0	0	1	1	0	0	0	0	0	0
Lemna leaves	0	0	74	0	11	0	0	0	0	0
Myriophyllum leaves	43	9	0	0	0	0	3	0	0	0
Myriophyllum seeds	0	0	0	0	0	0	0	0	0	0
Potamogeton seeds	2	0	0	0	1	0	0	0	0	0
Potamogeton winterbuds	2	0	0	0	2	2	0	0	0	2
Potamogeton leaves	2	0	4	2	2	1	0	0	0	6
Chara branchlets	0	0	0	0	0	0	0	5	0	0
Chara oospores	0	2	2	0	10	0	4	10	0	0
Filamentous Algae	12	0	0	3	15	0	0	0	0	0
Drepanocladus leaves	0	8	0	0	0	0	0	0	0	3
other aquatic moss	0	0	0	0	0	0	0	0	0	0
gastropode shells	5	0	0	0	10	0	0	0	1	2
Daphnia epphipa	1	0	0	9	5	0	17	0	2	0
ostracode shells	14	12	5	4	39	6	4	16	2	3
Orbid Mite carapaces	0	0	0	0	3	0	5	0	0	0
Cristatella statoblasts	1	2	2	0	0	0	0	0	1	0
other statoblasts	0	0	0	0	0	0	0	0	0	0
fresh water sponge gemules	0	3	1	2	0	11	0	0	0	0
Flatworm eggs	1	0	2	8	4	1	0	0	0	0
rhizopode tests	2	43	16	12	10	10	0	0	0	0

	SD 11	SD 12	SD 13	SD 14	SD 15	SD 16	SD 17	SD 18	SD 19	SD 20
Geum seeds	0	0	0	0	0	0	0	0	0	0
Salix seeds	0	1	0	0	0	0	0	0	0	2
Betula seeds	0	0	0	0	0	0	0	0	0	0
Poaceae seeds	0	0	0	0	0	0	0	0	0	0
Carex lenticular-type seeds	0	0	0	1	0	0	0	0	0	0
Carex trigonas-type seeds	0	0	0	0	0	0	0	0	0	0
Carex aquatilis-type seeds	0	0	0	0	0	0	0	0	0	0
Equisetum stems	0	0	0	0	0	0	0	0	0	0
Eleocharis seeds	0	0	0	0	0	0	0	0	0	0
Scirpus seeds	0	1	2	0	0	0	0	0	0	1
Sparganium seeds	0	0	0	0	0	0	0	0	0	0
Rumex seeds	0	0	0	0	0	0	0	0	0	0
Potentilla seeds	0	0	0	0	0	0	0	0	0	0
Ceratophyllum leaves	4	38	0	0	70	15	15	31	10	42
Ceratophyllum seeds	0	0	0	0	0	0	0	0	0	0
Lemna leaves	0	15	6	42	4	78	44	0	37	15
Myriophyllum leaves	0	0	15	3	12	2	7	2	2	6
Myriophyllum seeds	0	0	0	0	0	0	0	0	0	0
Potamogeton seeds	0	0	0	0	0	1	0	1	0	0
Potamogeton winter buds	0	2	0	0	0	0	2	0	0	0
Potamogeton leaves	0	3	0	27	50	0	1	0	0	0
Chara branchlets	0	4	3	0	0	0	0	2	0	0
Chara oospores	0	12	0	36	6	0	0	0	0	0
Filamentous Algae	0	0	9	0	0	0	0	0	0	0
Drepanocladus leaves	43	0	0	1	0	0	0	5	0	0
other aquatic moss leaves	0	0	0	0	0	0	0	0	0	0
gastropode shells	1	6	0	2	3	2	0	0	4	0
Daphnia epphipa	0	0	11	0	9	7	5	0	12	4
ostracode shells	0	7	18	0	0	0	0	0	14	0
Orbid Mite carapaces	0	0	0	0	3	2	0	0	0	0
Cristatella statoblasts	0	0	0	0	1	1	0	0	0	1
other statoblasts	5	0	0	0	0	0	0	0	0	0
fresh water sponge gemules	0	0	3	0	0	0	2	0	0	1
Flatworm eggs	0	0	9	6	12	6	2	0	9	0
rhizopode tests	4	0	17	0	0	0	0	0	0	0

	SD 21	SD 22	SD 23	SD 24	SD 25	SD 26	SD 27	SD 28	SD 29	SD 30
Geum seeds	0	0	0	0	0	0	0	0	0	0
Salix seeds	3	1	3	3	0	3	0	1	3	0
Betula seeds	0	1	2	0	0	1	0	1	0	0
Poaceae seeds	0	0	2	0	0	0	0	0	0	0
Carex lenticular-type seeds	0	0	0	0	0	0	0	0	0	0
Carex trigonas-type seeds	0	0	0	0	0	0	0	0	0	0
Carex aquatilis-type seeds	0	0	0	0	0	0	0	0	0	0
Equisetum stems	0	0	0	0	0	0	0	0	0	0
Eleocharis seeds	0	0	0	0	0	0	0	0	0	0
Scirpus seeds	0	0	1	1	0	0	0	0	2	0
Sparganium seeds	0	1	0	1	0	0	4	2	0	0
Rumex seeds	0	0	0	0	0	0	0	0	0	0
Potentilla seeds	0	0	0	0	0	0	0	0	0	0
Ceratophyllum leaves	2	12	5	3	2	18	0	0	3	0
Ceratophyllum seeds	0	0	0	0	0	0	0	2	0	0
Lemna leaves	33	30	3	1	0	32	0	0	0	0
Myriophyllum leaves	5	2	5	1	2	1	0	16	2	0
Myriophyllum seeds	0	1	0	0	0	0	0	0	0	0
Potamogeton seeds	1	0	0	0	0	0	0	0	2	0
Potamogeton winter buds	0	0	0	0	0	0	0	0	3	0
Potamogeton leaves	0	0	0	0	2	2	0	0	0	0
Chara branchlets	0	0	0	0	0	0	0	0	0	0
Chara oospores	13	7	0	0	1	1	0	21	6	0
Filamentous Algae	0	0	0	0	0	4	0	0	37	6
Drepanocladus leaves	2	0	84	3	22	13	0	0	0	0
other aquatic moss leaves	0	0	0	0	0	0	0	0	0	0
gastropode shells	0	0	2	0	0	1	0	61	2	2
Daphnia epphipa	0	10	12	0	1	3	14	0	0	7
ostracode shells	0	0	0	0	7	0	0	0	9	19
Orbid Mite carapaces	0	0	0	0	0	0	0	0	0	0
Cristatella statoblasts	0	1	0	0	0	1	0	0	2	0
other statoblasts	0	0	0	0	0	0	0	0	0	0
fresh water sponge gemules	0	1	8	0	3	3	0	1	0	0
Flatworm eggs	0	0	4	0	3	1	0	6	5	0
rhizopode tests	9	0	12	0	17	6	0	11	0	7

	SD 31	SD 32	SD 33	SD 34	SD 35	SD 36	SD 37	SD 38	SD 39	SD 40
Geum seeds	1	0	0	1	0	0	0	0	0	0
Salix seeds	0	0	0	0	0	0	0	0	0	0
Betula seeds	0	0	0	0	0	0	0	0	0	0
Poaceae seeds	0	0	0	0	0	0	0	0	0	0
Carex lenticular-type seeds	0	0	0	0	0	3	0	0	0	0
Carex trigonas-type seeds	5	0	2	0	0	0	0	0	0	0
Carex aquatilis-type seeds	0	0	15	2	0	0	0	0	0	0
Equisetum stems	0	0	0	0	0	0	0	0	4	0
Eleocharis seeds	0	0	0	1	0	0	0	0	0	0
Scirpus seeds	0	0	3	0	0	0	0	0	0	0
Sparganium seeds	0	0	6	0	0	0	0	0	0	1
Rumex seeds	0	0	0	2	0	0	0	0	0	0
Potentilla seeds	0	0	0	0	0	0	0	1	0	0
Ceratophyllum leaves	0	0	2	4	1	22	18	0	0	0
Ceratophyllum seeds	1	0	0	0	0	0	0	0	0	0
Lemna leaves	12	0	5	0	10	1	0	0	0	0
Myriophyllum leaves	0	0	0	4	5	0	0	24	17	19
Myriophyllum seeds	0	0	0	0	0	0	0	0	0	2
Potamogeton seeds	0	2	0	1	0	0	0	0	0	0
Potamogeton winter buds	1	1	0	0	0	0	0	0	0	1
Potamogeton leaves	3	5	4	0	0	0	1	1	0	2
Chara branchlets	3	0	0	0	0	0	0	0	4	0
Chara oospores	0	7	1	0	0	9	0	20	0	3
Filamentous Algae	13	0	14	44	5	65	0	10	0	46
Drepanocladus leaves	0	0	58	10	0	0	0	0	9	0
other aquatic moss leaves	2	0	4	0	0	0	0	0	0	2
gastropode shells	8	4	0	8	0	2	0	0	0	1
Daphnia epphipa	13	7	11	4	0	2	6	0	2	7
ostracode shells	37	80	0	38	0	20	2	33	0	25
Orbid Mite carapaces	0	7	1	0	0	1	0	0	0	1
Cristatella statoblasts	1	0	0	3	0	1	0	0	5	0
other statoblasts	0	0	0	0	0	0	0	0	0	0
fresh water sponge gemules	4	0	16	4	8	6	3	0	7	0
Flatworm eggs	0	6	2	5	0	17	0	6	0	7
rhizopode tests	4	25	24	23	0	32	24	16	12	19

Appendix II

Table 1. Living plant taxa identified growing in and around pond SD2 of the Slave River Delta, N.W.T.

Clade	**Order**	**Family**	**Species**
Bryophyta	Hypnales	Amblystegiaceae	*Drepanocladus sp.*
Equisetophyta	Equisetales	Equisetaceae	*Equisetum fluviatile*
Clade of uncertain position	Ceratophyllales	Ceratophylaceae	*Ceratophyllum demersum*
Monocots	Arales	Lemnaceae	*Lemna minor*
		Lemnaceae	*Lemna trisulca*
	Alismatales	Potamogetonaceae	*Potamogeton friesii*
		Potamogetonaceae	*Potamogeton graminus*
		Potamogetonaceae	*Potamogeton pusillus* var pusillus
		Potamogetonaceae	*Potamogeton richardsonii*
		Potamogetonaceae	*Potamogeton zosteriformis*
		Alismatceae	*Sagittaria latifolia* Willd.
		Alismatceae	*Sagittaria cuneata* Sheldon
	Poales	Poaceae	*Calamagrostis canadensis* var. canadensis (Michx.) P. Beauv.
		Cyperaceae	*Carex aquatilis* var altior
		Cyperaceae	*Carex utriculata*
		Cyperaceae	*Carex rostrata* Stokes.
		Cyperaceae	*Scripus validus* Vahl.
		Cyperaceae	*Scirpus lacustris*
		Typhaceae	*Typha latifolia*
Basal Tricolpates	Ranunculales	Ranunculaceae	*Caltha palustris*
Eurosids I	Rosales	Rosaceae	*Chaenomeles*
		Rosaceae	*Geum*
		Rosaceae	*Potentilla*
		Rosaceae	*Potintilla palustris*
	Fagales	Betulaceae	*Alnus crispa* Pursh (Ait)
		Betulaceae	*Alnus serrulata* Willd
	Malpighiales	Salicaceae	*Salix pedicellaris*
		Salicaceae	*Salix lutea* Nutt.
		Salicaceae	*Salix planifolia*
		Salicaceae	*Salix candida* Flugge
		Salicaceae	*Salix planifolia*
Eurosids II	Brassicales	Brassicaceae	*Iberis*
	Malvales	Thymelaeaceae	*Daphne*
		Cistaceae	*Helianthemum*
	Myrtales	Onagraceae	*Epilobium palustre* L.
Asterids	Cornales	Cornaceae	*Cronus stonifolia* michx
	Ericales	Primulaceae	*Primula*
Euasterids I	Lamiales	Lentibulariaceae	*Utricularia minor*
Euasterids II	Apiales	Apiaceae	*Sium sauve* Walt.

Table 2. Concentrations and percent abundance of taxa present in sediment samples by quadrat. Values for concentration were used to calculate the percent abundance by dividing remains of each taxon by the total remains in that sample from the respective quadrat.

Quadrat		*Chara* oospores	*Ceratophyllum* leaves	*Equisetum* stems	*Lemna* leaves	*Myriophyllum* leaves	*Potamogeton* leaves	*Potamogeton richardsonii* seeds	*Potamogeton pusillus* seeds	*Potamogeton friesii* seeds	*Potamogeton zosteriformis* seeds	*Sagittaria* seeds	*Salix* seeds	total
1	remains	0	0	0	0	8	16	0	0	0	0	0	0	24
	abundance	0%	0%	0%	0%	33%	67%	0%	0%	0%	0%	0%	0%	100%
2	remains	4	0	12	0	3	9	0	0	0	0	0	1	29
	abundance	14%	0%	41%	0%	10%	31%	0%	0%	0%	0%	0%	3%	100%
3	remains	22	0	3	0	10	6	0	0	0	0	0	0	41
	abundance	54%	0%	7%	0%	24%	15%	0%	0%	0%	0%	0%	0%	100%
4	remains	12	0	7	0	0	3	0	0	0	0	0	0	22
	abundance	55%	0%	32%	0%	0%	14%	0%	0%	0%	0%	0%	0%	100%
5	remains	2	0	0	0	5	11	0	1	0	0	0	0	19
	abundance	11%	0%	0%	0%	26%	58%	0%	5%	0%	0%	0%	0%	100%
6	remains	0	0	0	1	4	12	0	0	0	0	0	0	17
	abundance	0%	0%	0%	6%	24%	71%	0%	0%	0%	0%	0%	0%	100%
7	remains	10	0	3	0	2	34	0	0	0	0	0	0	49
	abundance	20%	0%	6%	0%	4%	69%	0%	0%	0%	0%	0%	0%	100%
8	remains	13	0	0	0	0	3	0	0	0	0	0	0	16
	abundance	81%	0%	0%	0%	0%	19%	0%	0%	0%	0%	0%	0%	100%
9	remains	2	0	4	0	3	8	1	0	1	2	0	1	22
	abundance	9%	0%	18%	0%	14%	36%	5%	0%	5%	9%	0%	5%	100%
10	remains	1	0	4	0	7	22	0	0	0	0	0	1	35
	abundance	3%	0%	11%	0%	20%	63%	0%	0%	0%	0%	0%	3%	100%
11	remains	0	0	0	0	2	6	0	0	0	1	0	0	9
	abundance	0%	0%	0%	0%	22%	67%	0%	0%	0%	11%	0%	0%	100%
12	remains	0	0	4	0	0	3	0	1	0	0	0	0	8
	abundance	0%	0%	50%	0%	0%	38%	0%	13%	0%	0%	0%	0%	100%
13	remains	12	0	0	0	0	6	0	0	0	0	0	0	18
	abundance	67%	0%	0%	0%	0%	33%	0%	0%	0%	0%	0%	0%	100%

Table 3. Percent cover of living plant taxa by quadrat in pond SD2 of the Slave River Delta. For the spatial distribution of these quadrats at SD2, see Figure 3-1A, chapter 3.

	Percent cover living vegetation												
Quadrat	*Chara* spp.	*Ceratophyllum dermersum*	*Equisetum* spp.	*Lemna* spp.	*Myriophyllum exalabenses*	total *Potamogeton* spp.	*Potamogeton richardsonii*	*Potamogeton pusillus*	*Potamogeton friesii*	*Potamogeton zosteriformis*	*Sagittaria* spp.	*Salix* spp.	
1	0.0%	10.5%	5.2%	42.1%	42.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	
2	0.0%	0.0%	0.0%	0.0%	50.0%	50.0%	0.0%	40.0%	5.0%	5.0%	0.0%	0.0%	
3	0.0%	0.0%	0.0%	0.0%	20.0%	80.0%	0.0%	40.0%	40.0%	0.0%	0.0%	0.0%	
4	0.0%	0.0%	0.0%	0.0%	10.0%	90.0%	10.0%	0.0%	80.0%	0.0%	0.0%	0.0%	
5	0.0%	0.0%	0.0%	0.0%	40.0%	60.0%	0.0%	0.0%	60.0%	0.0%	0.0%	0.0%	
6	2.0%	0.0%	0.0%	0.0%	8.0%	90.0%	0.0%	30.0%	50.0%	10.0%	0.0%	0.0%	
7	0.0%	0.0%	0.0%	0.0%	30.0%	70.0%	30.0%	0.0%	30.0%	10.0%	0.0%	0.0%	
8	0.0%	0.0%	0.0%	0.0%	30.0%	60.0%	20.0%	0.0%	40.0%	0.0%	10.0%	0.0%	
9	0.0%	0.0%	2.0%	0.0%	8.0%	90.0%	0.0%	90.0%	0.0%	0.0%	0.0%	0.0%	
10	0.0%	0.0%	0.0%	5.0%	40.0%	55.0%	0.0%	40.0%	15.0%	0.0%	0.0%	0.0%	
11	0.0%	0.0%	50.0%	16.7%	0.0%	33.3%	0.0%	0.0%	0.0%	33.3%	0.0%	0.0%	
12	0.0%	25.0%	0.0%	12.5%	0.0%	62.5%	0.0%	0.0%	50.0%	12.5%	0.0%	0.0%	
13	0.0%	15.0%	10.0%	0.0%	0.0%	75.0%	0.0%	0.0%	70.0%	5.0%	0.0%	0.0%	
whole pond:	0.15%	3.88%	5.17%	5.87%	21.39%	62.75%	values excluded from analysis				0.77%	0.00%	
where whole pond percent cover for each taxa is equal to $\sum(Q1_{taxa}:Q13_{taxa})/13$													

Appendix III

Table 1. Sediment dates by mid-point depth. Chronology dates are based on CRS modelled ^{210}Pb profile which was constrained using the1963 peak in $^{137\mathrm{Cs}}$ activity.

mid-point depth (cm)	Year (AD)	mid-point depth (cm)	Year (AD)	mid-point depth (cm)	Year (AD)
0.25	2004.00	16.75	1978.61	33.25	1945.57
0.75	2003.92	17.25	1977.80	33.75	1944.70
1.25	2003.68	17.75	1976.79	34.25	1943.67
1.75	2003.35	18.25	1975.35	34.75	1942.52
2.25	2002.86	18.75	1974.19	35.25	1941.64
2.75	2002.24	19.25	1973.34	35.75	1940.52
3.25	2001.40	19.75	1972.84	36.25	1939.41
3.75	2000.58	20.25	1971.06	36.75	1938.28
4.25	1999.66	20.75	1970.29	37.25	1937.26
4.75	1998.58	21.25	1970.11	37.75	1936.05
5.25	1997.65	21.75	1969.60	38.25	1935.01
5.75	1996.59	22.25	1968.85	38.75	1933.95
6.25	1995.52	22.75	1967.67	39.25	1932.83
6.75	1994.61	23.25	1966.73	39.75	1931.67
7.25	1993.80	23.75	1965.93	40.25	1930.51
7.75	1992.89	24.25	1965.44	40.75	1929.27
8.25	1991.88	24.75	1963.63	41.25	1928.01
8.75	1990.99	25.25	1963.08	41.75	1927.01
9.25	1990.04	25.75	1962.50	42.25	1926.00
9.75	1988.98	26.25	1961.78	42.75	1925.38
10.25	1988.00	26.75	1960.95	43.25	1924.59
10.75	1987.37	27.25	1959.53	43.75	1923.75
11.25	1986.88	27.75	1958.40	44.25	1922.71
11.75	1986.40	28.25	1956.90	44.75	1921.38
12.25	1985.95	28.75	1955.86	45.25	1920.42
12.75	1985.29	29.25	1955.46	45.75	1919.27
13.25	1984.67	29.75	1953.50	46.25	1918.40
13.75	1983.95	30.25	1952.21	47.00	1916.94
14.25	1983.12	30.75	1951.19	47.75	1915.93
14.75	1982.35	31.25	1950.45	48.25	1915.21
15.25	1981.29	31.75	1949.08	48.75	1914.20
15.75	1980.35	32.25	1947.27	49.25	1913.01
16.25	1979.43	32.75	1946.60		

Table 2. Concentration of macrofossil remains per 10cm^3 sediment samples by mid point depth (cm).

mid point depth (cm)	*Betula* sp. seeds	*Salix* spp. seeds	*Sagittaria cuneata* seeds	*Drepanocladus* stems	*Sphagnum* spp. Leaves	*Potentilla palustris* seeds	*Carex* -lenticular type seeds	*Typha latifolia*	*Equisetum* spp.	*Chara* spp. oospores	*Myriophyllum exalabenses* leaves	*Myriophyllum exalabenses* seeds	*Potamogeton* spp. leaves	*P.pusillus* seeds	*P.graminus* seeds	*Cristatella* spp. statoblasts	*Cidora* spp. Carapace	*Daphnia* spp. ephippia	filamentous algae strands	flatworm eggs	fresh water sponge gemules	gastropode shells	ostracode shells	*Rhizopoda* tests
0.25	0	0	0	0	0	0	1	0	4	0	0	0	26	0	0	0	2	0	2	0	0	3	4	2
0.75	0	0	0	0	0	1	0	0	2	0	0	0	13	0	0	0	0	1	0	0	0	1	9	3
1.25	0	0	0	0	0	0	0	0	2	0	0	0	11	2	1	0	8	1	0	0	0	9	11	7
1.75	0	0	0	0	0	0	0	0	7	0	6	0	22	0	0	0	26	0	2	3	0	3	46	16
2.25	0	0	0	0	0	0	0	0	0	1	9	0	12	0	0	0	15	0	1	10	0	2	22	18
2.75	0	0	0	0	0	0	0	0	0	2	10	0	10	2	0	2	0	3	0	0	0	1	57	0
3.25	0	0	0	1	0	0	0	0	0	0	13	0	9	0	0	3	0	1	2	0	0	1	143	6
3.75	0	0	0	0	0	0	0	0	7	3	0	0	11	0	0	0	0	0	0	0	0	3	44	0
4.25	0	0	0	1	0	0	3	0	6	1	1	0	11	0	0	0	0	1	0	0	0	0	29	3
4.75	0	1	0	2	2	0	1	0	4	0	2	0	8	0	0	0	0	0	0	0	0	1	36	0
5.25	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	8	5	1	0	1	0	21	6
5.75	0	0	0	1	0	0	0	0	0	0	5	0	4	0	0	0	17	3	0	0	0	0	24	6
6.25	0	0	0	0	0	0	0	0	0	0	6	0	5	0	0	0	0	0	0	0	0	3	31	5
6.75	0	1	0	0	0	0	0	0	0	1	21	0	5	0	0	0	56	0	0	0	0	3	38	21
7.25	0	0	0	0	0	0	0	0	0	8	12	0	3	1	0	0	52	0	0	0	0	0	43	19
7.75	0	0	0	0	0	0	0	0	0	9	2	0	0	0	0	0	85	0	0	0	0	1	74	37
8.25	0	0	0	0	0	0	0	0	0	14	3	0	3	0	0	0	14	0	0	0	0	1	99	3
8.75	0	0	0	0	0	0	0	0	0	11	3	0	1	0	0	0	0	1	0	0	0	1	40	8
9.25	0	0	0	0	0	0	0	0	0	5	2	0	1	0	0	0	0	0	0	0	0	1	26	4
9.75	0	0	0	0	0	0	0	0	0	8	8	1	1	0	0	0	23	0	0	0	0	2	11	6
10.25	0	0	0	0	0	0	0	0	0	1	4	0	4	0	0	0	27	0	0	0	0	1	30	4
10.75	0	0	0	0	0	0	0	0	0	3	6	0	4	0	0	0	23	0	0	0	0	0	62	0
11.25	0	0	0	0	0	0	0	0	0	5	0	0	6	0	0	1	19	0	0	0	0	0	71	0
11.75	0	0	0	0	0	0	0	0	0	13	0	0	3	0	0	1	23	0	0	0	0	0	70	0
12.25	0	0	0	0	0	0	0	0	29	27	1	0	8	0	0	0	0	0	0	6	0	0	33	3
12.75	0	0	0	0	0	0	0	0	19	4	2	0	5	0	0	0	0	0	0	0	0	0	38	2
13.25	0	0	0	0	0	0	0	0	20	14	0	0	10	0	0	0	0	0	0	5	0	0	23	8
13.75	0	0	0	0	0	0	0	0	3	3	0	0	12	0	0	0	0	1	0	0	0	0	9	116
14.25	0	0	0	0	0	0	0	0	5	4	0	0	7	0	0	0	0	0	0	5	0	0	35	16
14.75	0	0	0	0	0	0	0	0	2	3	0	0	4	0	0	0	0	0	0	0	0	0	18	12
15.25	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	2	0	0	13	5
15.75	0	0	0	0	0	0	0	0	0	2	3	0	4	0	0	0	0	0	0	0	0	2	15	6
16.25	0	0	0	0	0	0	0	0	0	1	0	0	5	0	0	0	0	0	0	0	0	1	20	7
16.75	0	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	2	17	6

mid point depth (cm)	*Betula* sp. seeds	*Salix* spp. seeds	*Sagittaria cuneata* seeds	*Drepanocladus* stems	*Sphagnum* spp. Leaves	*Potentilla palustris* seeds	*Carex* -lenticular type seeds	*Typha latifolia*	*Equisetum* spp.	*Chara* spp. oospores	*Myriophyllum exalabenses* leaves	*Myriophyllum exalabenses* seeds	*Potamogeton* spp. leaves	*P.pusillus* seeds	*P.graminus* seeds	*Cristatella* spp. statoblasts	*Cidora* spp. Carapace	*Daphnia* spp. ephippia	filamentous algae strands	flatworm eggs	fresh water sponge gemules	gastropode shells	ostracode shells	Rhizopoda tests
17.25	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	12	0
17.75	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	5	3
18.25	0	0	0	0	0	0	0	0	4	2	0	0	3	0	0	0	2	0	0	0	0	1	74	34
18.75	0	0	0	0	0	0	0	0	18	5	0	0	17	0	0	0	37	0	0	1	0	0	96	18
19.25	0	0	0	0	0	0	0	0	13	3	0	0	0	0	0	0	8	0	0	0	0	4	70	15
19.75	0	0	0	0	0	0	0	0	4	2	0	0	0	0	0	0	0	0	0	0	0	0	12	0
20.25	0	2	0	5	0	0	0	0	6	0	0	0	2	0	0	0	0	0	0	0	0	0	9	0
20.75	0	1	0	3	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0
21.25	0	2	0	3	0	0	0	0	4	1	0	0	4	0	0	0	0	0	0	0	0	0	5	0
21.75	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	15	0	0	0	10	3
22.25	0	0	0	1	0	0	0	0	23	3	0	0	13	0	0	0	14	0	0	0	0	0	13	8
22.75	0	0	0	1	0	0	0	0	10	2	0	0	7	0	0	0	0	0	0	0	0	0	14	12
23.25	0	0	0	0	0	0	0	0	0	0	0	0	8	0	0	0	0	0	0	0	0	3	3	5
23.75	0	0	0	0	0	0	0	0	0	8	0	0	34	0	0	0	15	0	0	0	0	0	56	17
24.25	0	0	0	1	0	0	0	0	0	10	0	0	16	0	0	0	0	0	0	0	3	0	14	4
25.25	0	0	0		0	0	0	0	0	0	2	0	4	0	0	1	0	3	0	0	0	0	85	29
25.75	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	40	4
26.25	0	0	0	0	0	0	0	0	3	0	0	0	1	0	0	0	0	0	0	0	0	1	0	2
26.75	0	1	0	0	0	0	0	0	0	1	9	0	2	0	0	0	0	3	0	0	0	0	16	2
27.25	0	0	0	0	0	0	0	0	12	18	16	0	0	0	0	0	0	0	0	0	0	0	0	0
27.75	0	0	0	0	0	0	0	0	6	8	2	0	1	0	0	1	0	0	0	2	0	0	27	0
28.25	2	0	0	0	0	0	0	0	0	9	9	1	5	0	0	3	0	3	6	0	0	0	156	0
28.75	0	0	1	1	0	0	0	0	9	0	3	1	3	0	0	0	21	4	0	0	0	0	67	3
29.25	0	0	4	13	3	0	0	0	0	2	16	0	5	0	0	0	0	0	0	0	0	0	99	0
29.75	0	0	8	0	0	0	0	0	0	0	1	0	3	0	0	0	0	0	0	0	0	0	119	0
30.25	0	0	9	0	0	0	0	0	0	0	3	0	2	1	0	0	0	0	0	5	0	0	33	0
30.75	0	1	13	4	0	0	0	0	0	0	3	0	4	0	0	3	0	0	0	0	0	0	104	0
31.25	0	0	11	0	0	0	0	0	0	0	2	0	2	1	0	0	0	0	0	3	0	0	57	0
31.75	0	0	14	0	0	0	0	0	0	0	2	0	2	0	0	0	0	0	0	0	0	0	59	0
32.25	0	0	16	0	0	0	0	0	0	0	2	0	2	0	0	0	0	0	0	0	0	0	19	0
32.75	0	0	9	0	0	0	0	0	0	0	2	0	2	0	0	0	0	0	0	0	0	0	45	0

mid point depth (cm)	*Betula* sp. seeds	*Salix* spp. seeds	*Sagittaria cuneata* seeds	*Drepanocladus* stems	*Sphagnum* spp. Leaves	*Potentilla palustris* seeds	*Carex* -lenticular type seeds	*Typha latifolia*	*Equisetum* spp.	*Chara* spp. oospores	*Myriophyllum exalabenses* leaves	*Myriophyllum exalabenses* seeds	*Potamogeton* spp. leaves	*P.pusillus* seeds	*P.graminus* seeds	*Cristatella* spp. statoblasts	*Cidora* spp. Carapace	*Daphnia* spp. ephippia	filamentous algae strands	flatworm eggs	fresh water sponge gemules	gastropode shells	ostracode shells	Rhizopoda tests
33.75	0	0	1	0	0	0	0	0	0	0	1	2	5	0	0	0	0	0	0	0	0	0	92	0
34.25	1	0	3	0	0	0	0	0	6	1	3	0	0	0	0	0	0	0	0	0	0	1	48	0
34.75	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	29	0
35.25	0	1	2	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	35	0
35.75	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	23	0
36.25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0
36.75	0	0	0	0	0	0	0	0	8	0	1	1	0	0	0	0	0	0	0	0	0	0	28	0
37.25	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	17	0
37.75	0	0	1	0	0	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	28	0
38.25	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14	0
38.75	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
39.25	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	19	0
39.75	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0
40.25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	0
40.75	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	43	0
41.25	0	0	0	0	0	0	0	0	3	1	2	0	0	0	0	0	0	0	0	0	0	0	37	0
41.75	0	0	0	0	0	0	0	0	12	11	4	1	0	0	0	0	0	0	0	0	0	0	85	0
42.25	0	0	0	0	0	0	0	0	15	15	4	0	0	0	0	0	0	0	0	0	0	0	71	0
42.75	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	95	0
43.25	0	0	0	0	0	0	0	0	22	80	3	0	0	0	0	1	0	0	0	0	0	0	340	0
43.75	0	0	0	0	0	0	0	0	24	38	0	0	0	0	0	0	0	2	0	0	0	0	204	0
44.25	0	0	0	0	0	0	0	0	17	102	4	0	0	0	0	0	0	0	0	0	0	0	102	0
44.75	0	0	0	0	0	0	0	0	10	10	0	0	0	0	0	0	0	0	0	0	0	0	33	0
45.25	0	0	0	0	0	0	0	0	2	6	0	0	0	0	0	0	0	0	0	0	0	0	69	0
45.75	0	0	0	0	0	0	0	0	15	6	1	0	0	0	0	0	0	0	0	0	0	0	137	0
46.25	0	0	0	0	0	0	0	0	0	3	5	0	0	1	0	0	0	0	0	0	0	0	125	4
46.75	0	0	0	0	0	0	0	0	0	2	6	0	0	0	0	0	0	0	0	0	0	0	67	0
47.75	0	0	0	0	0	0	0	0	0	2	2	0	0	0	0	0	0	0	0	0	0	0	27	0
48.25	0	0	0	0	0	0	0	0	2	7	8	3	0	0	0	0	0	0	0	0	0	0	0	0
48.75	0	0	0	0	0	0	0	0	0	1	9	4	0	0	0	0	0	0	0	0	0	0	182	0