CHEMOSTRATIGRAPHIC INVESTIGATIONS OF BEAVER WETLANDS ALONG JARRETT CREEK, NORTH CAROLINA, USA

by

CHRISTOPHER SEAN CAMERON

(Under the Direction of DAVID S. LEIGH)

ABSTRACT

This project examines differences in carbon and nitrogen soil geochemistry of two wetlands along Jarrett Creek, located in the Nantahala River Valley of western North Carolina, to characterize differences associated with the activity of North American beaver (*Castor canadensis*). Total carbon and nitrogen composition of soil samples from the beaver wetland, Jarrett Creek Meadows (JCM), show statistically higher values than those of the non-beaver wetland, Jarrett Creek Bog (JCB). Elevation of carbon and nitrogen content at JCM appears to reflect maintenance of the wetland by beaver. Enrichment of stable nitrogen (^{15}N) at JCB compared to JCM suggests differences in denitrification rates at these two wetlands as a result of beaver activity. Soil core data shows these dissimilarities persist with depth. These distinctions in the carbon and nitrogen soil geochemistry provide criteria to examine other Southern Blue Ridge wetlands to identify beaver activity within geomorphic and stratigraphic framework.

INDEX WORDS: Wetlands, Geochemistry, Stratigraphy, North American Beaver

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A.B., The University of Georgia, 2012

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The University of Georgia
August 2015

DEDICATION

I would like to dedicate this manuscript to all the friends and family who have journeyed with me throughout this process. I could not have completed it without your love and support along the way.

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CHAPTER 1

INTRODUCTION

The North American beaver (*Castor canadensis*) occurs in a wide range of environmental settings and can be found in all of the contiguous United States, Alaska, and Canada. It is widely accepted that modern beaver populations are only a fraction of what they were in pre-European contact times (Butler, 1995). Estimations of pre-contact beaver population in North America range from 60 to 400 million individuals, placing land cover by beaver wetlands on the order of tens of thousands of square miles (Naiman et al., 1988; Butler, 1995). The prevalence of beaver across North America is indicated by numerous historical accounts of their occurrence (Gurnell, 1998). Through its life habit of dam and lodge construction, the beaver fundamentally alters its surroundings on several scales of processes, time, and diversity (Burchsted et al., 2010).

Previous studies have synthesized the ecological role of the North American beaver and its function in landscape evolution (Naiman et al., 1988; Wright et al., 2002; Butler and Malanson, 2005; Westbrook et al., 2006; Burchsted et al., 2010; Little et al., 2012). Particular attention has been placed on the examinations of landscape heterogeneity and ecological diversity associated with beaver activity (Johnston and Naiman, 1987; Rosell et al., 2005; Anderson and Rosemond, 2010; Corenblit et al., 2011; Burchsted and Daniels, 2013). This introduction of new wetland environments creates opportunities for habitation by unique flora and fauna and serves as a primary facilitator for many endemic species (Burchsted et al., 2010).

Obstruction of river and stream channels by dams is the primary mechanism of fluvial geomorphic alteration (Butler, 1989; Westbrook et al., 2006; Pollock et al., 2007; Nyssen et al., 2011; Levine and Meyer, 2014). Beaver dams are built from local materials including wood, vegetation, sediment, soil, stones, and cobbles (Butler, 1995; Burchsted and Daniels, 2013). Dams vary in height but are usually in the range of a few meters tall (Ives, 1942; McComb et al., 1990; Persico and Meyer, 2009; Burchsted and Daniels, 2013). Dams are typically concave upstream structures and can occur as individual or concentric features that generate a laterally-stepped complex (Butler, 1995; Butler and Malanson, 2005). These structures can be situated either as valley floor environments or in-channel ones (Butler, 1995; Burchsted and Daniels, 2013). Individual dams operate over the course of years to decades depending on access to food and construction materials (Persico and Meyer, 2009; Burchsted and Daniels, 2013).

Beaver dams typically remain in place as the stream aggrades to its new equilibrium (Burchsted and Daniels, 2013). Dam constructions that span valley-floors are documented triggers for channel avulsion and result in the creation of multiple, downstream flow-paths (Tornqvist and Bridge, 2002; Burchsted et al., 2010). Eventually, dams are abandoned as conditions become unfavorable for beaver upkeep (Naiman et al., 1988; Persico and Meyer, 2009). Abandonment corresponds to a decline in base level, previously elevated by the active dam, as channels incise into the trapped sediments behind the dam (Butler and Malanson, 2005; Burchsted and Daniels, 2013). Resultant channels have higher width-depth ratios and continue to change as the abandoned dam proceeds to leak (Burchsted and Daniels, 2013). Dam failure may also result in a chain of events that produces unique depositional features of braided channel deposits with a lateral sequence of impoundments and meadows cut by multithread channels (Butler, 1989; Butler and Malanson, 2005; Green and Westbrook, 2009; Burchsted et al., 2010).

Active dams help to mitigate erosion processes (Butler, 1989). Other effects of dam construction include upstream aggradation and downstream degradation processes due to respective changes in base level conditions (Pollock et al., 2007; Burchsted and Daniels, 2013). Aggradation and incision processes related to beaver dams have been shown to affect surface level changes as a five-fold magnification of elevation (Pollock et al., 2007). The geographic extent over which these processes occur is a function of beaver occupation history and activity (Butler and Malanson, 1995; Persico and Meyer, 2009; Burchsted and Daniels, 2013). As the radius of habitat maintenance increases, impact is laterally extended from the immediate channel area (Westbrook et al., 2006; Corenblit et al., 2011; Burchsted and Daniels, 2013).

Dams cause sediment aggradation behind them, leading to the formation of ponds. These ponds serve a range of geomorphic and ecological functions. Ponds are an expression of changes in bankfull morphology associated with dam construction in such a way that, once ponds appear on the landscape, bankfull conditions are redefined as the lateral extent to which water flows across ponds (Burchsted and Daniels, 2013). Some effects of ponds on the fluvial system include increased evaporation and elevation of the groundwater table (Butler, 1989; Burchsted and Daniels, 2013). In-depth investigation of ponds, such as Butler and Malanson's (1995) study showed that pond sediments also exhibit unique properties of stratification, color, and subfossil material. Pond sediments are spatially heterogeneous, but this quality fades with increased occupation and activity (Butler and Malanson, 1995; Butler, 2012).

Beaver meadows form either from abandonment of active dams or from the failure of dams. In the case of habitat abandonment, beaver ponds fill-in with trapped sediment over time while the dam remains in place (Ives, 1942; Butler and Malanson, 1995; Polvi and Wohl, 2011; Burchsted and Daniels, 2013). The trapped, stabilized sediments eventually support vegetation growth and willow establishment (Cooper et al., 2006; Polvi and Wohl, 2011; Burchsted and Daniels, 2013). Remaining dams can also become overgrown with vegetation in this fashion (Burchsted et al., 2010). Meadow formation can occur in as few as 15 years (Ruedemann and Schoonmaker, 1938).

Inquiry concerning the North American beaver as a landscape engineer began with early investigations like those of Ruedemann and Schoonmaker (1938) and Ives (1942). Subsequent research has also taken into account geology, geomorphology, and landform dynamics in examination of beaver activity at reach-specific and valley-wide scale processes (Polvi and Wohl, 2012; Westbrook et al., 2011). These investigations have served to emphasize the importance of beaver activity in their respective fluvial systems and how they can drive alluvial processes on a valley-dynamic scale (Westbrook et al., 2011; Little et al., 2012).

The majority of geomorphic studies concerning beaver activity have focused on the northern, midwestern, and central United States with little attention on the southern Appalachians. Few studies have examined the effects of beaver activity on fluvial systems in the southern Appalachians and those that do so are restricted to the Piedmont (Butler, 1989; Townsend and Butler, 1996; Meentemeyer et al., 1998). Impacts of beaver activity have been investigated with remote sensing, hydrogeomorphology, and sedimentology techniques (Gurnell, 1998; Jakes et al., 2007; Butler and Malanson, 1995;

Polvi and Wohl, 2011). Research has shown that sediment packages associated with beaver activity are stratigraphically distinct from their surroundings (Persico and Meyer, 2009; Kramer et al., 2012; Levine and Meyer, 2014). Previous stratigraphic investigations have focused on location and identification of beaver activity, with little emphasis on distinguishing these sediments from other, existing wetland types (Butler and Malanson, 1995; Persico and Meyer, 2009; Kramer et al., 2012; Johnston, 2014).

The goal of this project was to describe geochemical properties of sediments associated with beaver and non-beaver wetlands to identify characteristics associated with beaver activity in the southeastern United States. This was done through analyses of carbon and nitrogen chemistry on both surface sediment samples and long cores obtained from wetlands along a Southern Blue Ridge stream in western North Carolina. A secondary goal of this study was to provide a stratigraphic framework for recognition of beaver activity in past fluvial environments and to potentially distinguish beaver and non-beaver wetlands from one another. This was accomplished by quantifying the observed differences in carbon and nitrogen compositions to develop criteria for future investigations of Southern Blue Ridge wetlands.

1. Study Area

Jarrett Creek is a tributary to the Nantahala River valley in western Macon County, North Carolina. It is situated within the southern extent of the Blue Ridge physiographic region. Three study sites were selected along Jarrett Creek, approximately 13 miles west of Franklin, North Carolina (Figure 1). This study area was selected based on the proximity of two, distinctly different wetlands previously identified by state survey (Schwartzman, 2010) and ease of access within the Nantahala National Forest.

Jarrett Creek Meadows (JCM) is the largest of the three sites and is an actively maintained Piedmont/Mountain Semipermanent Impoundment, according to state reports (Schwartzman, 2010). This wetland represents a complex of multiple meadows and ponds formed by beaver dam construction along this section of Jarrett Creek where the slope is greatly decreased. The multiple ponds located within JCM are the source of the Jarrett Creek Ponds (JCP) samples. Vegetation in this wetland is dominated by abundant grasses, rare flowers, and an open canopy (Schwartzman, 2010). Review of historic aerial photography for Jarrett Creek suggests beaver colonized the area around 25 years ago with the formation of the meadows. Prior to beaver arrival, JCM was described as a hemlock cove with abundant rhododendron (Schwartzman, pers. comm., 2013).

Jarret Creek Bog (JCB) is classified as a Southern Appalachian Bog by state survey (Schwartzman, 2010). It is located approximately three miles downstream from JCM, and there is no documentation of beaver activity at this wetland. Review of aerial photography suggests that JCB predates beaver activity along Jarrett Creek. The bog is noted as home to a thickly vegetated community of shrubs and sedges with *Sphagnum* moss dominating the surface-cover (Schwartzman, 2010).

Jarrett Creek Floodplain (JCF) is situated between Jarrett Creek Bog and Jarrett Creek Meadows. It is the only portion of Jarrett Creek between the meadows and bog where the gradient remains low enough to allow floodplain development. The vegetation of this site is different from that of the nearby wetlands with abundant hardwood trees, little surface vegetation cover, and rhododendron, which is thickest along the edges of JCF.

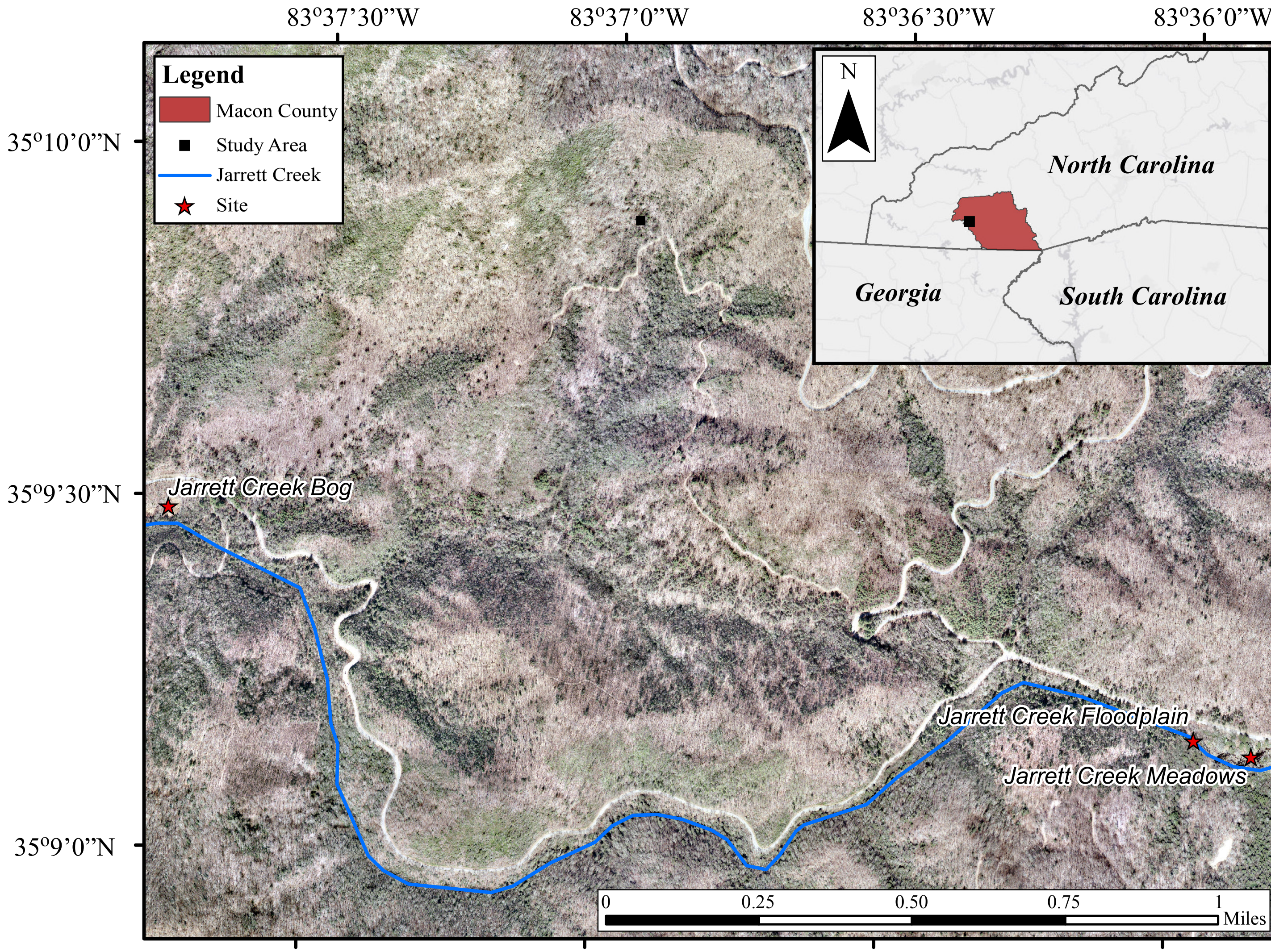

83°37'30"W
83°37'0"W
83°36'30"W
83°36'0"W
35°10'0"N
35°9'30"N
35°9'0"N
Legend
Macon County
Study Area
Jarrett Creek
Site
N
North Carolina
Georgia
South Carolina
Jarrett Creek Bog
Jarrett Creek Floodplain
Jarrett Creek Meadows
0
0.25
0.50
0.75
1
Miles

Figure 1: Study Area Map

CHAPTER 2

GEOCHEMICAL AND STRATIGRAPHIC INVESTIGATIONS

1. Methods

1.1 *Field Methods*

Data were collected at all sites from July to September 2014. Sediment samples were obtained using a hand-driven bucket auger (at JCB, JCF, and JCM) and a Russian corer (for JCP samples). These samples were taken along transects at 10-meter intervals. Each sample location was referenced in the field using a handheld GPS (Appendix A). Thirty locations at each site were selected to obtain the uppermost thirty centimeters of sediment using the appropriate coring device. At every location, vegetation cover or leaf litter was removed to expose the inorganic sediment surface. Each of these thirty samples was sub-sectioned into ten centimeter increments, corresponding to intervals of 0 to 10, 10 to 20, and 20 to 30 centimeters below the ground surface. These subsamples were bagged and labeled in the field according to depth. Across the JCB, JCF, JCM, and JCP sample sets a total of 356 (owing to three shallow profiles in JCB and one in JCM) samples were collected in this way. At each of the thirty sample locations, excluding the JCP collections, a tile probe was used to estimate depth to rock or refusal (DTR). As samples were collected, they were placed on ice and later refrigerated until lab analysis to minimize the oxidation of organic material.

A continuous core of 10 centimeter sample intervals extending was taken using a hand-driven auger at each of the sites (JCB, JCF, and JCM). The location to take these cores was determined by the deepest DTR values obtained from each set of thirty terrestrial samples. These locations roughly corresponded to the center of each sampling area. A total of 48 samples were collected from all three cores. Cores taken from both JCB and JCM were approximately one meter long, while the JCF core was 1.6 meters in length.

1.2 *Laboratory Methods*

Organic matter content in all samples was estimated using loss-on-ignition (LOI). Samples were first dried in a laboratory oven at 105^{o}C to remove excess moisture. Samples were then milled using a mortar and pestle until homogenized and passed through a two millimeter sieve. The mass of sediment in each sample greater than two millimeters was recorded and cataloged separately. Sediment that passed through the two millimeter sieve was used in LOI and subsequent laboratory analyses. Samples were combusted in a muffle furnace at 550^{o}C for approximately four hours (Heiri et al., 2001). This procedure was followed for all 10 centimeter intervals of every surface location and long cores, totaling 402 individual samples.

Carbon and nitrogen geochemical analyses were performed at the UGA Analytical Chemistry Laboratory on the 10 to 20 centimeter interval from each sample at all sites. The 10 to 20 centimeter interval was chosen for geochemical testing since it was below the rooting zone and recovered at all sample locations. Additionally, carbon and nitrogen analyses were performed on all samples from the long cores obtained at JCB, JCF, and JCM. The less than two millimeter sediment fraction of samples previously separated for LOI were further homogenized in a standard ball mill for two minutes each. Samples were then placed in laboratory-issue tin capsules and sediments weighed to a minimum of

20 milligrams. Analysis for stable nitrogen ($\delta^{15}N$), stable carbon ($\delta^{13}C$), total nitrogen, and total carbon in 168 samples was performed by a Carlo Erba NA1500 elemental analyzer-isotope ratio mass spectrometer.

1.3 *Data Analysis and Statistical Methods*

Data from loss-on-ignition, carbon, and nitrogen geochemical analyses were compiled with field measurements (color, depth to refusal, latitude, and longitude) in Microsoft Excel. LOI measurements were recorded both in percent and mass (g) values. Stable isotope data were recorded as per mil values; in the case of $\delta^{15}N$ versus air and $\delta^{13}C$ versus the Pee Dee belemnite (PDB) standard. Total nitrogen and total carbon data were expressed as percent values. The ratio of carbon to nitrogen (C:N) was calculated using the total carbon and total nitrogen values. The program R was used to conduct all statistical testing and multivariate analyses.

Estimation of median LOI values across all sites for each depth interval was computed using the Mann-Whitney U test due to the non-normal distributions of LOI datasets. The 95 percent confidence intervals of all median estimates were also constructed for JCB, JCF, JCM, and JCP. Both median values and associated confidence intervals were calculated within the wilcox.test function of R, which employs standard algorithms to construct these estimates of non-parametric data (Bauer, 1972; Hollander and Wolfe, 1973).

Interpolated surface maps of JCB, JCF, and JCM for all geochemical variables were constructed in ArcMap 10.1 to visualize spatial patterns. Calculation of individual surfaces was done using the inverse distance weighted (IDW) tool in the ArcMap Spatial

Analyst toolbox. The interpolation method used by IDW is structured so that its maximum and minimum values cannot be above or below those of input data (Watson and Philip, 1985). Additionally, estimates (and 95 percent confidence intervals) of average $\delta^{15}N$, $\delta^{13}C$, total nitrogen, total carbon, and C:N were computed in R following the same methodology as LOI calculations.

To reduce dimensionality and identify possible groupings of data, an ordination of geochemical variables was made by nonmetric multidimensional scaling (NMDS). This ordination technique was chosen since it makes no assumptions about normality of data and is considered a robust, non-parametric technique (Minchin, 1987). The NMDS was computed in R using the metaMDS function of the vegan package. The metaMDS function is a method that calculates a dissimilarity matrix of input data (based on the specified distance calculation method), scales the resultant dissimilarities to axis-scores, and orients axes such that maximum variance occurs along the primary axis (NMDS1). Examination of calculated stress with increasing dimensionality was done to determine the appropriate number of dimensions to specify in the metaMDS function. Review of the stress-dimensionality scree plot associated with these data suggested the use of two dimensions in the final NMDS. The NMDS inputs of this study were $\delta^{15}N$, $\delta^{13}C$, total nitrogen, total carbon, and C:N values. Because these were environmentally-distributed variables, the euclidean distance calculation was specified in metaMDS (Mardia et al., 1979).

Evaluation of sample groupings from NMDS output was conducted using a discriminant function analysis (DFA). This was done in R using the lda function of the MASS package. This function performs a linear discriminant analysis of the input data matrix along a specified grouping variable. For this study, the input data matrix was the NMDS axis-scores (NMDS1, NMDS2) and the grouping variable was site ID (JCB, JCF, JCM, or JCP). The DFA results were evaluated by percent successful identification of sample by site. A second round of DFA was performed on the geochemical variables with the grouping variable as site ID.

2. Results

2.1 *Loss-On-Ignition*

The percent values of LOI for each interval at all sample locations was used to create profiles reflecting trends with depth that are referenced to the average trend at each site. The resulting profiles were organized by site for JCB (Figure 2), JCF (Figure 3), JCM (Figure 4), and JCP (Figure 5). The JCB profiles show decreasing percent LOI with depth. Similarly, the form of the JCF profiles is negative linear, with the exception of samples JCF 20 and JCF 28 (Figure 3). At both JCB and JCF, the majority of individual profiles approximate the average rate of LOI with depth. JCM and JCP profiles show much more variability in LOI-depth relationships with respect to percent value and profile form. Samples such as JCM 18 and JCM 22 exhibit sharp increases in LOI with depth (Figure 4). Other profiles, like JCP 1 and JCP 2, show marked deviations from the average rate of percent LOI at the site (Figure 5).

A comparison of the median and 95% confidence intervals of percent LOI for the 0 to 10, 10 to 20, and 20 to 30 centimeter intervals across sites is given in Figure 6. At all depths, the JCM site shows statistically higher and unique values for percent LOI compared to JCB, JCF, or JCP. While the LOI for JCB and JCF is similar (Figure 6A, B, and C), differences in percent LOI show that JCB has higher overall values at all depth intervals (Figure 6A, B, and C). Excluding the 0 to 10 centimeter interval, JCP has intermediate LOI values similar to JCB.

Profiles of percent LOI with depth for the JCB, JCF, and JCM long-cores are given in Figure 7. The JCB and JCF profiles show lower values of percent LOI compared to JCM but show a roughly linear relationship with depth (Figure 7A and B). The JCM core shows both greater percent LOI values and variability with depth (Figure 7C). The upper 30 centimeters of all three cores is consistent with the general trends observed in shallow LOI profiles at each site. Differences in percent LOI across these three profiles continues down-core and they do not converge until approximately 90 centimeters depth.

2.2 *Geochemistry*

The visualization of carbon and nitrogen results are presented as surface raster maps for JCB (Figure 8), JCF (Figure 9), and JCM (Figure 10). At all three sites, values for total percent carbon and total percent nitrogen are spatially coincident. Additionally, more positive values for $\delta^{13}C$ and $\delta^{15}N$ are spatially correlated to one another. The percent carbon and nitrogen values appear inversely related to stable isotopic measurements such that high total carbon (or nitrogen) values correspond to depleted ^{13}C (or ^{15}N) values (Figure 8, 9, 10). These observed spatial correlations are supported by estimations of Spearman's ρ for each variable (Table 1). The JCP samples show the greatest range in both $\delta^{15}N$ and C:N values (Figure 11). However, the JCM samples show the most variability in total nitrogen (Figure 11A). JCB and JCF samples group tightly by comparison and show generally more positive $\delta^{15}N$ values (Figure 11A, B, and D).

Average values and associated confidence intervals for carbon and nitrogen measurements show unique values corresponding to individual sites (Figure 12). Comparison of stable isotopic values across sites shows that JCF possesses the most positive $\delta^{13}C$ scores (Figure 12A) and JCB exhibits the most positive $\delta^{15}N$ values (Figure 12B). Statistically, the JCP samples again show the greatest variability in $\delta^{15}N$ values (Figure 12B). Both total percent carbon and nitrogen values are the highest in JCM

(Figure 12C and D). Comparison of the C:N for all sites shows that JCP possesses highest values (Figure 12E).

Profiles of all geochemical variables in the JCB, JCF, and JCM long-cores (Figure 13) shows convergence of values around 90 centimeters. The exception to this trend is the $\delta^{15}N$ profile for all three sites which possesses a unique trend with depth at JCB, JCF, and JCM (Figure 13B). Trends in $\delta^{13}C$ show increases with depth at all sites (Figure 13A) with JCB peaking around 60 centimeters. Both total nitrogen and carbon composition decrease in all cores with depth (Figure 13C and D). The C:N profiles for JCM and JCB remain close to one another until 60 centimeters (Figure 13E) after which they deviate such that JCM increases with depth and JCB begins to decrease back to surface-level values. The C:N of the JCF core shows higher deviations in values with depth.

2.3 *Multivariate Analysis*

The output of the NMDS shows grouping of samples based on site (Figure 14). The most scatter in this output is with the JCP sample group along both the NMDS1 and NMDS2 axes. Samples corresponding to JCB and JCF score positively along NMDS1 with few exceptions. Conversely, samples from JCM and JCP generally score negatively along the NMDS1 axis. The JCP samples have the most positive scores along NMDS2 but some JCF samples possess values of similar magnitude.

Evaluation of NMDS groupings using the axis scores in DFA shows that the JCF and JCP groups have the greatest spread along linear discriminants (Figure 15). The grouping of JCB and JCF along linear discriminants is almost identical (Figure 15). The majority of misclassification occurred distinguishing JCB and JCF from one another for the five primary geochemical variables (total carbon, total nitrogen, $\delta^{13}C$, $\delta^{15}N$ and C:N) in DFA (Figure 16). Successful site identification based on these five variables was 80 percent with the most frequent misclassification occurring at JCF and JCP (Table 2). The DFA results of all geochemical variables shows grouping of values separated by site ID (Table 2,3). The sites scoring negatively along linear discriminants are both the beaver wetland sets JCP and JCM (Figure 16). Conversely, both JCF and JCB score positively along linear discriminants with some overlap between JCM and JCF (Figure 16). Comparison of discriminant score ranges shows considerable overlap among non-beaver and beaver sample points rather than between the beaver and non-beaver sample sites (Figure 16). The coefficients of linear discriminates for all input measurements suggests the following equation to determine beaver activity at sites based on C, $\delta^{13}C$, N, $\delta^{15}N$, and C:N values:

(*Equation 1*) $$Site = 0.15\mathbf{C} - 0.58\boldsymbol{\delta}^{\mathbf{13}}\mathbf{C} - 5.14\mathbf{N} + 0.31\boldsymbol{\delta}^{\mathbf{15}}\mathbf{N} - 0.34(\mathbf{C}:\mathbf{N})$$

Where:

C= total carbon, expressed as %

$\boldsymbol{\delta}^{\mathbf{13}}$C= ^{13}C composition, expressed in per mil

N= total nitrogen, expressed as %

$\boldsymbol{\delta}^{\mathbf{15}}$N= ^{15}N composition, expressed in per mil

C:N= the ratio of total carbon to nitrogen

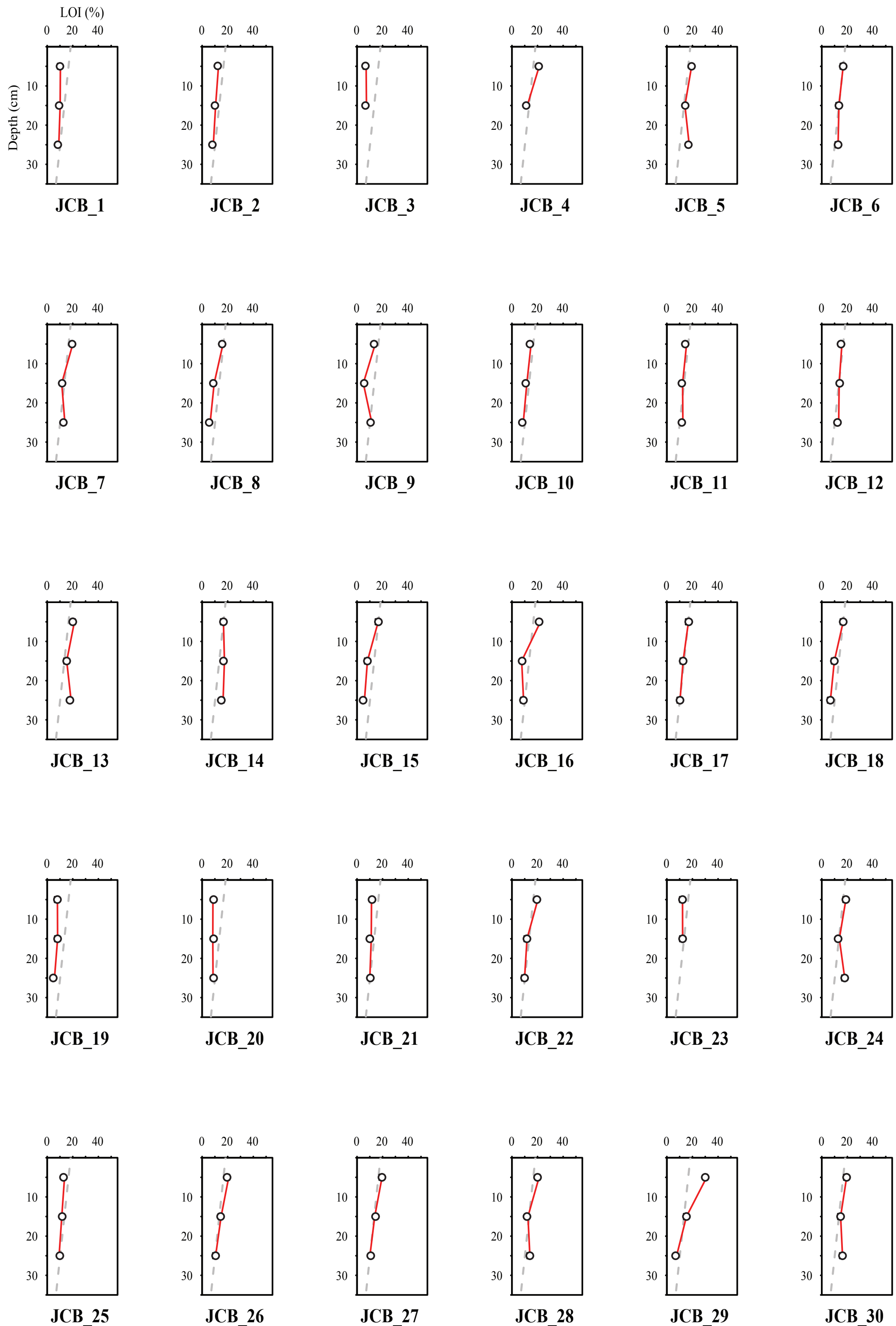

LOI (%)
Depth (cm)
0 20 40
10 20 30
JCB_1
JCB_2
JCB_3
JCB_4
JCB_5
JCB_6
JCB_7
JCB_8
JCB_9
JCB_10
JCB_11
JCB_12
JCB_13
JCB_14
JCB_15
JCB_16
JCB_17
JCB_18
JCB_19
JCB_20
JCB_21
JCB_22
JCB_23
JCB_24
JCB_25
JCB_26
JCB_27
JCB_28
JCB_29
JCB_30

Figure 2: Loss-On-Ignition (LOI) profiles for each sample location at Jarrett Creek Bog. The dashed line plots the average profile of the site calculated from the sum of values at each depth interval divided by the total number of samples.

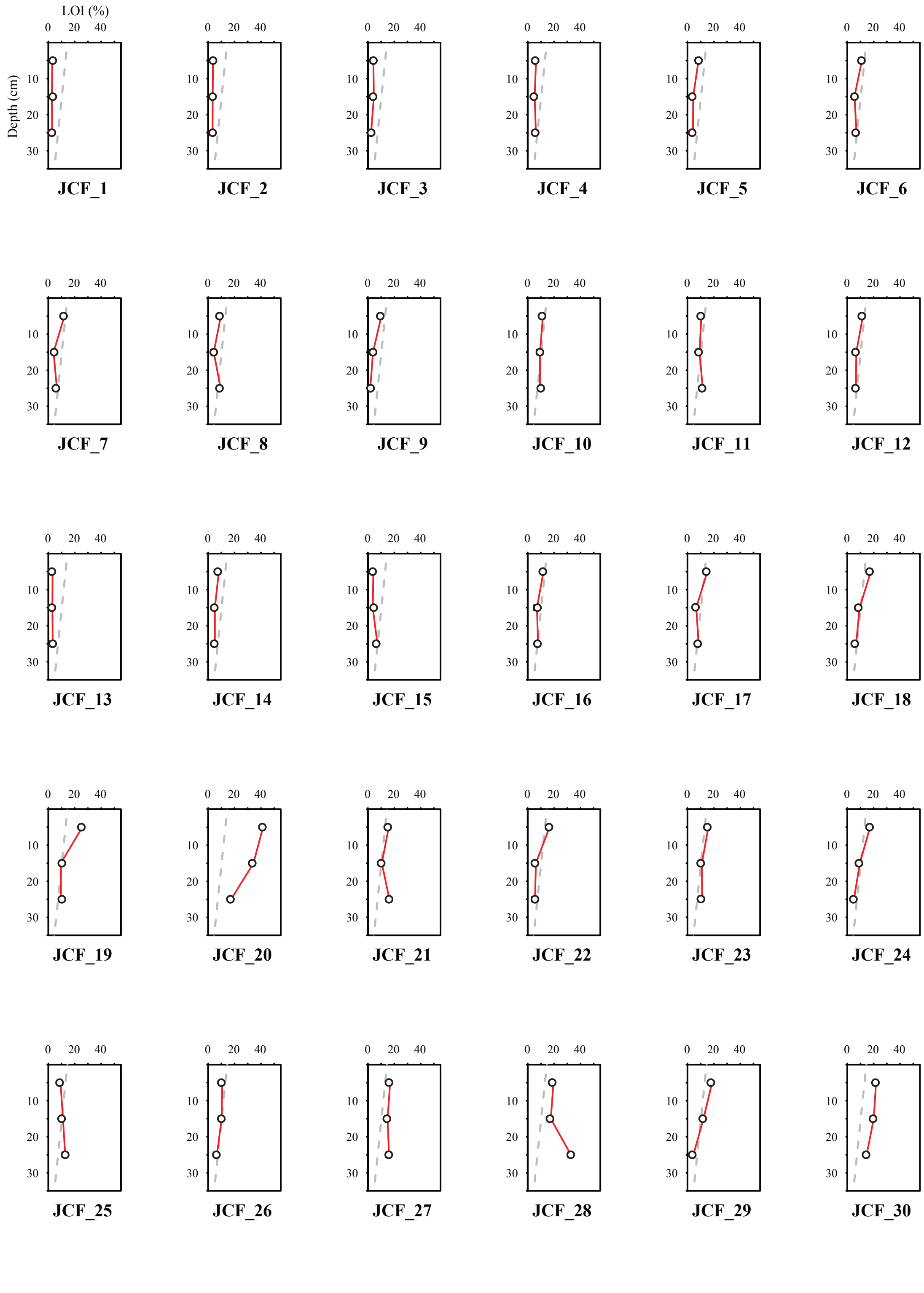

LOI (%)
Depth (cm)
0 20 40
10 20 30
JCF_1
JCF_2
JCF_3
JCF_4
JCF_5
JCF_6
JCF_7
JCF_8
JCF_9
JCF_10
JCF_11
JCF_12
JCF_13
JCF_14
JCF_15
JCF_16
JCF_17
JCF_18
JCF_19
JCF_20
JCF_21
JCF_22
JCF_23
JCF_24
JCF_25
JCF_26
JCF_27
JCF_28
JCF_29
JCF_30

Figure 3: Loss-On-Ignition (LOI) profiles for each sample location at Jarrett Creek Floodplain. The dashed line plots the average profile of the site calculated from the sum of values at each depth interval divided by the total number of samples.

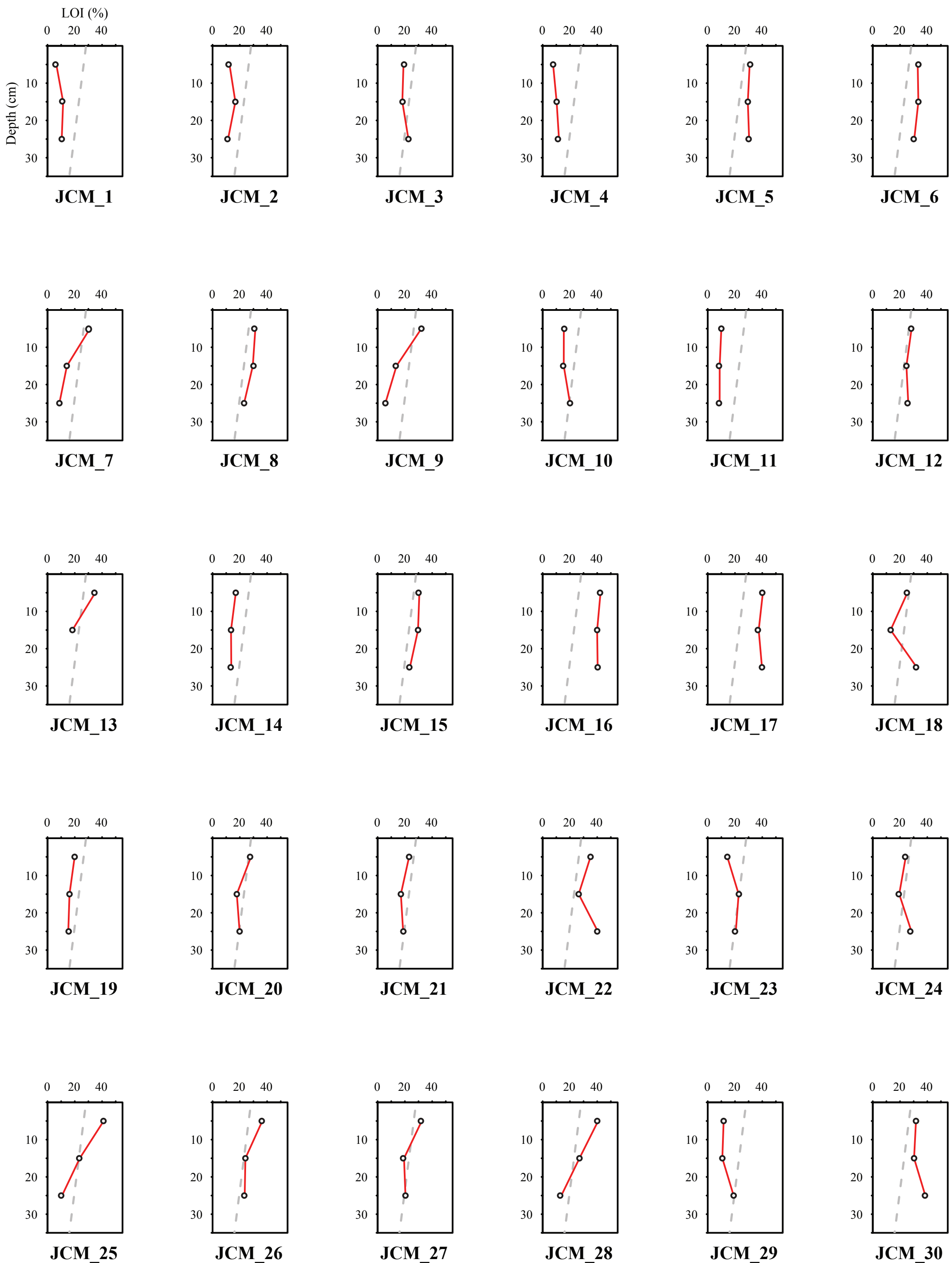

LOI (%)
Depth (cm)
JCM_1
JCM_2
JCM_3
JCM_4
JCM_5
JCM_6
JCM_7
JCM_8
JCM_9
JCM_10
JCM_11
JCM_12
JCM_13
JCM_14
JCM_15
JCM_16
JCM_17
JCM_18
JCM_19
JCM_20
JCM_21
JCM_22
JCM_23
JCM_24
JCM_25
JCM_26
JCM_27
JCM_28
JCM_29
JCM_30

Figure 4: Loss-On-Ignition (LOI) profiles for each sample location at Jarrett Creek Meadows. The dashed line plots the average profile of the site calculated from the sum of values at each depth interval divided by the total number of samples.

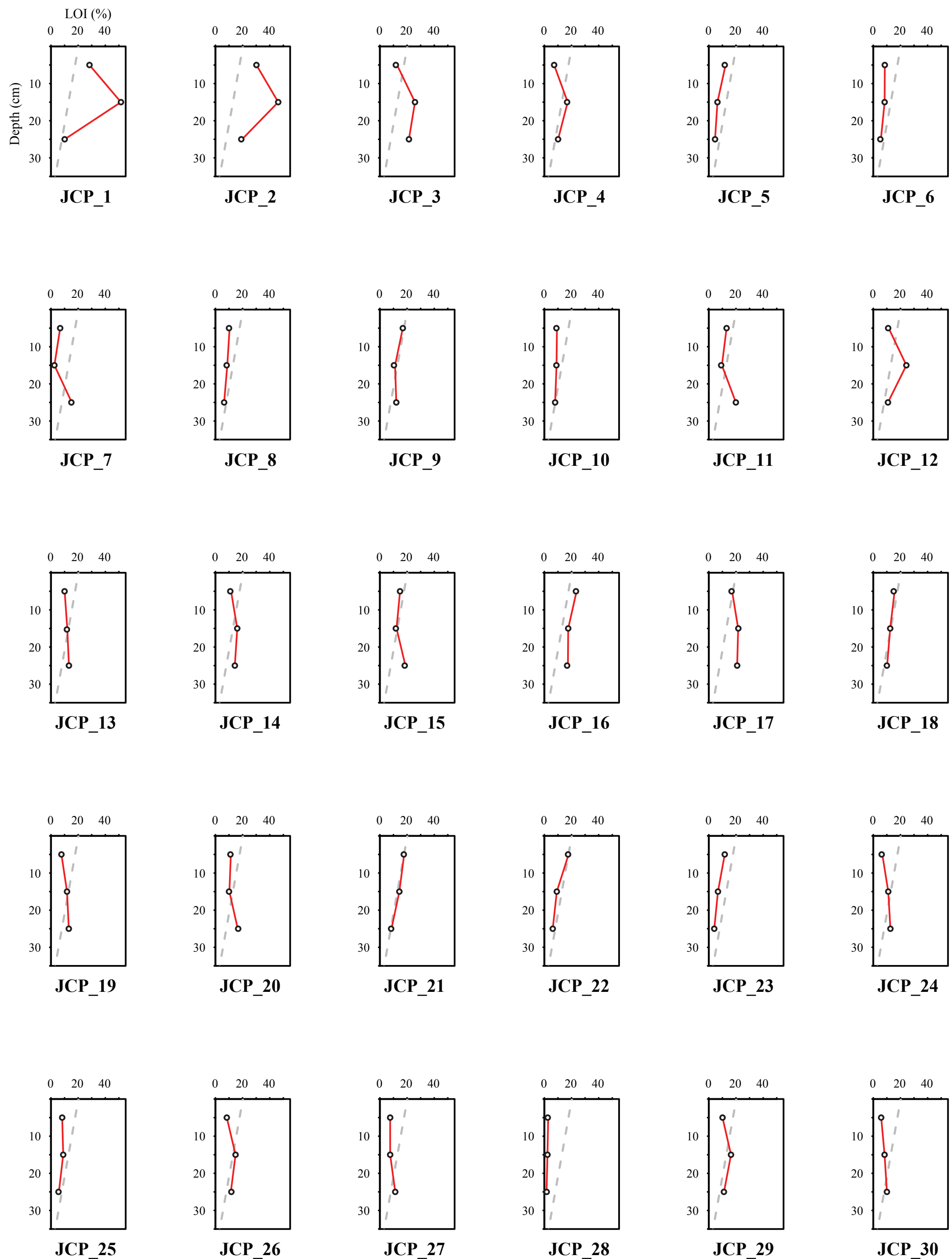

LOI (%)
Depth (cm)
0 20 40
10 20 30
JCP_1
JCP_2
JCP_3
JCP_4
JCP_5
JCP_6
JCP_7
JCP_8
JCP_9
JCP_10
JCP_11
JCP_12
JCP_13
JCP_14
JCP_15
JCP_16
JCP_17
JCP_18
JCP_19
JCP_20
JCP_21
JCP_22
JCP_23
JCP_24
JCP_25
JCP_26
JCP_27
JCP_28
JCP_29
JCP_30

Figure 5: Loss-On-Ignition (LOI) profiles for each sample location at Jarrett Creek Ponds. The dashed line plots the average profile of the site calculated from the sum of values at each depth interval divided by the total number of samples.

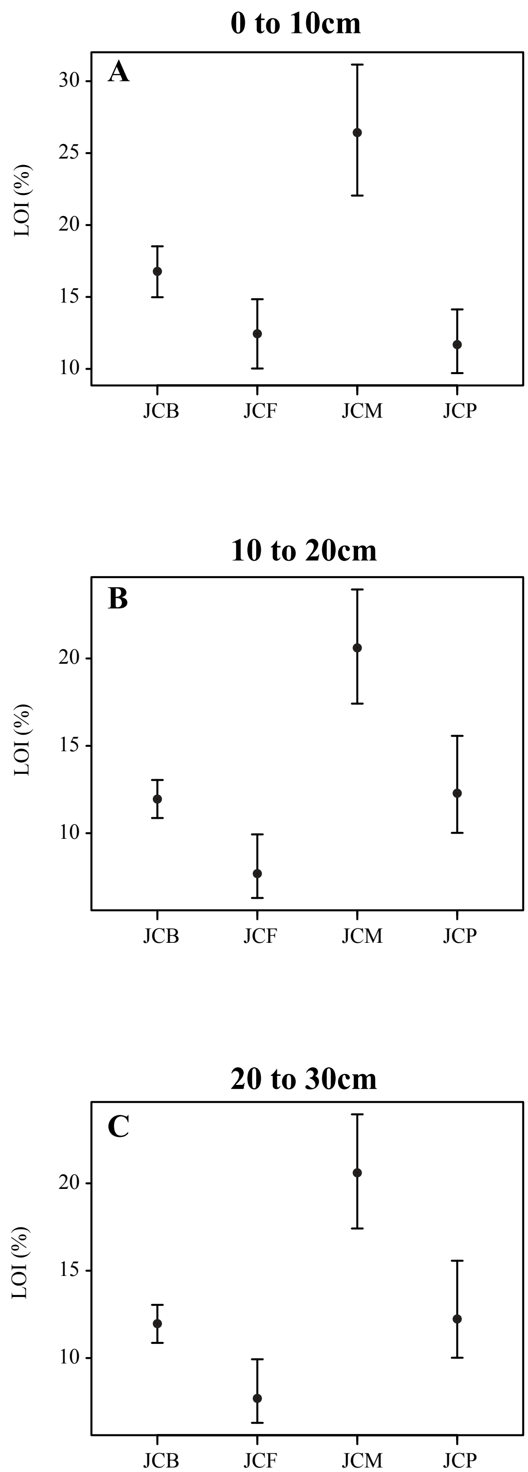

0 to 10cm
A
LOI (%)
30
25
20
15
10
JCB
JCF
JCM
JCP
10 to 20cm
B
LOI (%)
20
15
10
JCB
JCF
JCM
JCP
20 to 30cm
C
LOI (%)
20
15
10
JCB
JCF
JCM
JCP

Figure 6: Median LOI values (%) for each depth interval across all sites: **(A)** 0-10cm, **(B)** 10-20cm, **(C)** 20-30cm. Brackets show the 95% confidence interval of each estimate.

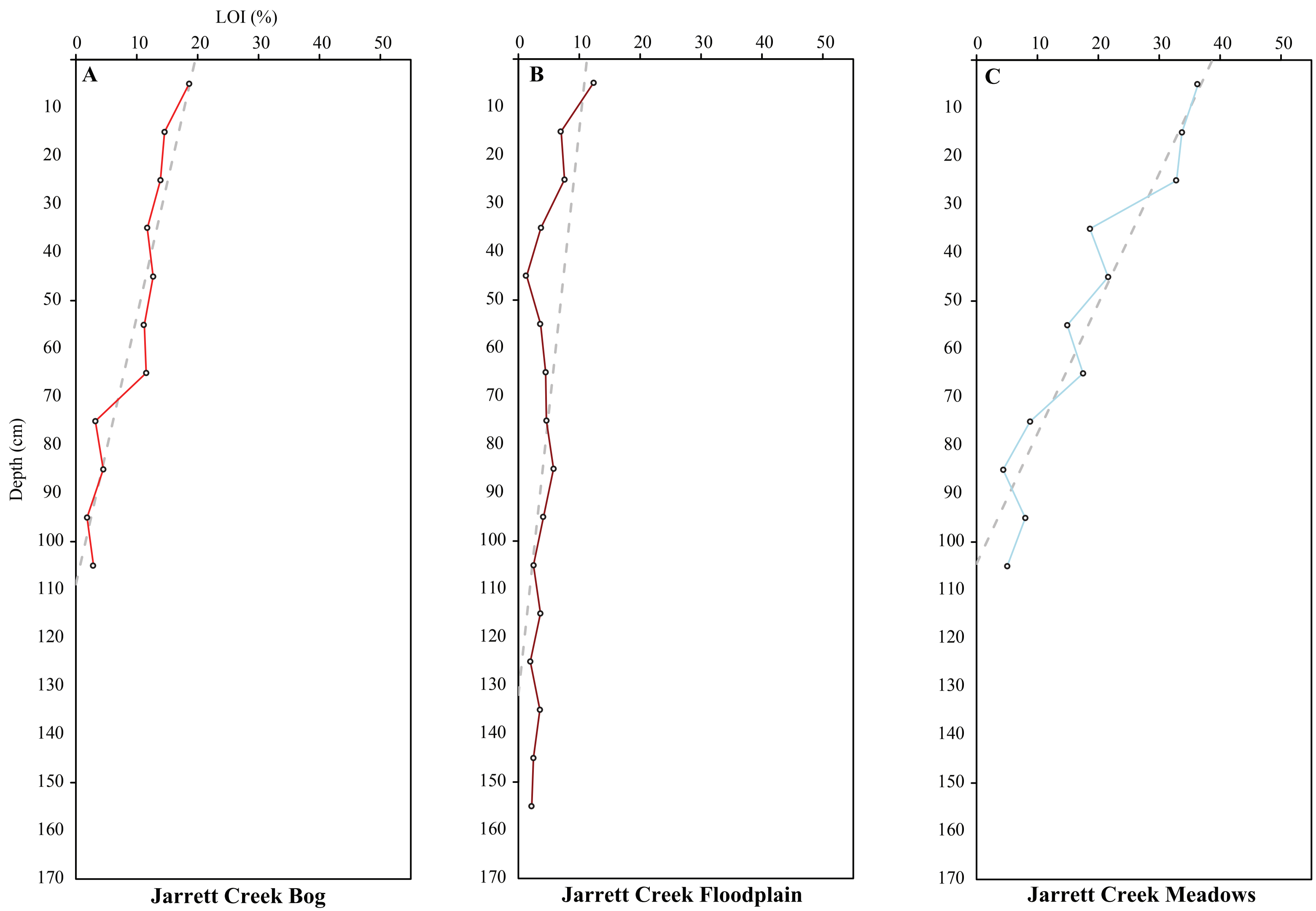

LOI (%)
Depth (cm)
A
B
C
Jarrett Creek Bog
Jarrett Creek Floodplain
Jarrett Creek Meadows

Figure 7: LOI profiles for long cores taken from each site: **(A)** Jarrett Creek Bog, **(B)** Floodplain, **(C)** Meadows. The dashed line plots the relationship between LOI (%) and depth for each core calculated from a linear regression of the two variables.

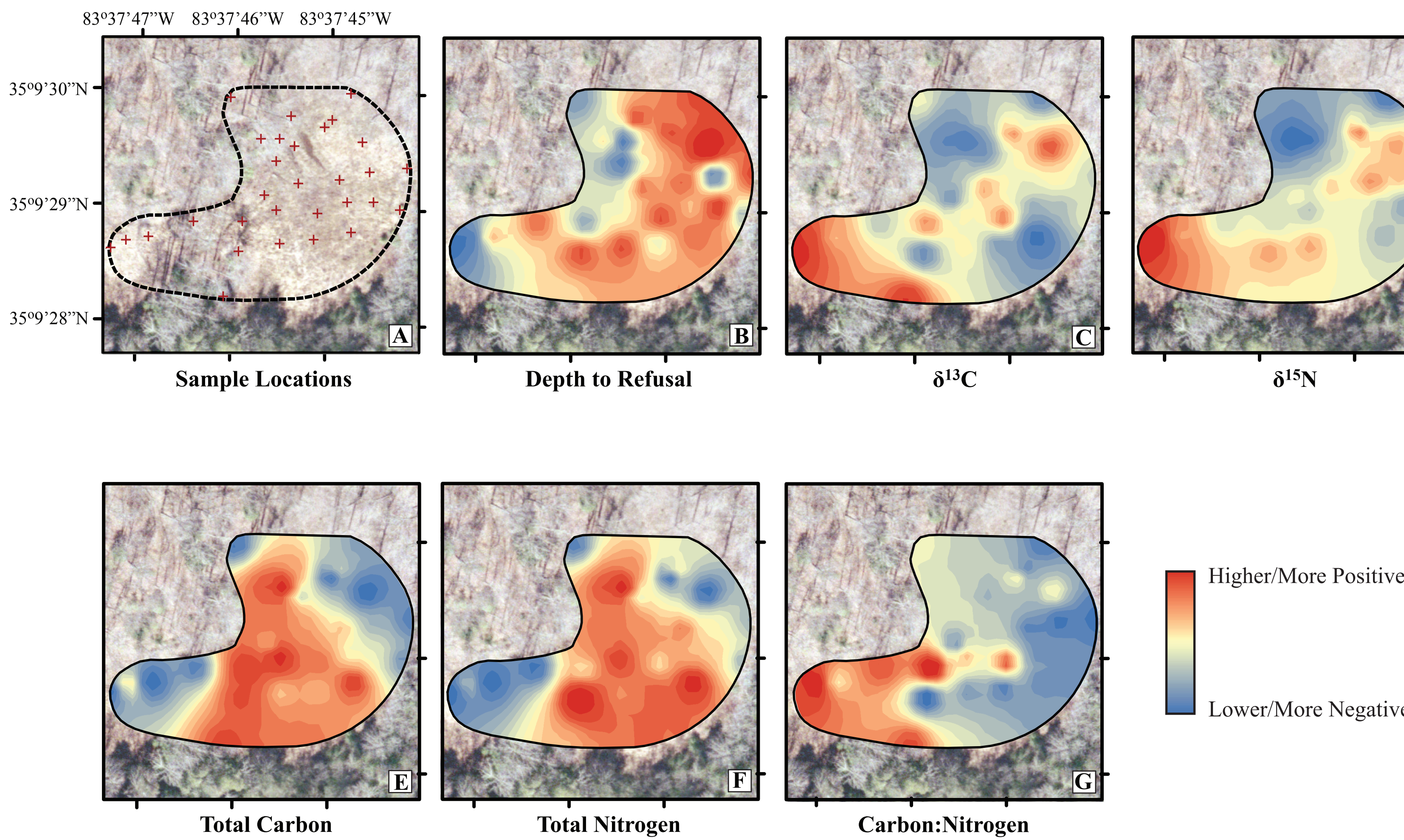
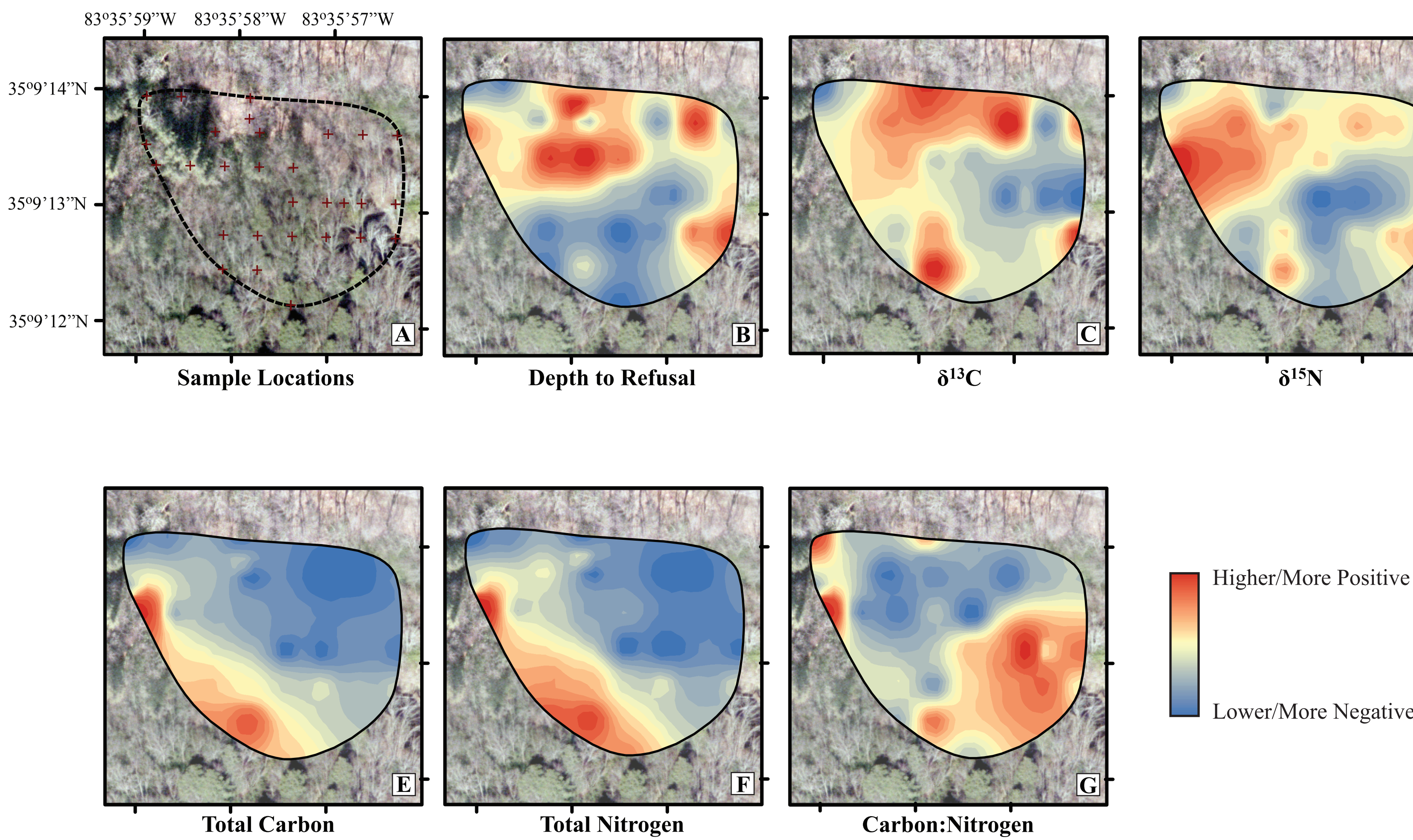
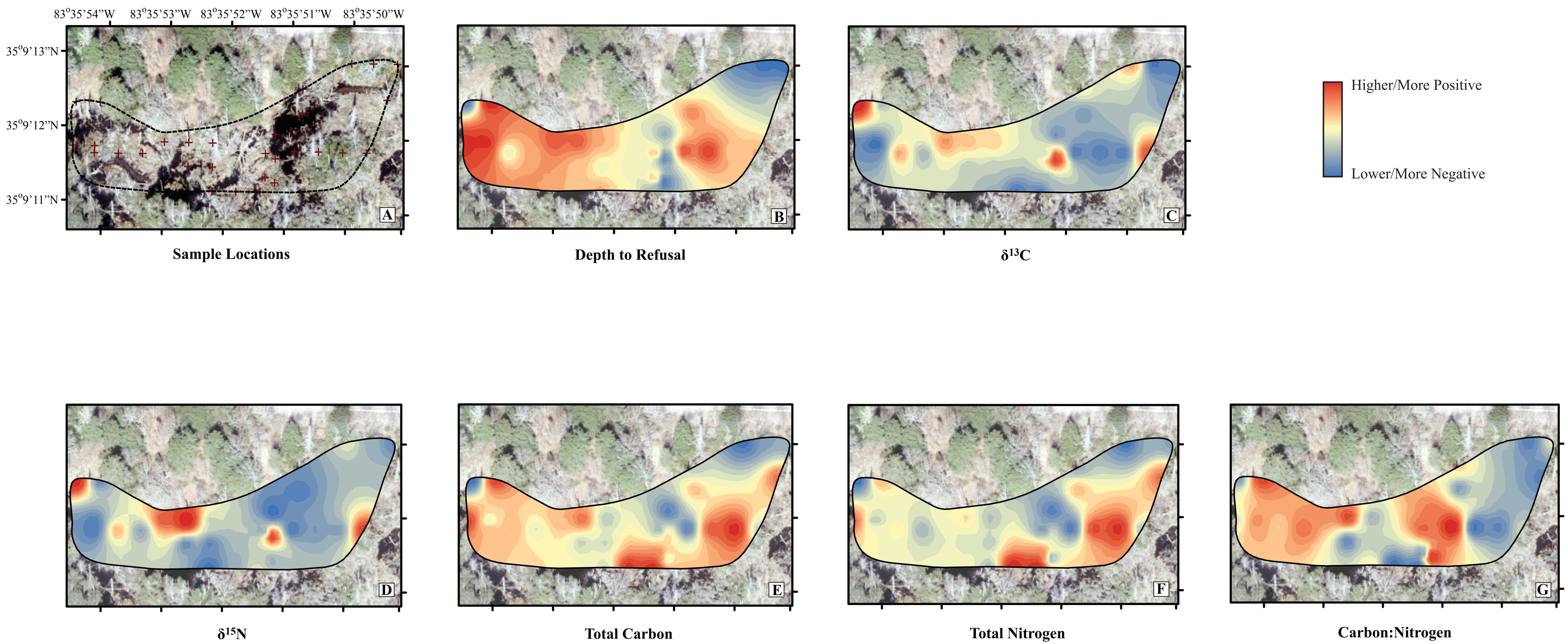

83°37'47"W
83°37'46"W
83°37'45"W
35°9'30"N
35°9'29"N
35°9'28"N
A
B
C
D
E
F
G
Sample Locations
Depth to Refusal
δ13C
δ15N
Total Carbon
Total Nitrogen
Carbon:Nitrogen
Higher/More Positive
Lower/More Negative

Figure 8: Interpolated surface maps (1:1000 scale) for Jarrett Creek Bog based on geochemical measurements: **(A)** Sample Locations **(B)** Depth To Refusal **(C)** $\delta^{13}C$ **(D)** $\delta^{15}N$ **(E)** Total Carbon (%) **(F)** Total Nitrogen (%) **(G)** Carbon:Nitrogen.



83°35'59"W
83°35'58"W
83°35'57"W
35°9'14"N
35°9'13"N
35°9'12"N
A
Sample Locations
B
Depth to Refusal
C
δ13C
D
δ15N
E
Total Carbon
F
Total Nitrogen
G
Carbon:Nitrogen
Higher/More Positive
Lower/More Negative

Figure 9: Interpolated surface maps (1:1000 scale) for Jarrett Creek Floodplain based on geochemical measurements: **(A)** Sample Locations **(B)** Depth To Refusal **(C)** $\delta^{13}C$ **(D)** $\delta^{15}N$ **(E)** Total Carbon (%) **(F)** Total Nitrogen (%) **(G)** Carbon:Nitrogen.



83°35’54”W
83°35’53”W
83°35’52”W
83°35’51”W
83°35’50”W
35°9’13”N
35°9’12”N
35°9’11”N
A
Sample Locations
B
Depth to Refusal
C
δ13C
Higher/More Positive
Lower/More Negative
D
δ15N
E
Total Carbon
F
Total Nitrogen
G
Carbon:Nitrogen

Figure 10: Interpolated surface maps (1:1000 scale) for Jarrett Creek Meadows based on geochemical measurements: **(A)** Sample Locations **(B)** Depth To Refusal **(C)** $\delta^{13}C$ **(D)** $\delta^{15}N$ **(E)** Total Carbon (%) **(F)** Total Nitrogen (%) **(G)** Carbon:Nitrogen.

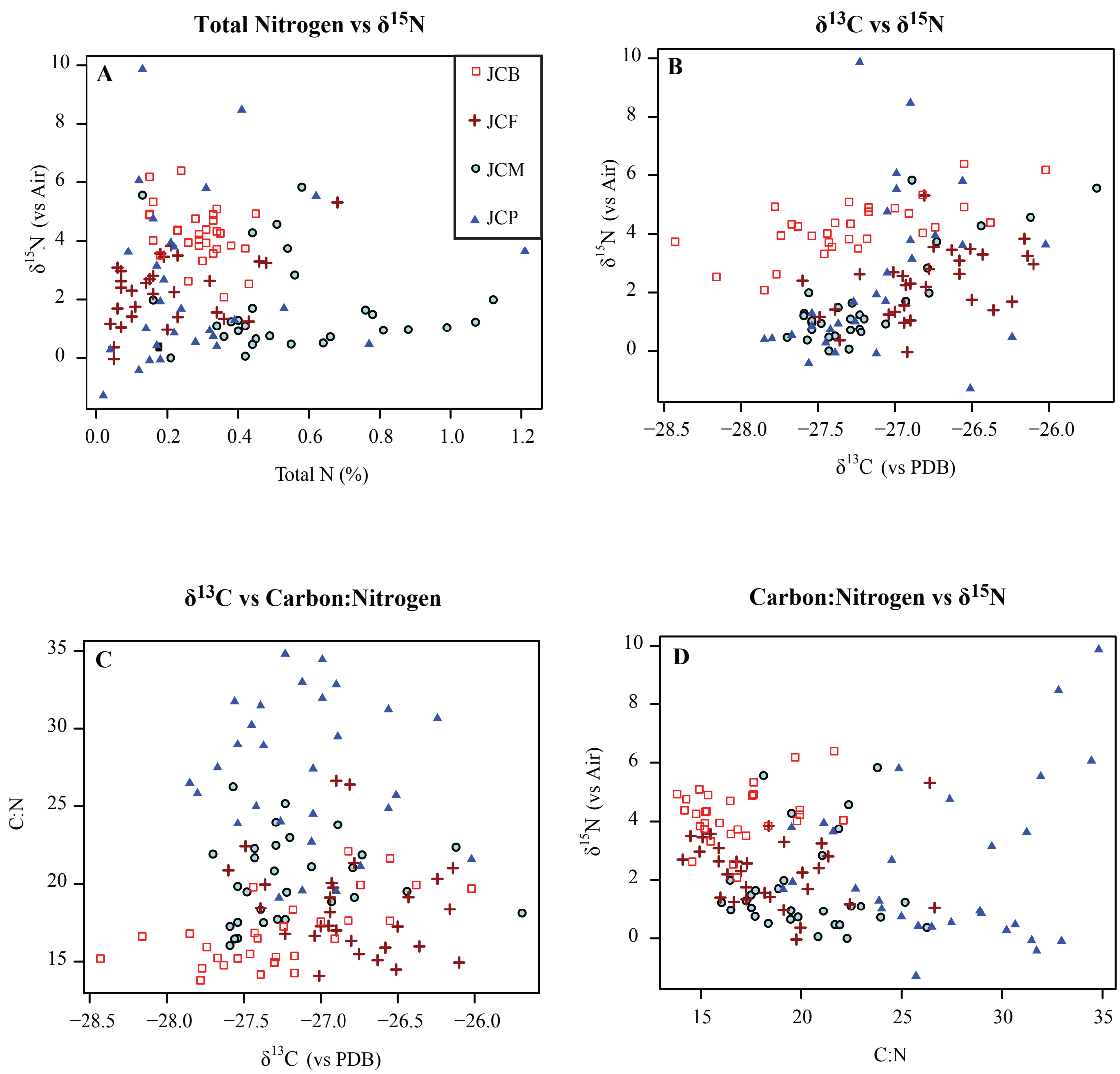

Total Nitrogen vs δ15N
A
JCB
JCF
JCM
JCP
δ15N (vs Air)
Total N (%)
δ13C vs δ15N
B
δ15N (vs Air)
δ13C (vs PDB)
δ13C vs Carbon:Nitrogen
C
C:N
δ13C (vs PDB)
Carbon:Nitrogen vs δ15N
D
δ15N (vs Air)
C:N

Figure 11: Plots of geochemical measurements across sites: **(A)** Total Nitrogen versus $\delta^{15}N$ **(B)** $\delta^{13}C$ versus $\delta^{15}N$ **(C)** $\delta^{13}C$ versus Carbon:Nitrogen **(D)** Carbon:Nitrogen versus $\delta^{15}N$.

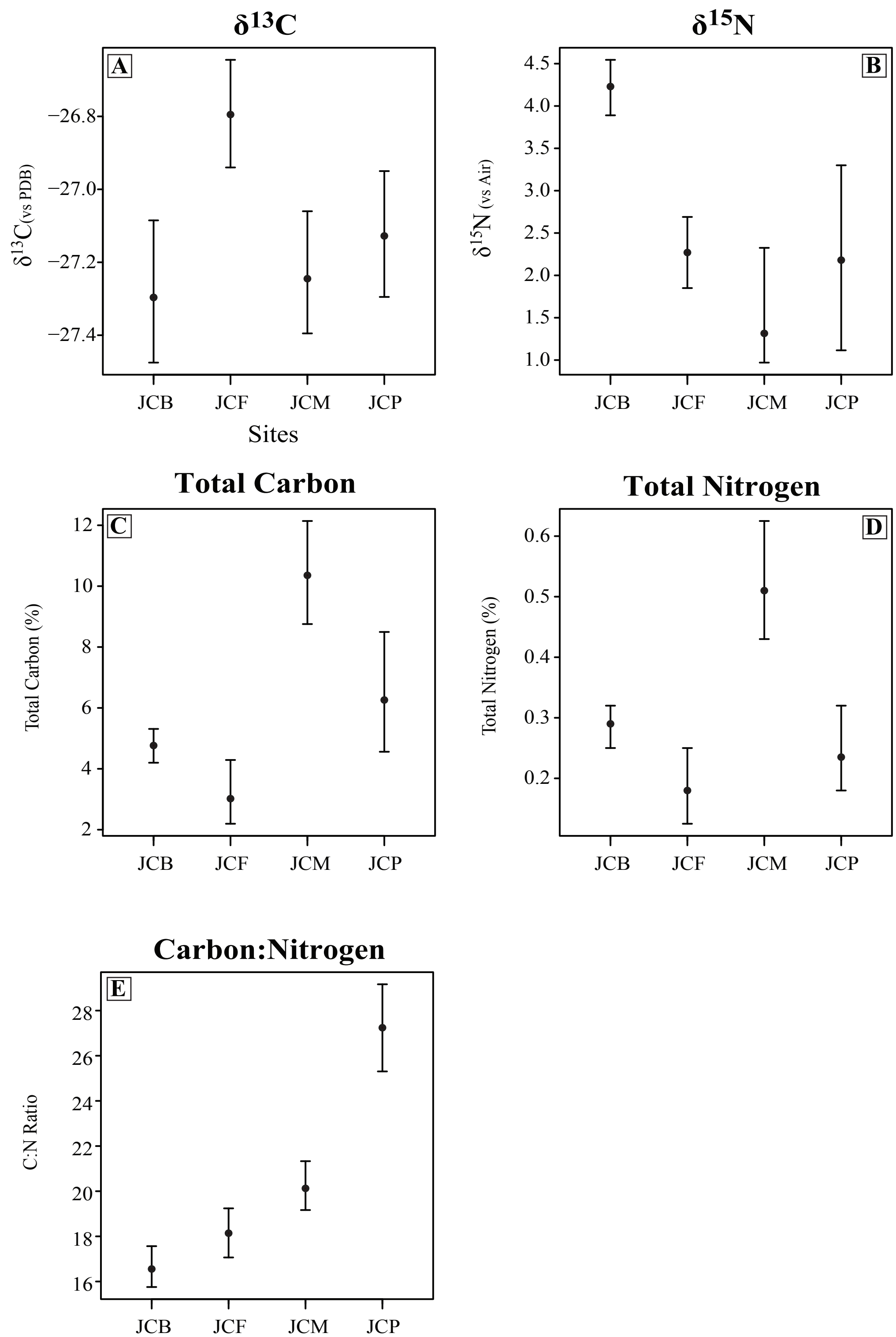

δ13C
A
−26.8
−27.0
−27.2
−27.4
δ13C(vs PDB)
JCB
JCF
JCM
JCP
Sites
δ15N
B
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
δ15N (vs Air)
JCB
JCF
JCM
JCP
Total Carbon
C
12
10
8
6
4
2
Total Carbon (%)
JCB
JCF
JCM
JCP
Total Nitrogen
D
0.6
0.5
0.4
0.3
0.2
Total Nitrogen (%)
JCB
JCF
JCM
JCP
Carbon:Nitrogen
E
28
26
24
22
20
18
16
C:N Ratio
JCB
JCF
JCM
JCP

Figure 12: Average values of geochemical variables across sites: **(A)** $\delta^{13}C$ **(B)** $\delta^{15}N$ **(C)** Total Carbon (%) **(D)** Total Nitrogen (%) **(E)** Carbon:Nitrogen. Brackets show the 95% confidence intervals.

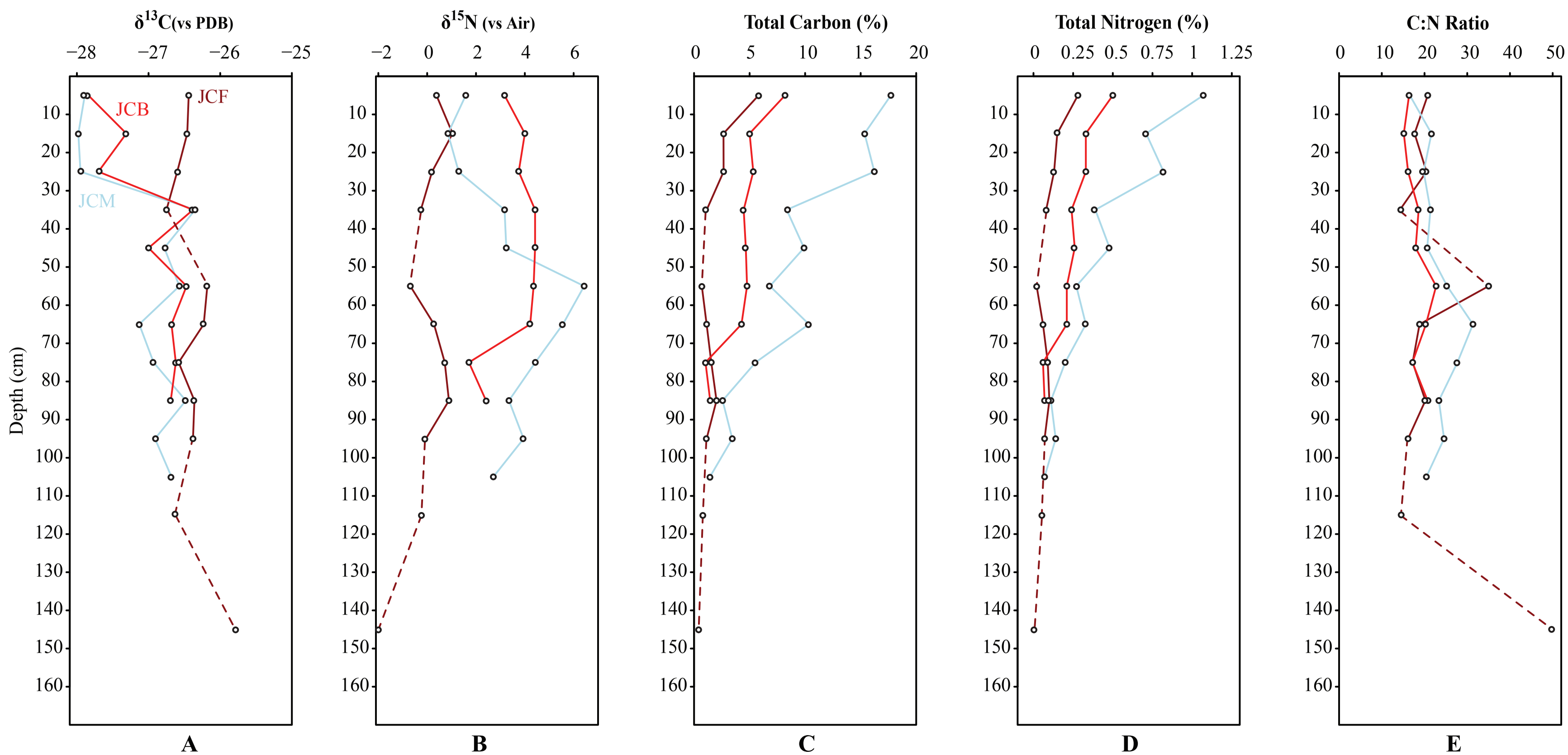
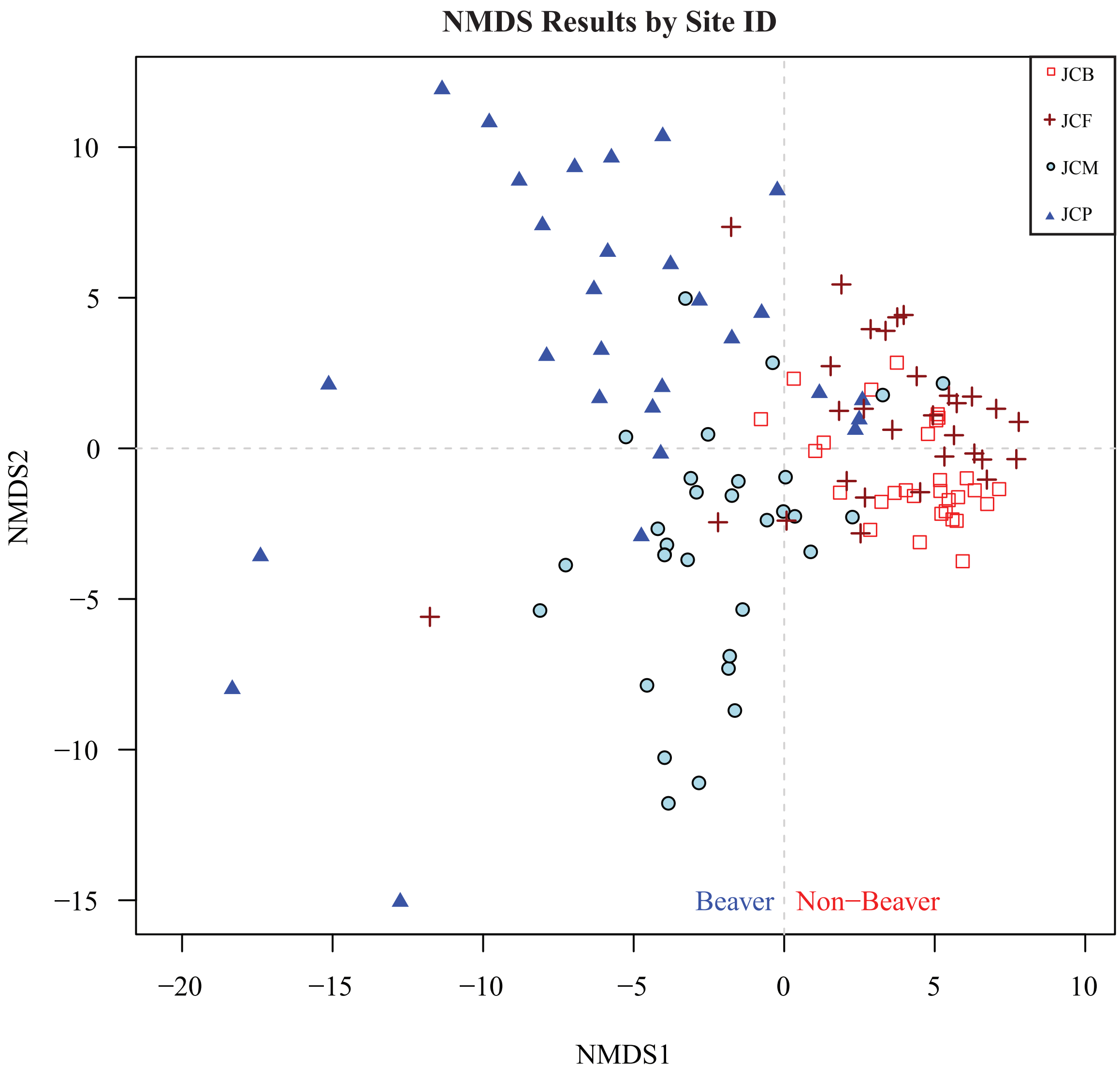
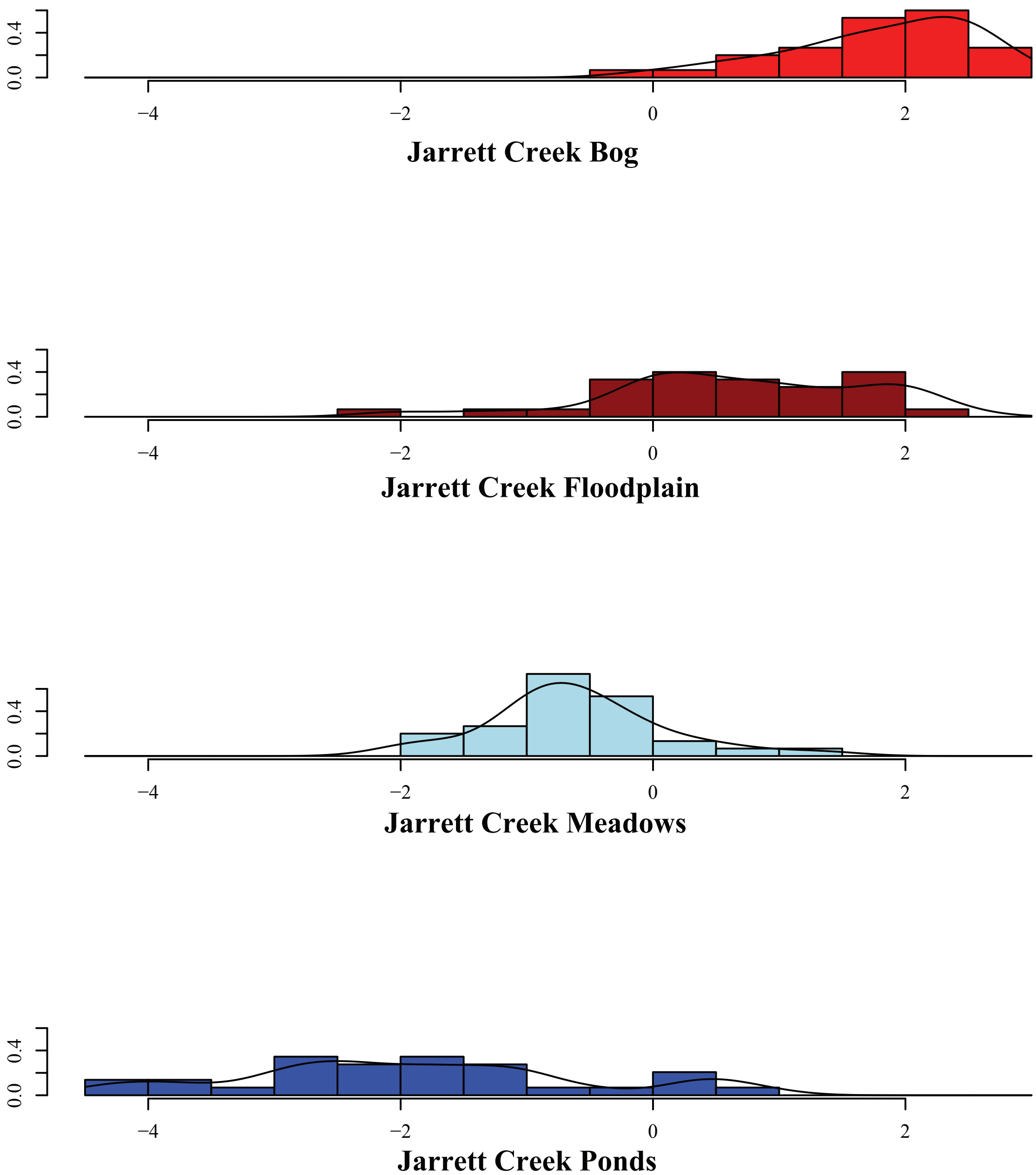

δ13C(vs PDB)
JCB
JCF
JCM
Depth (cm)
A
δ15N (vs Air)
B
Total Carbon (%)
C
Total Nitrogen (%)
D
C:N Ratio
E

Figure 13: Geochemical profiles for long cores taken from each site: **(A)** $\delta^{13}C$ **(B)** $\delta^{15}N$ **(C)** Total Carbon (%) **(D)** Total Nitrogen (%) **(E)** Carbon:Nitrogen.



NMDS Results by Site ID
JCB
JCF
JCM
JCP
10
5
0
−5
−10
−15
NMDS2
−20
−15
−10
−5
0
5
10
NMDS1
Beaver
Non−Beaver

Figure 14: Non-metric Multidimensional Scaling (NMDS) results.



0.0
0.4
−4
−2
0
2
Jarrett Creek Bog
Jarrett Creek Floodplain
Jarrett Creek Meadows
Jarrett Creek Ponds

Figure 15: Study sites plotted along Discriminant Function Analysis (DFA) scores. Inputs to this function were the values of all five geochemical variables: $\delta^{13}C$, $\delta^{15}N$, Total Carbon (%), Total Nitrogen (%), and Carbon:Nitrogen.

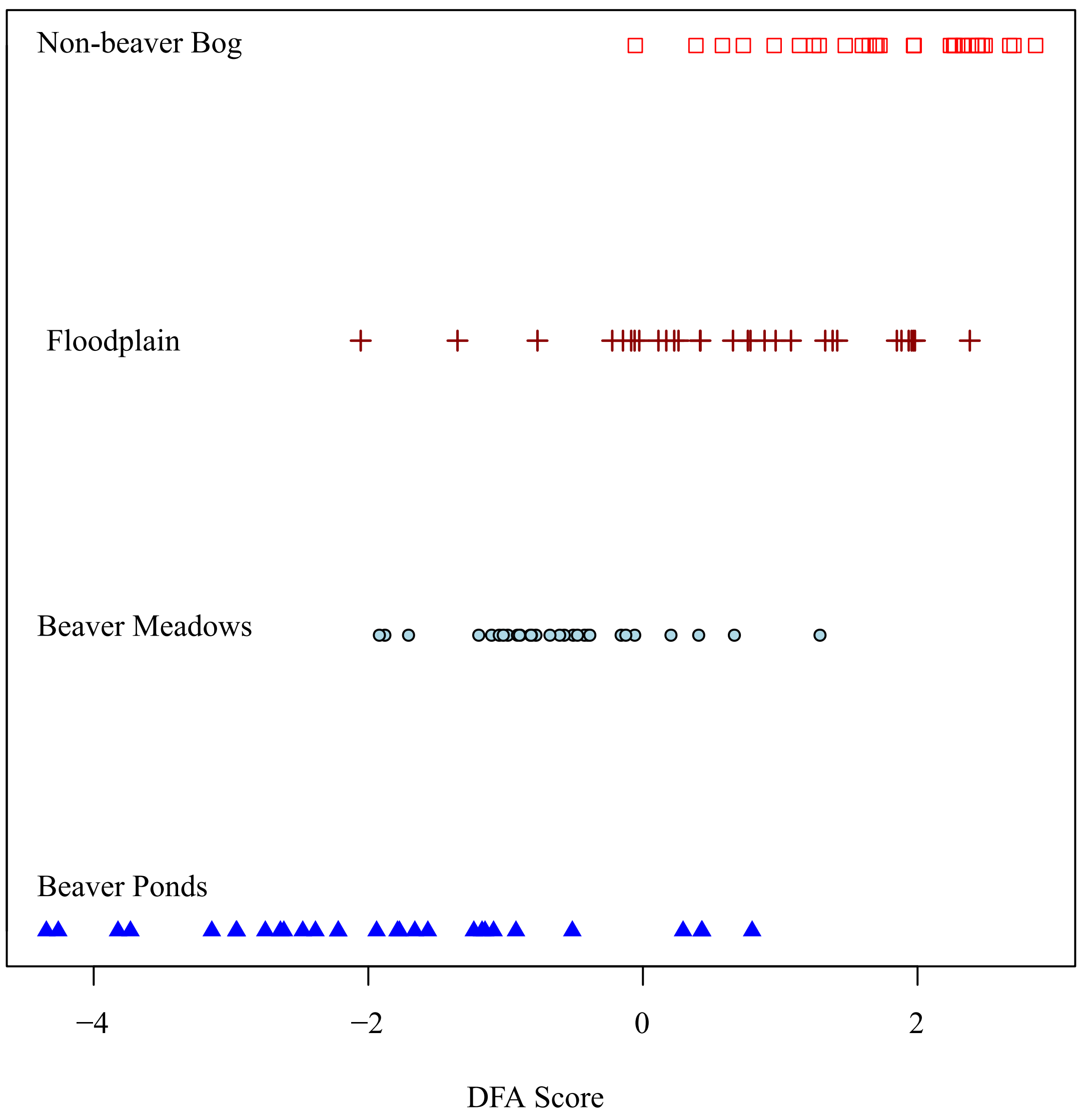

Non-beaver Bog
Floodplain
Beaver Meadows
Beaver Ponds
−4
−2
0
2
DFA Score

Figure 16: DFA score line.

Spearman's ρ

	DTR	Total C	$\delta^{13}C$	Total N	$\delta^{15}N$	C:N
DTR		0.16	-0.23	0.19	0.11	-0.15
Total C	0.16		-0.25	0.98	-0.18	0.28
$\delta^{13}C$	-0.23	-0.25		-0.29	0.31	0.20
Total N	0.19	0.98	-0.29		-0.14	0.10
$\delta^{15}N$	0.11	-0.18	0.31	-0.14		-0.33
C:N	-0.15	0.28	0.20	0.10	-0.33	

Table 1: Spearman rank ρ correlations between primary geochemical variables.

	Predicted Site (%)				
	JCB	JCF	JCM	JCP	
JCB	83	17			
JCF	7	77	10	7	
JCM		10	80	10	
JCP		14	7	79	
Overall					**80**

Table 2: Classification results of Discriminate Function Analysis (DFA) by study site based on geochemical variables ($\delta^{13}C$, $\delta^{15}N$, Total Carbon (%), Total Nitrogen (%), and Carbon:Nitrogen).

	DFA Scores Summary		
Site	**Minimum**	**Maximum**	**Average**
JCM	-1.92	1.29	-0.69
JCP	-4.34	0.80	-1.91
JCF	-2.06	2.38	0.67
JCB	-0.06	2.86	1.80

Table 3: Summary of linear discriminant values by site.

3. Discussion

3.1 *Landscape heterogeneity*

The results of LOI, carbon, and nitrogen analyses indicate that beaver activity at the JCM site has created a complex, heterogeneous landscape. This is consistent with literature suggesting beaver activity has the capacity to produce mosaic landscapes (Johnston and Naiman, 1987; Remillard et al., 1987; Naiman et al., 1988; Johnston and Naiman, 1990; Wright et al., 2002; John and Klein, 2004; Rosell et al., 2005; Corenblit et al., 2011; Levine and Meyer, 2014). By increasing the surface area of the wetland, beaver introduce a greater range of inputs to the local pond system through increased boundary interaction and promotion of local patch dynamics (Johnston and Naiman, 1987; Naiman et al., 1988, 2000; Westbrook et al., 2006). The variation in LOI profiles (Figure 4) and marked shifts in LOI values with depth (Figure 6) compared to the more linear, non-beaver sites JCB and JCF can be interpreted as a reflection of increased landscape heterogeneity. In some areas of JCM, we see relatively higher or lower LOI values, but there is no definitive trend across the sample area. In the case of JCM, the local effects of plant cover, productivity, and sedimentation depend on location within the meadows. The combination of these factors results in these observed, non-uniform trends. The JCP samples show the similar, non-uniform patterns with LOI profiles of stratigraphic and compositional variation (Figure 5). This suggests that pond formation and sedimentation also is spatially heterogeneous.

Interpolated geochemical surfaces for JCM show spatial trends and variability as a function of proximity to dams and ponds (Figure 10). Both carbon and nitrogen values change across dam boundaries such that they are highest immediately behind dams and decrease in relative value with increasing distance from dam locations (Figure 10E and F). This variability in geochemical characteristics is supported by the raw data and NMDS results where both JCM and JCP show the greatest range in values (Figure 14).

By contrast, both the JCB and JCF sites show more homogeneous depositional and geochemical systems. LOI values at both sites stabilize with depth (Figure 6) and closely conform to overall site trends (Figures 2 and 3). Changes in geochemical surfaces across JCB appear to be a result of landscape position. The higher elevations along the eastern side of the bog show different values compared to the western edge of the site (Figure 8). Specifically, along the eastern side of JCB there are lower total carbon and nitrogen values whereas there are some of the highest values along the western edge. The changes in geochemical variables within the JCF site also appear correlated to elevation differences on either side of Jarrett Creek. The southernmost bank was higher in elevation than the northern one and differences in geochemistry seem to reflect this spatial relationship (Figure 9).

3.2 *Geochemical alteration due to beaver activity*

Through the constant management associated with dams and ponds, beaver continue to facilitate wetland processes as long as they are active in an area (Ives, 1942; Naiman et al., 1986, 1988; Ford and Naiman, 1998). Carbon and nitrogen composition data show statistically higher values associated with beaver activity compared to other sites (Figure 12C and D). This is consistent with other reported high values of nitrogen associated with beaver activity (Naiman and Melillo, 1984; Francis et al., 1985; Pinay et al., 1995; Margolis et al., 2001). The cause of these elevated values is believed to be associated with increased sedimentation and microbial nitrogen fixation (Naiman and Melillo, 1984; Francis et al., 1985). Comparison of the JCB, JCF, and JCM long-cores shows similar results with the difference in total nitrogen values remaining separate with depth until about one meter (Figure 13D).

Values of ^{13}C composition in soil organic matter are generally influenced by the combination of local chemical and biological processes (Faure and Mensing, 2005). Negative $\delta^{13}C$ values (versus PDB) reflect the photosynthetic uptake of plants and the formation of biogenic compounds, which favors ^{12}C over ^{13}C (Faure and Mensing, 2005). Additionally, the metabolic pathways of differing plant types, such as C3 and C4 plants, are reflected in $\delta^{13}C$ values (Faure and Mensing, 2005). Oxidation of C promotes enrichment of ^{13}C in soils and leads to more positive $\delta^{13}C$ values versus PDB (Faure and Mensing, 2005). The more positive values of $\delta^{13}C$ at JCF compared to all other, wetland sample sites likely reflects the lack of biological discrimination and more oxic conditions in the active floodplain environment.

The fractionation of N isotopes is predominately the result of N_2 transformations by microbial metabolic activity (Faure and Mensing, 2005). In the nitrogen cycle, fixation, nitrification, and denitrification are all controlled by these biological processes and local rate-limiting compounds, such as nitrate (Faure and Mensing, 2005). The rates of nitrification and denitrification are dependent anoxic conditions, with denitrification favored in increasing anoxia (Faure and Mensing, 2005). Denitrification promotes extensive depletion of ^{15}N in soils (Faure and Mensing, 2005). The $\delta^{15}N$ values across sites shows that JCM and JCP have more negative overall values. This suggests that beaver activity at JCM has promoted increased rates of denitrification and nitrate retention (Cirmo and Driscoll, 1993; Naiman et al., 1994; Correll et al., 2000; Margolis et al., 2001; Faure and Mensing, 2005). Denitrification is a process that discriminates against the heavier ^{15}N isotope so an increase in denitrification rates could explain the lower $\delta^{15}N$ present in JCM. Conversely, the more positive $\delta^{15}N$ values at JCB can be attributed to higher rates of nitrification resulting from more oxidized conditions. This $\delta^{15}N$ relationship is also supported by the observation that beaver activity promotes increased anoxic conditions, which is required for denitrification (Cirmo and Driscoll, 1993; Margolis et al., 2001; Burchsted et al., 2010; Briggs et al., 2013). Differences in $\delta^{15}N$ measurements across sites continues with depth, as reflected in long-core data (Figure 13B). The marked shift in $\delta^{15}N$ at JCM around 50 centimeters could be a reflection of beaver occupation of Jarrett Creek. Below this 50 centimeter division, $\delta^{15}N$ values approximate those of the non-beaver JCB site.

3.3 *Stratigraphic recognition of beaver wetlands*

Patterns in sediment deposition and sediment packages associated with beaver activity have been studied with respect to distribution, landform generation, and channel adjustment (Persico and Meyer, 2009; Burchsted et al., 2010; Burchsted and Daniels, 2013; Levine and Meyer, 2014). Processes of sediment transport in meadows, deposition in ponds, and transport in open reaches have been described (Butler and Malanson, 1995; Burchsted et al., 2010; Butler, 2012). Reaches of stream impacted by beaver are known to have overall finer sediments than in unaffected portions, but some differences in sedimentology remain due to individual characteristics of reaches (Burchsted and Daniels, 2013). Examination of downstream trends show packages of fine sediment similar to those in the pond setting, but absent from unimpacted streams of similar character, suggesting a preservation of sediments downstream from dam structures (Burchsted and Daniels, 2013). A cyclical pattern of sediment transport and deposition has been documented as reflections of aggradation and degradation episodes following dam construction and failure (Persico and Meyer, 2009; Burchsted and Daniels, 2013). These seasonal and spatial patterns present complications when thinking about beaver-generated deposits as homogeneous over time (Burchsted and Daniels, 2013).

The identification of beaver-associated deposits in the Holocene (11.5ka ago to present) has implications for understanding the pre-European extent of wetlands in the Southeast (Butler, 1991; Bulluck and Rowe, 2006; Jakes et al., 2007). Walter and Merritts (2008) suggested that the pre-European condition for the majority of the eastern United States was represented by wetland systems with multiple-channel networks. They posit that beaver may have played a significant role in the establishment and facilitation of this regime. Detection of beaver-assisted wetlands and recognition of the scale at which they impact the landscape would aid in analyzing the extent to which fluvial systems were altered by beaver. Specifically, the role of beaver in fluvial-system alteration is potentially significant for understanding baseline conditions of stream restoration and rehabilitation (Burchsted et al., 2010). Persico and Meyer (2008) demonstrated a relationship between beaver-associated deposits and Holocene climatic change.

Using the combination of carbon and nitrogen measurements employed by this study, a chemostratigraphic framework emerges showing that there is a difference in the overall composition in the organic fraction of beaver and non-beaver wetland sediments in the

Southern Blue Ridge. Based on existing literature, these observed differences in soil organic matter composition, particularly total N and $\delta^{15}N$ values as determined in this study, can persist for time periods on the order of 10^3 years, depending on local, site-specific factors such as erosion, fertilizer inputs, and climatic shifts (Amundson et al, 2003). This understanding of the N cycle suggests that these measurements could be used as criteria for site identification, but requires an understanding of local chemical and biological processes to which the N cycle is sensitive (Amundson et al, 2003). The JCM site shows double the organic matter content (both carbon and nitrogen) compared to JCB, also distinguishing itself from the floodplain and pond environments. Stable nitrogen (^{15}N) measurements show that JCM is depleted compared to other wetlands (JCB). Multivariate analysis shows a separation of samples into two groups along the primary NMDS axis appearing to reflect the difference beaver activity has on the combination of total carbon, total nitrogen, $\delta^{13}C$, $\delta^{15}N$, and C:N values at these sites. Additionally, DFA results support the separation of wetland types as beaver and non-beaver (Table 3, 4). These statistical differences provide the basis for Equation 1 which can be viewed as a criteria to determine beaver activity at a wetland. The output values of Equation 1 should be compared to the suggested groupings from DFA to evaluate beaver and non-beaver categorization (Table 4, Figure 17). All multivariate results partition Jarrett Creek Bog from Jarrett Creek Meadows, further highlighting the geochemical differences between these wetlands (Figure 17). Long-core trends (Figure 13) show consistently unique carbon, nitrogen, and isotopic differences between the bog and meadows, suggesting stratigraphic preservation of the relationships seen in the 10 to 20cm sections of the sediment profiles.

CHAPTER 3

CONCLUSION

Previous research suggests the magnitude of landscape change induced by beaver activity is similar to impacts of the last glacial maximum in certain areas (Anderson and Rosemond, 2010). Ruedemann and Schoonmaker (1938) posited that beaver activity was primarily responsible for much of the fertile valleys associated with farmlands in North America. While there is considerable dispute over the magnitude of landscape alteration that beaver are responsible for in North America, it is undeniable that this animal has a profound impact on the fluvial systems it colonizes and fundamentally alters key environmental conditions.

When considering beaver-induced changes in the context of geochemistry, it is possible to relate observed trends to local processes. This enables an understanding beaver activity from a chemostratigraphic viewpoint. It has been shown that beaver can affect chemical cycles through the genesis and alteration of wetland systems (Naiman et al., 1994). This study illustrates how these geochemical and geomorphic processes associated with beaver activity are expressed in selected Southern Blue Ridge wetlands. By using the organic fraction of sediments from wetlands along Jarrett Creek, it is possible to develop a framework that validates previous scientific studies and provides a guide for investigations of wetlands in the region. The results of this study further distinguish non-beaver and beaver wetlands in the region. Based on these findings, criteria for chemostratigraphic recognition of beaver activity suggest a carbon content of at least 10 percent and a nitrogen content of at least 0.5 percent. In both cases, this is roughly double that of the surrounding environments. Stable isotopic analysis indicates that beaver wetlands are depleted with respect to ^{15}N compared to other wetlands. This difference shows that non-beaver wetlands possess $\delta^{15}N$ values of 4.0 to 4.5 per mil versus beaver wetland values averaging 1.5 to 2.0 per mil. These geochemical differences persist stratigraphically for at least one meter depth, based on collected long cores. Further research on this topic should evaluate allochthonous inputs and potential diagenetic influences and between these wetland types to assess the extent to which these factors impact C and N geochemical measurements. Since it is believed that beaver were present in the southeast United States for millennia undisturbed, using these criteria that distinguishes beaver from non-beaver wetlands is essential in quantifying the geographic and stratigraphic extent of their history in this region.

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APPENDICIES

APPENDIX A

SAMPLE DATA

A1. Loss-On-Ignition data and descriptive information

*Latitude and longitude values are expressed in UTM units
**DTR measures the Depth-To-Refusal as recorded in field surveys

Site.ID	Smpl.No	Depth.cm	Latitude*	Longitude*	DTR** (cm)	LOI (%)
JCM	1	5	263384	3893137	58	6.4603
JCM	2	5	263384	3893127	45	12.4062
JCM	3	5	263384	3893117	40	18.9615
JCM	4	5	263392	3893130	93	7.6425
JCM	5	5	263402	3893130	95	30.7403
JCM	6	5	263412	3893130	78	32.952
JCM	7	5	263422	3893130	80	31.0906
JCM	8	5	263430	3893152	65	31.3884
JCM	9	5	263434	3893167	40	32.1046
JCM	10	5	263424	3893167	40	15.5114
JCM	11	5	263415	3893167	47	9.9824
JCM	12	5	263395	3893146	85	28.4436
JCM	13	5	263395	3893156	70	34.9982
JCM	14	5	263380	3893129	80	17.0447
JCM	15	5	263380	3893119	82	30.6188
JCM	16	5	263378	3893113	60	42.4189
JCM	17	5	263368	3893113	75	40.4395
JCM	18	5	263358	3893113	81	25.3979
JCM	19	5	236348	3893123	78	19.8833
JCM	20	5	263358	3893123	70	28.1721
JCM	21	5	263358	3893133	80	23.0781
JCM	22	5	263348	3893133	90	35.0976
JCM	23	5	263338	3893133	90	14.3737
JCM	24	5	263329	3893128	80	24.2043
JCM	25	5	263319	3893128	68	41.1808
JCM	26	5	263309	3893128	90	36.4743
JCM	27	5	263309	3893131	102	32.3437
JCM	28	5	263300	3893131	101	40.6833
JCM	29	5	263301	3893149	40	11.6672

JCM	30	5	263311	3893149	101	31.6887
JCM	1	15	263384	3893137	58	11.4497
JCM	2	15	263384	3893127	45	16.7174
JCM	3	15	263384	3893117	40	18.1223
JCM	4	15	263392	3893130	93	10.2422
JCM	5	15	263402	3893130	95	29.4175
JCM	6	15	263412	3893130	78	33.4301
JCM	7	15	263422	3893130	80	14.2312
JCM	8	15	263430	3893152	65	29.4986
JCM	9	15	263434	3893167	40	13.8556
JCM	10	15	263424	3893167	40	15.4601
JCM	11	15	263415	3893167	47	8.774
JCM	12	15	263395	3893146	85	24.6858
JCM	13	15	263395	3893156	70	18.2605
JCM	14	15	263380	3893129	80	13.5294
JCM	15	15	263380	3893119	82	29.6381
JCM	16	15	263378	3893113	60	39.9485
JCM	17	15	263368	3893113	75	37.3895
JCM	18	15	263358	3893113	81	13.0985
JCM	19	15	236348	3893123	78	16.1235
JCM	20	15	263358	3893123	70	17.7629
JCM	21	15	263358	3893133	80	17.0473
JCM	22	15	263348	3893133	90	26.4112
JCM	23	15	263338	3893133	90	22.679
JCM	24	15	263329	3893128	80	19.405
JCM	25	15	263319	3893128	68	23.642
JCM	26	15	263309	3893128	90	24.0774
JCM	27	15	263309	3893131	102	19.3704
JCM	28	15	263300	3893131	101	26.9786
JCM	29	15	263301	3893149	40	10.717
JCM	30	15	263311	3893149	101	30.2891
JCM	1	25	263384	3893137	58	10.4219
JCM	2	25	263384	3893127	45	11.3619
JCM	3	25	263384	3893117	40	22.6034
JCM	4	25	263392	3893130	93	11.9787
JCM	5	25	263402	3893130	95	30.3633
JCM	6	25	263412	3893130	78	30.4278
JCM	7	25	263422	3893130	80	8.7081
JCM	8	25	263430	3893152	65	23.1142
JCM	9	25	263434	3893167	40	5.6933
JCM	10	25	263424	3893167	40	20.0331
JCM	11	25	263415	3893167	47	8.7548
JCM	12	25	263395	3893146	85	26.03
JCM	14	25	263380	3893129	80	13.7349
JCM	15	25	263380	3893119	82	23.683

JCM	16	25	263378	3893113	60	40.3118
JCM	17	25	263368	3893113	75	39.7895
JCM	18	25	263358	3893113	81	32.2237
JCM	19	25	236348	3893123	78	15.2258
JCM	20	25	263358	3893123	70	19.8243
JCM	21	25	263358	3893133	80	18.7101
JCM	22	25	263348	3893133	90	40.4436
JCM	23	25	263338	3893133	90	20.6068
JCM	24	25	263329	3893128	80	28.3584
JCM	25	25	263319	3893128	68	10.653
JCM	26	25	263309	3893128	90	23.5741
JCM	27	25	263309	3893131	102	20.4288
JCM	28	25	263300	3893131	101	13.6897
JCM	29	25	263301	3893149	40	18.9953
JCM	30	25	263311	3893149	101	38.5361
JCP	1	5				28.337
JCP	2	5				30.1701
JCP	3	5				12.6389
JCP	4	5				7.1972
JCP	5	5				12.324
JCP	6	5				8.4885
JCP	7	5				6.7754
JCP	8	5				10.43
JCP	9	5				16.8666
JCP	10	5				9.2825
JCP	11	5				13.0864
JCP	12	5				11.3448
JCP	13	5				10.0737
JCP	14	5				11.5221
JCP	15	5				14.8245
JCP	16	5				23.7216
JCP	17	5				17.1558
JCP	18	5				15.7022
JCP	19	5				7.6991
JCP	20	5				11.3448
JCP	21	5				17.8596
JCP	22	5				17.8405
JCP	23	5				11.7246
JCP	24	5				6.6664
JCP	25	5				8.2605
JCP	26	5				8.3649
JCP	27	5				7.5726
JCP	28	5				2.8291
JCP	29	5				10.1005
JCP	30	5				5.8402

JCP	1	15	51.5161
JCP	2	15	46.2176
JCP	3	15	25.8263
JCP	4	15	17.1845
JCP	5	15	6.3732
JCP	6	15	8.3673
JCP	7	15	2.5404
JCP	8	15	8.7364
JCP	9	15	11.1624
JCP	10	15	8.9748
JCP	11	15	9.6456
JCP	12	15	24.3526
JCP	13	15	12.0036
JCP	14	15	16.0657
JCP	15	15	12.2598
JCP	16	15	17.5623
JCP	17	15	21.6106
JCP	18	15	12.4703
JCP	19	15	11.8163
JCP	20	15	10.2765
JCP	21	15	14.325
JCP	22	15	9.1677
JCP	23	15	6.7338
JCP	24	15	11.0322
JCP	25	15	9.0111
JCP	26	15	14.8042
JCP	27	15	7.5674
JCP	28	15	2.2946
JCP	29	15	16.3359
JCP	30	15	8.315
JCP	1	25	10.093
JCP	2	25	19.6208
JCP	3	25	21.3797
JCP	4	25	10.0964
JCP	5	25	4.5826
JCP	6	25	5.6022
JCP	7	25	15.3109
JCP	8	25	6.4056
JCP	9	25	12.0714
JCP	10	25	7.9343
JCP	11	25	19.9219
JCP	12	25	10.8053
JCP	13	25	13.2153
JCP	14	25	14.2899
JCP	15	25	18.7725

JCP	16	25				17.3366
JCP	17	25				20.8734
JCP	18	25				10.203
JCP	19	25				13.1388
JCP	20	25				16.4372
JCP	21	25				8.5491
JCP	22	25				6.1771
JCP	23	25				4.0022
JCP	24	25				12.6116
JCP	25	25				5.833
JCP	26	25				11.3506
JCP	27	25				11.3031
JCP	28	25				1.6205
JCP	29	25				11.201
JCP	30	25				10.047
JCF	1	5	263222	3893169	50	2.9587
JCF	2	5	263232	3893169	42	3.6894
JCF	3	5	263237	3893169	40	4.1101
JCF	4	5	263242	3893169	50	6.3168
JCF	5	5	263252	3893169	65	8.355
JCF	6	5	263252	3893189	50	11.0608
JCF	7	5	263242	3893189	90	12.1955
JCF	8	5	263232	3893189	45	9.6322
JCF	9	5	263212	3893189	50	10.1667
JCF	10	5	263209	3893193	100	11.5456
JCF	11	5	263199	3893189	50	10.5091
JCF	12	5	263179	3893185	80	11.8433
JCF	13	5	263179	3893199	40	3.1983
JCF	14	5	263189	3893199	41	8.0897
JCF	15	5	263209	3893199	60	4.1103
JCF	16	5	263222	3893179	80	11.9654
JCF	17	5	263212	3893179	98	14.9915
JCF	18	5	263202	3893179	90	17.8439
JCF	19	5	263192	3893179	60	25.7532
JCF	20	5	263182	3893179	65	41.6078
JCF	21	5	263252	3893159	90	15.7777
JCF	22	5	263242	3893159	78	16.5386
JCF	23	5	263232	3893159	43	15.8107
JCF	24	5	263222	3893159	35	17.2587
JCF	25	5	263212	3893159	45	9.198
JCF	26	5	263202	3893159	40	10.7179
JCF	27	5	263202	3893149	40	16.8405
JCF	28	5	263212	3893149	58	19.508
JCF	29	5	263222	3893139	38	18.6551
JCF	30	5	263222	3893139	35	21.7775

JCF	1	15	263222	3893169	50	2.6144
JCF	2	15	263232	3893169	42	3.4406
JCF	3	15	263237	3893169	40	4.5063
JCF	4	15	263242	3893169	50	5.2584
JCF	5	15	263252	3893169	65	4.2994
JCF	6	15	263252	3893189	50	5.4512
JCF	7	15	263242	3893189	90	3.9152
JCF	8	15	263232	3893189	45	4.2453
JCF	9	15	263212	3893189	50	3.851
JCF	10	15	263209	3893193	100	9.2484
JCF	11	15	263199	3893189	50	9.1382
JCF	12	15	263179	3893185	80	6.8276
JCF	13	15	263179	3893199	40	3.0613
JCF	14	15	263189	3893199	41	5.1087
JCF	15	15	263209	3893199	60	3.6813
JCF	16	15	263222	3893179	80	6.9941
JCF	17	15	263212	3893179	98	6.6823
JCF	18	15	263202	3893179	90	9.3358
JCF	19	15	263192	3893179	60	9.4862
JCF	20	15	263182	3893179	65	34.3294
JCF	21	15	263252	3893159	90	10.5259
JCF	22	15	263242	3893159	78	6.2292
JCF	23	15	263232	3893159	43	10.906
JCF	24	15	263222	3893159	35	9.5238
JCF	25	15	263212	3893159	45	11.0803
JCF	26	15	263202	3893159	40	10.262
JCF	27	15	263202	3893149	40	14.885
JCF	28	15	263212	3893149	58	17.5017
JCF	29	15	263222	3893139	38	12.0863
JCF	30	15	263222	3893139	35	20.0506
JCF	1	25	263222	3893169	50	2.8546
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JCF	3	25	263237	3893169	40	2.4028
JCF	4	25	263242	3893169	50	6.1865
JCF	5	25	263252	3893169	65	4.1567
JCF	6	25	263252	3893189	50	7.0175
JCF	7	25	263242	3893189	90	6.4508
JCF	8	25	263232	3893189	45	9.4753
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JCF	11	25	263199	3893189	50	11.5407
JCF	12	25	263179	3893185	80	6.5696
JCF	13	25	263179	3893199	40	3.294
JCF	14	25	263189	3893199	41	5.1252
JCF	15	25	263209	3893199	60	7.1497

JCF	16	25	263222	3893179	80	7.8302
JCF	17	25	263212	3893179	98	8.3734
JCF	18	25	263202	3893179	90	6.6906
JCF	19	25	263192	3893179	60	9.5724
JCF	20	25	263182	3893179	65	17.4194
JCF	21	25	263252	3893159	90	16.2959
JCF	22	25	263242	3893159	78	5.4826
JCF	23	25	263232	3893159	43	10.9963
JCF	24	25	263222	3893159	35	5.0213
JCF	25	25	263212	3893159	45	12.7435
JCF	26	25	263202	3893159	40	6.5896
JCF	27	25	263202	3893149	40	15.96
JCF	28	25	263212	3893149	58	32.7359
JCF	29	25	263222	3893139	38	4.4738
JCF	30	25	263222	3893139	35	14.6517
JCB	1	5	260528	3893767	95	10.3415
JCB	2	5	260512	3893761	95	12.7959
JCB	3	5	260496	3893766	55	7.1226
JCB	4	5	260505	3893740	70	21.3158
JCB	5	5	260514	3893743	90	19.3258
JCB	6	5	260525	3893744	90	16.7149
JCB	7	5	260533	3893746	45	20.0067
JCB	8	5	260543	3893747	95	16.3325
JCB	9	5	260541	3893736	62	14.2304
JCB	10	5	260534	3893738	100	14.9593
JCB	11	5	260527	3893738	80	15.405
JCB	12	5	260519	3893735	95	15.7338
JCB	13	5	260508	3893736	73	21.282
JCB	14	5	260499	3893733	58	16.6871
JCB	15	5	260486	3893733	90	16.5459
JCB	16	5	260474	3893729	82	22.2796
JCB	17	5	260468	3893728	40	16.8588
JCB	18	5	260464	3893726	37	16.7254
JCB	19	5	260531	3893754	120	7.9998
JCB	20	5	260521	3893758	95	8.4611
JCB	21	5	260513	3893753	79	11.3244
JCB	22	5	260504	3893755	78	20.2554
JCB	23	5	260509	3893755	40	12.247
JCB	24	5	260508	3893749	40	18.8346
JCB	25	5	260523	3893760	87	13.5561
JCB	26	5	260528	3893730	90	20.7894
JCB	27	5	260518	3893728	70	19.5421
JCB	28	5	260509	3893727	95	21.2104
JCB	29	5	260498	3893725	95	31.1046
JCB	30	5	260494	3893713	77	19.4011

JCB	31	5	260506	3893712	70	16.824
JCB	32	5	260518	3893714	47	21.6374
JCB	1	15	260528	3893767	95	10.1278
JCB	2	15	260512	3893761	95	10.5567
JCB	3	15	260496	3893766	55	7.3829
JCB	4	15	260505	3893740	70	12.0015
JCB	5	15	260514	3893743	90	14.1191
JCB	6	15	260525	3893744	90	13.3912
JCB	7	15	260533	3893746	45	11.3631
JCB	8	15	260543	3893747	95	9.4331
JCB	9	15	260541	3893736	62	4.9235
JCB	10	15	260534	3893738	100	11.6524
JCB	11	15	260527	3893738	80	12.3034
JCB	12	15	260519	3893735	95	13.577
JCB	13	15	260508	3893736	73	15.2425
JCB	14	15	260499	3893733	58	17.4531
JCB	15	15	260486	3893733	90	8.1314
JCB	16	15	260474	3893729	82	7.606
JCB	17	15	260468	3893728	40	12.708
JCB	18	15	260464	3893726	37	9.8156
JCB	19	15	260531	3893754	120	8.1432
JCB	20	15	260521	3893758	95	8.3593
JCB	21	15	260513	3893753	79	11.1167
JCB	22	15	260504	3893755	78	11.7773
JCB	23	15	260509	3893755	40	12.3239
JCB	24	15	260508	3893749	40	13.7165
JCB	25	15	260523	3893760	87	11.3988
JCB	26	15	260528	3893730	90	14.8452
JCB	27	15	260518	3893728	70	13.8391
JCB	28	15	260509	3893727	95	12.5125
JCB	29	15	260498	3893725	95	15.3179
JCB	30	15	260494	3893713	77	14.7112
JCB	31	15	260506	3893712	70	13.3014
JCB	32	15	260518	3893714	47	18.0902
JCB	1	25	260528	3893767	95	9.0857
JCB	2	25	260512	3893761	95	8.7699
JCB	5	25	260514	3893743	90	17.4691
JCB	6	25	260525	3893744	90	12.7386
JCB	7	25	260533	3893746	45	13.798
JCB	8	25	260543	3893747	95	6.3153
JCB	9	25	260541	3893736	62	11.5046
JCB	10	25	260534	3893738	100	8.8724
JCB	11	25	260527	3893738	80	12.5129
JCB	12	25	260519	3893735	95	13.2015
JCB	13	25	260508	3893736	73	18.6602

JCB	14	25	260499	3893733	58	16.3835
JCB	15	25	260486	3893733	90	5.8087
JCB	16	25	260474	3893729	82	9.0854
JCB	17	25	260468	3893728	40	10.2708
JCB	18	25	260464	3893726	37	6.7487
JCB	19	25	260531	3893754	120	5.7135
JCB	20	25	260521	3893758	95	8.5354
JCB	21	25	260513	3893753	79	10.0154
JCB	22	25	260504	3893755	78	9.8676
JCB	24	25	260508	3893749	40	17.9096
JCB	25	25	260523	3893760	87	9.3015
JCB	26	25	260528	3893730	90	10.5645
JCB	27	25	260518	3893728	70	10.0667
JCB	28	25	260509	3893727	95	14.0141
JCB	29	25	260498	3893725	95	7.6263
JCB	30	25	260494	3893713	77	16.1966
JCB	31	25	260506	3893712	70	9.6529
JCB	32	25	260518	3893714	47	23.2906

A2. Geochemical Data

Site.ID	Smpl.No	C (%)	$\delta^{13}C$ (vs PDB)	N (%)	$\delta^{15}N$ (vs Air)	C:N
JCM	1	4.63	-27.43	0.21	0	22.27
JCM	2	11.29	-26.12	0.51	4.57	22.35
JCM	3	9.64	-27.23	0.38	1.24	25.17
JCM	4	4.65	-27.57	0.18	0.37	26.25
JCM	5	14.56	-27.54	0.88	0.97	16.49
JCM	6	17.25	-27.54	0.99	1.04	17.51
JCM	7	8.51	-26.44	0.44	4.28	19.52
JCM	8	13.69	-27.37	0.78	1.49	17.49
JCM	9	7.22	-27.54	0.36	0.73	19.84
JCM	10	6.92	-27.59	0.4	1.29	17.25
JCM	11	2.99	-26.78	0.16	1.98	19.14
JCM	12	11.65	-27.39	0.64	0.51	18.34
JCM	13	8.44	-27.06	0.4	0.93	21.1
JCM	14	7.81	-27.2	0.34	1.1	22.97
JCM	15	13.37	-27.28	0.76	1.64	17.71
JCM	16	18.39	-27.56	1.12	1.99	16.45
JCM	17	17.21	-27.59	1.07	1.23	16.03
JCM	18	8.77	-27.3	0.42	0.06	20.83
JCM	19	8.65	-27.23	0.49	0.75	17.69
JCM	20	8.74	-27.22	0.45	0.65	19.47
JCM	21	8.32	-26.93	0.44	1.7	18.86
JCM	22	13.88	-26.89	0.58	5.83	23.8
JCM	23	11.72	-26.73	0.54	3.74	21.86
JCM	24	9.42	-27.29	0.42	1.1	22.47
JCM	25	11.76	-26.79	0.56	2.83	21.04
JCM	26	11.81	-27.43	0.55	0.47	21.67
JCM	27	9.57	-27.7	0.44	0.46	21.91
JCM	28	15.75	-27.48	0.81	0.95	19.49
JCM	29	2.32	-25.69	0.13	5.56	18.11
JCM	30	15.84	-27.29	0.66	0.72	23.96
JCP	1	26.01	-26.02	1.21	3.64	21.58
JCP	2	2.56	-27.83	0.18	27.37	14.07
JCP	3	13.42	-26.9	0.41	8.47	32.82
JCP	4	9.36	-27.54	0.39	1.29	23.88
JCP	5	23.5	-26.24	0.77	0.47	30.65
JCP	6	4.35	-27.23	0.13	9.87	34.81
JCP	7	1.09	-27.45	0.04	0.28	30.22
JCP	8	4.44	-27.8	0.17	0.42	25.82
JCP	9	4.53	-27.27	0.24	1.68	19.11
JCP	10	3.56	-27.12	0.18	1.93	19.57
JCP	11	3.43	-27.26	0.14	1.01	24.01

JCP	12	12.05	-27.06	0.53	1.7	22.69
JCP	13	4.28	-27.05	0.16	4.76	27.4
JCP	14	9.1	-27.37	0.32	0.94	28.9
JCP	15	7.78	-27.67	0.28	0.54	27.48
JCP	16	9.06	-27.85	0.34	0.39	26.49
JCP	17	19.71	-26.99	0.62	5.53	31.94
JCP	18	4.23	-26.9	0.22	3.79	19.52
JCP	19	4.41	-26.74	0.21	3.95	21.12
JCP	20	4.68	-27.05	0.19	2.67	24.51
JCP	21	7.63	-26.56	0.31	5.8	24.86
JCP	22	5.07	-26.89	0.17	3.14	29.49
JCP	23	2.69	-26.56	0.09	3.62	31.22
JCP	24	6.29	-27.54	0.22	0.86	28.97
JCP	25	4.2	-26.99	0.12	6.06	34.45
JCP	26	8.17	-27.42	0.33	0.74	24.99
JCP	27	3.65	-27.56	0.12	-0.42	31.73
JCP	28	0.54	-26.51	0.02	-1.28	25.71
JCP	29	4.98	-27.12	0.15	-0.09	32.97
JCP	30	5.6	-27.39	0.18	-0.06	31.47
JCF	1	1.05	-26.92	0.05	-0.04	19.76
JCF	2	1.04	-27.36	0.05	0.36	19.96
JCF	3	1.81	-26.9	0.07	1.05	26.63
JCF	4	1.92	-27.39	0.1	1.42	18.44
JCF	5	1.42	-27.6	0.07	2.4	20.87
JCF	6	1.81	-26.5	0.11	1.75	17.24
JCF	7	1.16	-27.23	0.07	2.62	16.77
JCF	8	0.97	-26.1	0.07	2.96	14.94
JCF	9	0.99	-26.58	0.06	3.08	15.89
JCF	10	3.63	-26.36	0.23	1.4	15.97
JCF	11	3.35	-26.51	0.23	3.49	14.49
JCF	12	2.66	-26.8	0.16	2.19	16.32
JCF	13	0.99	-27.49	0.04	1.17	22.41
JCF	14	1.73	-26.9	0.1	2.3	16.99
JCF	15	1.28	-26.24	0.06	1.69	20.32
JCF	16	2.1	-27.01	0.15	2.69	14.08
JCF	17	2.44	-26.95	0.14	2.56	17.29
JCF	18	2.79	-26.63	0.19	3.45	15.09
JCF	19	2.71	-26.75	0.18	3.56	15.48
JCF	20	18.02	-26.81	0.68	5.31	26.39
JCF	21	3.86	-26.16	0.21	3.84	18.36
JCF	22	3.33	-26.78	0.16	2.8	21.34
JCF	23	4.37	-26.93	0.22	2.25	20.06
JCF	24	3.86	-26.94	0.2	0.97	19.13
JCF	25	5.05	-26.58	0.32	2.63	15.89
JCF	26	6.18	-26.94	0.34	1.56	18.16

JCF	27	7.14	-27.04	0.43	1.25	16.64
JCF	28	10.06	-26.14	0.48	3.24	21.01
JCF	29	6.14	-27	0.36	1.34	17.26
JCF	30	8.71	-26.43	0.46	3.29	19.15
JCB	1	3.77	-27.77	0.26	2.62	14.57
JCB	2	5.36	-27.41	0.33	3.56	16.49
JCB	3	3.02	-27.24	0.18	3.5	17.24
JCB	4	5.23	-27.67	0.34	4.33	15.23
JCB	5	5.38	-26.91	0.33	4.7	16.46
JCB	6	5.07	-27.3	0.34	5.09	14.93
JCB	7	3.94	-27.17	0.28	4.76	14.27
JCB	8	3.21	-27.39	0.23	4.38	14.17
JCB	9	3.58	-27.29	0.23	4.35	15.29
JCB	10	4.58	-27.46	0.3	3.31	15.49
JCB	11	4.66	-27.54	0.31	3.94	15.2
JCB	12	5.78	-26.74	0.29	4.23	19.93
JCB	13	6.89	-27.18	0.38	3.84	18.34
JCB	14	6.47	-26.82	0.29	4.04	22.09
JCB	15	3.21	-27.44	0.16	4.02	19.79
JCB	16	2.64	-27	0.15	4.88	17.55
JCB	17	5.14	-26.55	0.24	6.39	21.63
JCB	18	2.99	-26.02	0.15	6.18	19.7
JCB	19	2.64	-26.55	0.15	4.92	17.61
JCB	20	2.89	-26.82	0.16	5.33	17.62
JCB	21	4.2	-27.74	0.26	3.95	15.93
JCB	22	6	-27.85	0.36	2.08	16.79
JCB	23	7.09	-28.16	0.43	2.53	16.61
JCB	24	5.71	-27.43	0.34	3.72	16.83
JCB	25	4.38	-27.3	0.29	3.83	14.96
JCB	26	6.41	-28.43	0.42	3.74	15.19
JCB	27	5.16	-27.63	0.35	4.26	14.77
JCB	28	5.06	-27.17	0.33	4.9	15.36
JCB	29	6.15	-27.78	0.45	4.93	13.8
JCB	30	6.24	-26.38	0.31	4.39	19.93

A3. Long Core Data

Site	Depth	LOI (%)	C (%)	$\delta^{13}C$ (vs PDB)	N (%)	$\delta^{15}N$ (vs Air)	C:N
JCFC	5	12.3082	5.81	-26.44	0.28	0.38	20.75
JCFC	15	7.0266	2.65	-26.46	0.15	1.04	17.66667
JCFC	25	7.5763	2.66	-26.6	0.13	0.2	20.46154
JCFC	35	3.7068	1.14	-26.75	0.08	-0.26	14.25
JCFC	45	1.3603					
JCFC	55	3.6501	0.7	-26.18	0.02	-0.69	35
JCFC	65	4.4796	1.13	-26.23	0.06	0.28	18.83333
JCFC	75	4.6004	1.55	-26.58	0.09	0.72	17.22222
JCFC	85	5.774	2.02	-26.36	0.1	0.89	20.2
JCFC	95	4.1289	1.13	-26.38	0.07	-0.05	16.14286
JCFC	105	2.4822					
JCFC	115	3.6274	0.89	-26.61	0.06	-0.19	14.83333
JCFC	125	1.9599					
JCFC	135	3.5309					
JCFC	145	2.4755	0.5	-25.77	0.01	-1.93	50
JCFC	155	2.1978					
JCMC	5	36.4025	17.72	-27.89	1.07	1.58	16.56075
JCMC	15	33.7287	15.35	-27.98	0.71	0.85	21.61972
JCMC	25	32.8517	16.23	-27.95	0.82	1.29	19.79268
JCMC	35	18.6201	8.34	-26.35	0.39	3.17	21.38462
JCMC	45	21.606	9.9	-26.78	0.48	3.24	20.625
JCMC	55	14.8962	6.83	-26.57	0.27	6.43	25.2963
JCMC	65	17.4929	10.34	-27.13	0.33	5.56	31.33333
JCMC	75	8.7916	5.54	-26.93	0.2	4.43	27.7
JCMC	85	4.3551	2.57	-26.48	0.11	3.35	23.36364
JCMC	95	8.0082	3.44	-26.91	0.14	3.95	24.57143
JCMC	105	5.0398	1.43	-26.68	0.07	2.71	20.42857
JCBC	5	18.5979	8.19	-27.84	0.5	3.17	16.38
JCBC	15	14.5603	5	-27.31	0.33	4	15.15152
JCBC	25	13.8855	5.33	-27.7	0.33	3.75	16.15152
JCBC	35	11.7233	4.47	-26.38	0.24	4.42	18.625
JCBC	45	12.687	4.66	-27	0.26	4.42	17.92308
JCBC	55	11.2434	4.77	-26.47	0.21	4.36	22.71429
JCBC	65	11.5449	4.27	-26.68	0.21	4.22	20.33333
JCBC	75	3.1959	1.03	-26.62	0.06	1.71	17.16667
JCBC	85	4.4989	1.45	-26.69	0.07	2.41	20.71429
JCBC	95	1.832					
JCBC	105	2.9017					

APPENDIX B

[R] CODE

```
#Load libraries required for tests
#vegan is needed for NMDS, MASS for DFA, and plotrix for formatting plots
library(vegan)
library(MASS)
library(plotrix)

#import the data
#"surfacedata.csv" contains all my shallow samples
surface.data <-read.csv("surfacedata.csv", header=TRUE, sep=",")
#"coredata.csv" contains all my long core samples (including geochem measurements)
core.data <-read.csv("coredata.csv", header=TRUE, sep=",")
#"geochem.surface.csv" contains all the geochem measurements for my shallow samples
geochem.surface <-read.csv("geochem.surface.csv", header=TRUE, sep=",")
#remove JCP2 outlier
geochem.culled <- geochem.surface[-32, ]

#splitting data into 2 objects, one for descriptive properties and another for measured
variables
#Sample.Props contains externals and descriptors including lat-long and site ID
Sample.Props <- geochem.culled[ ,-c(12:18)]
#Sample.Measures should contain my laboratory data on carbon and nitrogen
Sample.Measures <- geochem.culled[ ,c(12:18)]

###########LOSS-ON-IGNITION PROFILES###############################
#calculate site average for each depth interval
#plot each sample location profile

#building table of site average at each depth
Averages <- list()
Averages[[1]] <- JCB.LOI.5.average <-
mean(surface.data$LOI.Perc[surface.data$Site.ID=="JCB" &
surface.data$Depth.cm=="5"])
Averages[[2]] <- JCF.LOI.5.average <-
mean(surface.data$LOI.Perc[surface.data$Site.ID=="JCF" &
surface.data$Depth.cm=="5"])
Averages[[3]] <- JCM.LOI.5.average <-
mean(surface.data$LOI.Perc[surface.data$Site.ID=="JCM" &
surface.data$Depth.cm=="5"])
Averages[[4]] <- JCP.LOI.5.average <-
mean(surface.data$LOI.Perc[surface.data$Site.ID=="JCP" &
surface.data$Depth.cm=="5"])
```

```
Averages[[5]] <- JCB.LOI.15.average <-
mean(surface.data$LOI.Perc[surface.data$Site.ID=="JCB" &
surface.data$Depth.cm=="15"])
Averages[[6]] <- JCF.LOI.15.average <-
mean(surface.data$LOI.Perc[surface.data$Site.ID=="JCF" &
surface.data$Depth.cm=="15"])
Averages[[7]] <- JCM.LOI.15.average <-
mean(surface.data$LOI.Perc[surface.data$Site.ID=="JCM" &
surface.data$Depth.cm=="15"])
Averages[[8]] <- JCP.LOI.15.average <-
mean(surface.data$LOI.Perc[surface.data$Site.ID=="JCP" &
surface.data$Depth.cm=="15"])
Averages[[9]] <- JCB.LOI.25.average <-
mean(surface.data$LOI.Perc[surface.data$Site.ID=="JCB" &
surface.data$Depth.cm=="25"])
Averages[[10]] <- JCF.LOI.25.average <-
mean(surface.data$LOI.Perc[surface.data$Site.ID=="JCF" &
surface.data$Depth.cm=="25"])
Averages[[11]] <- JCM.LOI.25.average <-
mean(surface.data$LOI.Perc[surface.data$Site.ID=="JCM" &
surface.data$Depth.cm=="25"])
Averages[[12]] <- JCP.LOI.25.average <-
mean(surface.data$LOI.Perc[surface.data$Site.ID=="JCP" &
surface.data$Depth.cm=="25"])
#formatting table
LOI.averages.table <- data.frame(matrix(unlist(Averages), nrow=3, ncol=4, byrow=T))
colnames(LOI.averages.table) <- c("JCB", "JCF", "JCM", "JCP")
LOI.average <- cbind(Depth.cm=c(5,15,25), LOI.averages.table)
LOI.avg <-as.data.frame(LOI.average)

#creating an "average profile" based on a regression of the site average
JCM.avg.reg <- lm(LOI.avg$Depth.cm~LOI.avg$JCM)
JCF.avg.reg <- lm(LOI.avg$Depth.cm~LOI.avg$JCF)
JCP.avg.reg <- lm(LOI.avg$Depth.cm~LOI.avg$JCP)
JCB.avg.reg <- lm(LOI.avg$Depth.cm~LOI.avg$JCB)

#plotting each sample LOI profile by sample number
windows(18,8)
par(mfrow=c(5,6))
plot(surface.data$LOI.Perc, surface.data$Depth.cm, type="n", xlim=c(0,55),
ylim=c(35,0), axes=FALSE, xaxs="i", yaxs="i", xlab=NA, ylab=NA)
box()
axis(2, tck=-0.015, las=1, labels=NA)
axis(2, lwd=0, line=-0.4, at=c(10, 20, 30), las=1)
mtext(side=2, "Depth (cm)", line=2, cex=0.75)
axis(3, tck=-0.015, labels=NA)
```

```
axis(3, lwd=0, line=-0.4)
mtext(side=3, "LOI (%)", line=1.75, cex=0.75)
mtext(side=1, "JCM_1", line=1, font=2, cex=1)
abline(JCM.avg.reg, col="gray", lty=2, lwd=1.25)
points(surface.data$LOI.Perc[surface.data$Site.ID=="JCM" &
surface.data$Smpl.No=="1"], surface.data$Depth.cm[surface.data$Site.ID=="JCM"  &
surface.data$Smpl.No=="1"])
points(surface.data$LOI.Perc[surface.data$Site.ID=="JCM" &
surface.data$Smpl.No=="1"], surface.data$Depth.cm[surface.data$Site.ID=="JCM"  &
surface.data$Smpl.No=="1"], type="l", col="red")
#this plotting command is repeated for each of the 30 samples from each site

############## LONG CORES############################################
#plotting profiles for my long cores

#LOI profiles
windows(9,12)
plot(core.data$LOI.Perc, core.data$Depth.cm, type="n", xlim=c(0,55), ylim=c(170,0),
axes=FALSE, xaxs="i", yaxs="i", xlab=NA, ylab=NA)
box()
axis(2, tck=-0.015, las=1, labels=NA)
axis(2, lwd=0, line=-0.4, at=c(10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120, 130, 140,
150, 160, 170), las=1)
mtext(side=2, "Depth (cm)", line=2, cex=0.75)
axis(3, tck=-0.015, labels=NA)
axis(3, lwd=0, line=-0.4)
mtext(side=3, "LOI (%)", line=1.75, cex=0.75)
mtext(side=1, "LOI Profiles for Long Core Samples", line=1, font=2, cex=1)

#creating regression line from profiles
JCF.reg <-lm(formula = core.data$Depth.cm[core.data$Site.ID == "JCFC"] ~
core.data$LOI.Perc[core.data$Site.ID == "JCFC"])
JCM.reg <-lm(formula = core.data$Depth.cm[core.data$Site.ID == "JCMC"] ~
core.data$LOI.Perc[core.data$Site.ID == "JCMC"])
JCB.reg <-lm(formula = core.data$Depth.cm[core.data$Site.ID == "JCBC"] ~
core.data$LOI.Perc[core.data$Site.ID == "JCBC"])

#making LOI plots
windows(12, 9)
par(mfrow=c(1,3))

#JCB
plot(core.data$LOI.Perc, core.data$Depth.cm, type="n", xlim=c(0,55), ylim=c(170,0),
axes=FALSE, xaxs="i", yaxs="i", xlab=NA, ylab=NA)
box()
axis(2, tck=-0.015, las=1, labels=NA)
```

```
axis(2, lwd=0, line=-0.4, at=c(10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120, 130, 140,
150, 160, 170), las=1)
mtext(side=2, "Depth (cm)", line=2, cex=0.75)
axis(3, tck=-0.015, labels=NA)
axis(3, lwd=0, line=-0.4)
mtext(side=3, "LOI (%)", line=1.75, cex=0.75)
mtext(side=1, "JCB Long Core LOI Profile", line=1, font=2, cex=1)
points(core.data$LOI.Perc[core.data$Site.ID=="JCBC"],
core.data$Depth.cm[core.data$Site.ID=="JCBC"], type="l", col="red")
points(core.data$LOI.Perc[core.data$Site.ID=="JCBC"],
core.data$Depth.cm[core.data$Site.ID=="JCBC"])
abline(JCB.reg, col="gray", lwd=1.5, lty=2)

#JCF
plot(core.data$LOI.Perc, core.data$Depth.cm, type="n", xlim=c(0,55), ylim=c(170,0),
axes=FALSE, xaxs="i", yaxs="i", xlab=NA, ylab=NA)
box()
axis(2, tck=-0.015, las=1, labels=NA)
axis(2, lwd=0, line=-0.4, at=c(10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120, 130, 140,
150, 160, 170), las=1)
mtext(side=2, "Depth (cm)", line=2, cex=0.75)
axis(3, tck=-0.015, labels=NA)
axis(3, lwd=0, line=-0.4)
mtext(side=3, "LOI (%)", line=1.75, cex=0.75)
mtext(side=1, "JCF Long Core LOI Profile", line=1, font=2, cex=1)
points(core.data$LOI.Perc[core.data$Site.ID=="JCFC"],
core.data$Depth.cm[core.data$Site.ID=="JCFC"], type="l", col="dark red")
points(core.data$LOI.Perc[core.data$Site.ID=="JCFC"],
core.data$Depth.cm[core.data$Site.ID=="JCFC"])
abline(JCF.reg, col="gray", lwd=1.5, lty=2)

#JCM
plot(core.data$LOI.Perc, core.data$Depth.cm, type="n", xlim=c(0,55), ylim=c(170,0),
axes=FALSE, xaxs="i", yaxs="i", xlab=NA, ylab=NA)
box()
axis(2, tck=-0.015, las=1, labels=NA)
axis(2, lwd=0, line=-0.4, at=c(10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120, 130, 140,
150, 160, 170), las=1)
mtext(side=2, "Depth (cm)", line=2, cex=0.75)
axis(3, tck=-0.015, labels=NA)
axis(3, lwd=0, line=-0.4)
mtext(side=3, "LOI (%)", line=1.75, cex=0.75)
mtext(side=1, "JCM Long Core LOI Profile", line=1, font=2, cex=1)
points(core.data$LOI.Perc[core.data$Site.ID=="JCMC"],
core.data$Depth.cm[core.data$Site.ID=="JCMC"], type="l", col="light blue")
```

```
points(core.data$LOI.Perc[core.data$Site.ID=="JCMC"],
core.data$Depth.cm[core.data$Site.ID=="JCMC"])
abline(JCM.reg, col="gray", lwd=1.5, lty=2)

#making geochemical profiles
windows(14, 7)
par(mfrow=c(1,5))

#Total Carbon
plot(core.data$Total.C, core.data$Depth.cm, type="n", xlim=c(0,20), ylim=c(170,0),
axes=FALSE, xaxs="i", yaxs="i", xlab=NA, ylab=NA)
box()
axis(2, tck=-0.015, las=1,
labels=c(10,20,30,40,50,60,70,80,90,100,110,120,130,140,150,160),
at=c(10,20,30,40,50,60,70,80,90,100,110,120,130,140,150,160))
mtext(side=2, "Depth (cm)", line=2.5, cex=0.75)
axis(3, tck=-0.015, labels=c(0,5,10,15,20), at=c(0,5,10,15,20))
mtext(side=3, "Total Carbon (%)", line=2.2, cex=0.75)
mtext(side=1, "Total Carbon Profiles", line=1, font=2, cex=1)
text(x=12.5, y=40, labels="JCM", col="light blue", cex=1.25)
text(x=2, y=10, labels="JCF", col="dark red", cex=1.25)
text(x=7.5, y=25, labels="JCB", col="red", cex=1.25)
#Adding JCFC
points(core.data$Total.C[core.data$Site.ID=="JCFC"],
core.data$Depth.cm[core.data$Site.ID=="JCFC"])
points(core.data$Total.C[core.data$Site.ID=="JCFC"],
core.data$Depth.cm[core.data$Site.ID=="JCFC"], type="l", col="dark red")
#Adding JCMC
points(core.data$Total.C[core.data$Site.ID=="JCMC"],
core.data$Depth.cm[core.data$Site.ID=="JCMC"])
points(core.data$Total.C[core.data$Site.ID=="JCMC"],
core.data$Depth.cm[core.data$Site.ID=="JCMC"], type="l", col="light blue")
#Adding JCBC
points(core.data$Total.C[core.data$Site.ID=="JCBC"],
core.data$Depth.cm[core.data$Site.ID=="JCBC"])
points(core.data$Total.C[core.data$Site.ID=="JCBC"],
core.data$Depth.cm[core.data$Site.ID=="JCBC"], type="l", col="red")

#Total Nitrogen
plot(core.data$Total.N, core.data$Depth.cm, type="n", xlim=c(-0.1,1.3), ylim=c(170,0),
axes=FALSE, xaxs="i", yaxs="i", xlab=NA, ylab=NA)
box()
axis(2, tck=-0.015, las=1,
labels=c(10,20,30,40,50,60,70,80,90,100,110,120,130,140,150,160),
at=c(10,20,30,40,50,60,70,80,90,100,110,120,130,140,150,160))
mtext(side=2, "Depth (cm)", line=2.5, cex=0.75)
```

```
axis(3, tck=-0.015, labels=c(0, 0.25, 0.5, 0.75, 1, 1.25), at=c(0, 0.25, 0.5, 0.75, 1, 1.25))
mtext(side=3, "Total Nitrogen (%)", line=2.2, cex=0.75)
mtext(side=1, "Total Nitrogen Profiles", line=1, font=2, cex=1)
#Adding JCFC
points(core.data$Total.N[core.data$Site.ID=="JCFC"],
core.data$Depth.cm[core.data$Site.ID=="JCFC"])
points(core.data$Total.N[core.data$Site.ID=="JCFC"],
core.data$Depth.cm[core.data$Site.ID=="JCFC"], type="l", col="dark red")
#Adding JCMC
points(core.data$Total.N[core.data$Site.ID=="JCMC"],
core.data$Depth.cm[core.data$Site.ID=="JCMC"])
points(core.data$Total.N[core.data$Site.ID=="JCMC"],
core.data$Depth.cm[core.data$Site.ID=="JCMC"], type="l", col="light blue")
#Adding JCBC
points(core.data$Total.N[core.data$Site.ID=="JCBC"],
core.data$Depth.cm[core.data$Site.ID=="JCBC"])
points(core.data$Total.N[core.data$Site.ID=="JCBC"],
core.data$Depth.cm[core.data$Site.ID=="JCBC"], type="l", col="red")

#d15N
plot(core.data$d15N, core.data$Depth.cm, type="n", xlim=c(-2.1,7), ylim=c(170,0),
axes=FALSE, xaxs="i", yaxs="i", xlab=NA, ylab=NA)
box()
axis(2, tck=-0.015, las=1,
labels=c(10,20,30,40,50,60,70,80,90,100,110,120,130,140,150,160),
at=c(10,20,30,40,50,60,70,80,90,100,110,120,130,140,150,160))
mtext(side=2, "Depth (cm)", line=2.5, cex=0.75)
axis(3, tck=-0.015, labels=c(-2,0, 2, 4, 6), at=c(-2,0,2,4,6))
mtext(side=3, "d15N (vs Air)", line=2.2, cex=0.75)
mtext(side=1, "D15N Profiles", line=1, font=2, cex=1)
#Adding JCFC
points(core.data$d15N[core.data$Site.ID=="JCFC"],
core.data$Depth.cm[core.data$Site.ID=="JCFC"])
points(core.data$d15N[core.data$Site.ID=="JCFC"],
core.data$Depth.cm[core.data$Site.ID=="JCFC"], type="l", col="dark red")
#Adding JCMC
points(core.data$d15N[core.data$Site.ID=="JCMC"],
core.data$Depth.cm[core.data$Site.ID=="JCMC"])
points(core.data$d15N[core.data$Site.ID=="JCMC"],
core.data$Depth.cm[core.data$Site.ID=="JCMC"], type="l", col="light blue")
#Adding JCBC
points(core.data$d15N[core.data$Site.ID=="JCBC"],
core.data$Depth.cm[core.data$Site.ID=="JCBC"])
points(core.data$d15N[core.data$Site.ID=="JCBC"],
core.data$Depth.cm[core.data$Site.ID=="JCBC"], type="l", col="red")
```

```
#d13C
plot(core.data$d13C, core.data$Depth.cm, type="n", xlim=c(-28.1,-25), ylim=c(170,0),
axes=FALSE, xaxs="i", yaxs="i", xlab=NA, ylab=NA)
box()
axis(2, tck=-0.015, las=1,
labels=c(10,20,30,40,50,60,70,80,90,100,110,120,130,140,150,160),
at=c(10,20,30,40,50,60,70,80,90,100,110,120,130,140,150,160))
mtext(side=2, "Depth (cm)", line=2.5, cex=0.75)
axis(3, tck=-0.015, labels=c(-28, -27, -26, -25), at=c(-28, -27, -26, -25))
mtext(side=3, "d13C (vs PDB)", line=2.2, cex=0.75)
mtext(side=1, "D13C Profiles", line=1, font=2, cex=1)
#Adding JCFC
points(core.data$d13C[core.data$Site.ID=="JCFC"],
core.data$Depth.cm[core.data$Site.ID=="JCFC"])
points(core.data$d13C[core.data$Site.ID=="JCFC"],
core.data$Depth.cm[core.data$Site.ID=="JCFC"], type="l", col="dark red")
#Adding JCMC
points(core.data$d13C[core.data$Site.ID=="JCMC"],
core.data$Depth.cm[core.data$Site.ID=="JCMC"])
points(core.data$d13C[core.data$Site.ID=="JCMC"],
core.data$Depth.cm[core.data$Site.ID=="JCMC"], type="l", col="light blue")
#Adding JCBC
points(core.data$d13C[core.data$Site.ID=="JCBC"],
core.data$Depth.cm[core.data$Site.ID=="JCBC"])
points(core.data$d13C[core.data$Site.ID=="JCBC"],
core.data$Depth.cm[core.data$Site.ID=="JCBC"], type="l", col="red")

#C.N
plot(core.data$C.N, core.data$Depth.cm, type="n", xlim=c(0,52), ylim=c(170,0),
axes=FALSE, xaxs="i", yaxs="i", xlab=NA, ylab=NA)
box()
axis(2, tck=-0.015, las=1,
labels=c(10,20,30,40,50,60,70,80,90,100,110,120,130,140,150,160),
at=c(10,20,30,40,50,60,70,80,90,100,110,120,130,140,150,160))
mtext(side=2, "Depth (cm)", line=2.5, cex=0.75)
axis(3, tck=-0.015, labels=c(0, 10, 20, 30, 40, 50), at=c(0, 10, 20, 30, 40, 50))
mtext(side=3, "C:N Values", line=2.2, cex=0.75)
mtext(side=1, "C:N Profiles", line=1, font=2, cex=1)
#Adding JCFC
points(core.data$C.N[core.data$Site.ID=="JCFC"],
core.data$Depth.cm[core.data$Site.ID=="JCFC"])
points(core.data$C.N[core.data$Site.ID=="JCFC"],
core.data$Depth.cm[core.data$Site.ID=="JCFC"], type="l", col="dark red")
#Adding JCMC
points(core.data$C.N[core.data$Site.ID=="JCMC"],
core.data$Depth.cm[core.data$Site.ID=="JCMC"])
```

```
points(core.data$C.N[core.data$Site.ID=="JCMC"],
core.data$Depth.cm[core.data$Site.ID=="JCMC"], type="l", col="light blue")
#Adding JCBC
points(core.data$C.N[core.data$Site.ID=="JCBC"],
core.data$Depth.cm[core.data$Site.ID=="JCBC"])
points(core.data$C.N[core.data$Site.ID=="JCBC"],
core.data$Depth.cm[core.data$Site.ID=="JCBC"], type="l", col="red")

############## GEOCHEM PLOTS########################################
#make comparative plots
windows(8,11)
par(mfrow=c(3,2))

#Total N vs d15N
plot(geochem.culled$Total.N, geochem.culled$d15N, type="n", main="A", xlab="Total
N (%)", ylab="d15N (vs Air)")
points(geochem.culled$Total.N[geochem.culled$Site.ID=="JCM"],
geochem.culled$d15N[geochem.culled$Site.ID=="JCM"], pch=21, col="black",
bg="light blue")
points(geochem.culled$Total.N[geochem.culled$Site.ID=="JCF"],
geochem.culled$d15N[geochem.culled$Site.ID=="JCF"], pch=3, lwd=1.25, col="dark
red")
points(geochem.culled$Total.N[geochem.culled$Site.ID=="JCB"],
geochem.culled$d15N[geochem.culled$Site.ID=="JCB"], pch=0, lwd=0.75, col="red")
points(geochem.culled$Total.N[geochem.culled$Site.ID=="JCP"],
geochem.culled$d15N[geochem.culled$Site.ID=="JCP"], pch=17, col="blue")

#Total C vs Total N
plot(geochem.culled$Total.C, geochem.culled$Total.N, type="n", main="B",
xlab="Total C (%)", ylab="Total N (%)")
points(geochem.culled$Total.C[geochem.culled$Site.ID=="JCM"],
geochem.culled$Total.N[geochem.culled$Site.ID=="JCM"], pch=21, col="black",
bg="light blue")
points(geochem.culled$Total.C[geochem.culled$Site.ID=="JCF"],
geochem.culled$Total.N[geochem.culled$Site.ID=="JCF"], pch=3, lwd=1.25, col="dark
red")
points(geochem.culled$Total.C[geochem.culled$Site.ID=="JCB"],
geochem.culled$Total.N[geochem.culled$Site.ID=="JCB"], pch=0, lwd=0.75, col="red")
points(geochem.culled$Total.C[geochem.culled$Site.ID=="JCP"],
geochem.culled$Total.N[geochem.culled$Site.ID=="JCP"], pch=17, col="blue")

#d13C vs d15N
plot(geochem.culled$d13C, geochem.culled$d15N, type="n", main="C", xlab="d13C (vs
PDB)", ylab="d15N (vs Air)")
```

```
points(geochem.culled$d13C[geochem.culled$Site.ID=="JCM"],
geochem.culled$d15N[geochem.culled$Site.ID=="JCM"], pch=21, col="black",
bg="light blue")
points(geochem.culled$d13C[geochem.culled$Site.ID=="JCF"],
geochem.culled$d15N[geochem.culled$Site.ID=="JCF"], pch=3, lwd=1.25, col="dark
red")
points(geochem.culled$d13C[geochem.culled$Site.ID=="JCB"],
geochem.culled$d15N[geochem.culled$Site.ID=="JCB"], pch=0, lwd=0.75, col="red")
points(geochem.culled$d13C[geochem.culled$Site.ID=="JCP"],
geochem.culled$d15N[geochem.culled$Site.ID=="JCP"], pch=17, col="blue")

#d13C vs C:N
plot(geochem.culled$d13C, geochem.culled$C.N, type="n", main="D", xlab="d13C (vs
PDB)", ylab="C:N")
points(geochem.culled$d13C[geochem.culled$Site.ID=="JCM"],
geochem.culled$C.N[geochem.culled$Site.ID=="JCM"], pch=21, col="black", bg="light
blue")
points(geochem.culled$d13C[geochem.culled$Site.ID=="JCF"],
geochem.culled$C.N[geochem.culled$Site.ID=="JCF"], pch=3, lwd=1.25, col="dark
red")
points(geochem.culled$d13C[geochem.culled$Site.ID=="JCB"],
geochem.culled$C.N[geochem.culled$Site.ID=="JCB"], pch=0, lwd=0.75, col="red")
points(geochem.culled$d13C[geochem.culled$Site.ID=="JCP"],
geochem.culled$C.N[geochem.culled$Site.ID=="JCP"], pch=17, col="blue")

#C:N vs d15N
plot(geochem.culled$C.N, geochem.culled$d15N, type="n", main="E", xlab="C:N",
ylab="d15N (vs Air)")
points(geochem.culled$C.N[geochem.culled$Site.ID=="JCM"],
geochem.culled$d15N[geochem.culled$Site.ID=="JCM"], pch=21, col="black",
bg="light blue")
points(geochem.culled$C.N[geochem.culled$Site.ID=="JCF"],
geochem.culled$d15N[geochem.culled$Site.ID=="JCF"], pch=3, lwd=1.25, col="dark
red")
points(geochem.culled$C.N[geochem.culled$Site.ID=="JCB"],
geochem.culled$d15N[geochem.culled$Site.ID=="JCB"], pch=0, lwd=0.75, col="red")
points(geochem.culled$C.N[geochem.culled$Site.ID=="JCP"],
geochem.culled$d15N[geochem.culled$Site.ID=="JCP"], pch=17, col="blue")
#end of geochem plots

############## CONFIDENCE INTERVALS ##################################
#estimating 95% confidence intervals for each variable using Mann Whitney U
#compile data using ‘tests’
#tabulate results using ‘sapply’
#plot results using ‘plotCI’
```

```
#Total Carbon
tests <- list()
tests[[1]] <- wilcox.test(geochem.culled$Total.C[geochem.culled$Site.ID=="JCB"],
conf.int=TRUE, conf.level=0.95)
tests[[2]] <- wilcox.test(geochem.culled$Total.C[geochem.culled$Site.ID=="JCF"],
conf.int=TRUE, conf.level=0.95)
tests[[3]] <- wilcox.test(geochem.culled$Total.C[geochem.culled$Site.ID=="JCM"],
conf.int=TRUE, conf.level=0.95)
tests[[4]] <- wilcox.test(geochem.culled$Total.C[geochem.culled$Site.ID=="JCP"],
conf.int=TRUE, conf.level=0.95)

Total.C.wilcox.table <- sapply(tests, function(x) {
        c( x$estimate[1],
          ci.lower = x$conf.int[1],
          ci.upper = x$conf.int[2],
          p.value=x$p.value)
})

#formatting table
colnames(Total.C.wilcox.table) <- c("JCB", "JCF", "JCM", "JCP")
Total.C.Sites <- t(Total.C.wilcox.table)
Total.C.Sites <- cbind(Site.No=c(1,2,3,4), Total.C.Sites)
Total.C <-as.data.frame(Total.C.Sites)
colnames(Total.C) <- c("Site.ID", "Median", "CI.Lower", "CI.Upper", "p.value")

#plotting results
windows()
plotCI(Total.C$Site.ID, Total.C$Median, ui=Total.C$CI.Upper, li=Total.C$CI.Lower,
xlab="Sites", ylab="Mean Total Carbon", xlim=c(0.5,4.5), axes=FALSE, pch=16)
box()
axis(1, tck=-0.015, labels=NA)
axis(1, at=c(1,2,3,4), labels=c("JCB", "JCF", "JCM", "JCP"))
axis(2, tck=-0.015, las=1, labels=NA)
axis(2, lwd=0, line=-0.4, las=1)
mtext(side=3, "Total Carbon 95% Confidence Intervals", line=1, font=2, cex=1)

#Total Nitrogen
tests <- list()
tests[[1]] <- wilcox.test(geochem.culled$Total.N[geochem.culled$Site.ID=="JCB"],
conf.int=TRUE, conf.level=0.95)
tests[[2]] <- wilcox.test(geochem.culled$Total.N[geochem.culled$Site.ID=="JCF"],
conf.int=TRUE, conf.level=0.95)
tests[[3]] <- wilcox.test(geochem.culled$Total.N[geochem.culled$Site.ID=="JCM"],
conf.int=TRUE, conf.level=0.95)
tests[[4]] <- wilcox.test(geochem.culled$Total.N[geochem.culled$Site.ID=="JCP"],
conf.int=TRUE, conf.level=0.95)
```

```
Total.N.wilcox.table <- sapply(tests, function(x) {
        c( x$estimate[1],
          ci.lower = x$conf.int[1],
          ci.upper = x$conf.int[2],
          p.value=x$p.value)
})

#formatting table
colnames(Total.N.wilcox.table) <- c("JCB", "JCF", "JCM", "JCP")
Total.N.Sites <- t(Total.N.wilcox.table)
Total.N.Sites <- cbind(Site.No=c(1,2,3,4), Total.N.Sites)
Total.N <-as.data.frame(Total.N.Sites)
colnames(Total.N) <- c("Site.ID", "Median", "CI.Lower", "CI.Upper", "p.value")

#plotting results
windows()
plotCI(Total.N$Site.ID, Total.N$Median, ui=Total.N$CI.Upper, li=Total.N$CI.Lower,
xlab="Sites", ylab="Mean Total Nitrogen", xlim=c(0.5,4.5), axes=FALSE, pch=16)
box()
axis(1, tck=-0.015, labels=NA)
axis(1, at=c(1,2,3,4), labels=c("JCB", "JCF", "JCM", "JCP"))
axis(2, tck=-0.015, las=1, labels=NA)
axis(2, lwd=0, line=-0.4, las=1)
mtext(side=3, "Total Nitrogen 95% Confidence Intervals", line=1, font=2, cex=1)

#d13C
tests <- list()
tests[[1]] <- wilcox.test(geochem.culled$d13C[geochem.culled$Site.ID=="JCB"],
conf.int=TRUE, conf.level=0.95)
tests[[2]] <- wilcox.test(geochem.culled$d13C[geochem.culled$Site.ID=="JCF"],
conf.int=TRUE, conf.level=0.95)
tests[[3]] <- wilcox.test(geochem.culled$d13C[geochem.culled$Site.ID=="JCM"],
conf.int=TRUE, conf.level=0.95)
tests[[4]] <- wilcox.test(geochem.culled$d13C[geochem.culled$Site.ID=="JCP"],
conf.int=TRUE, conf.level=0.95)

table.d13C <- sapply(tests, function(x) {
        c( x$estimate[1],
          ci.lower = x$conf.int[1],
          ci.upper = x$conf.int[2],
          p.value=x$p.value)
})

#formatting table
colnames(table.d13C) <- c("JCB", "JCF", "JCM", "JCP")
```

```
d13C.Sites <- t(table.d13C)
d13C.Sites <- cbind(Site.No=c(1,2,3,4), d13C.Sites)
d13C <-as.data.frame(d13C.Sites)
colnames(d13C) <- c("Site.ID", "Mean", "CI.Lower", "CI.Upper", "p.value")

#plotting results
windows()
plotCI(d13C$Site.ID, d13C$Mean, ui=d13C$CI.Upper, li=d13C$CI.Lower,
xlab="Sites", ylab="Mean d13C", xlim=c(0.5,4.5), axes=FALSE, pch=16)
box()
axis(1, tck=-0.015, labels=NA)
axis(1, at=c(1,2,3,4), labels=c("JCB", "JCF", "JCM", "JCP"))
axis(2, tck=-0.015, las=1, labels=NA)
axis(2, lwd=0, line=-0.4, las=1)
mtext(side=3, "d13C 95% Confidence Intervals", line=1, font=2, cex=1)

#d15N
tests <- list()
tests[[1]] <- wilcox.test(geochem.culled$d15N[geochem.culled$Site.ID=="JCB"],
conf.int=TRUE, conf.level=0.95)
tests[[2]] <- wilcox.test(geochem.culled$d15N[geochem.culled$Site.ID=="JCF"],
conf.int=TRUE, conf.level=0.95)
tests[[3]] <- wilcox.test(geochem.culled$d15N[geochem.culled$Site.ID=="JCM"],
conf.int=TRUE, conf.level=0.95)
tests[[4]] <- wilcox.test(geochem.culled$d15N[geochem.culled$Site.ID=="JCP"],
conf.int=TRUE, conf.level=0.95)

table.d15N <- sapply(tests, function(x) {
        c( x$estimate[1],
          ci.lower = x$conf.int[1],
          ci.upper = x$conf.int[2],
          p.value=x$p.value)
})

#formatting table
colnames(table.d15N) <- c("JCB", "JCF", "JCM", "JCP")
d15N.Sites <- t(table.d15N)
d15N.Sites <- cbind(Site.No=c(1,2,3,4), d15N.Sites)
d15N <-as.data.frame(d15N.Sites)
colnames(d15N) <- c("Site.ID", "Mean", "CI.Lower", "CI.Upper", "p.value")

#plotting results
windows()
plotCI(d15N$Site.ID, d15N$Mean, ui=d15N$CI.Upper, li=d15N$CI.Lower,
xlab="Sites", ylab="Mean d15N", xlim=c(0.5,4.5), axes=FALSE, pch=16)
box()
```

```
axis(1, tck=-0.015, labels=NA)
axis(1, at=c(1,2,3,4), labels=c("JCB", "JCF", "JCM", "JCP"))
axis(2, tck=-0.015, las=1, labels=NA)
axis(2, lwd=0, line=-0.4, las=1)
mtext(side=3, "d15N 95% Confidence Intervals", line=1, font=2, cex=1)


#C.N
tests <- list()
tests[[1]] <- wilcox.test(geochem.culled$C.N[geochem.culled$Site.ID=="JCB"],
conf.int=TRUE, conf.level=0.95)
tests[[2]] <- wilcox.test(geochem.culled$C.N[geochem.culled$Site.ID=="JCF"],
conf.int=TRUE, conf.level=0.95)
tests[[3]] <- wilcox.test(geochem.culled$C.N[geochem.culled$Site.ID=="JCM"],
conf.int=TRUE, conf.level=0.95)
tests[[4]] <- wilcox.test(geochem.culled$C.N[geochem.culled$Site.ID=="JCP"],
conf.int=TRUE, conf.level=0.95)

table.C.N <- sapply(tests, function(x) {
        c( x$estimate[1],
          ci.lower = x$conf.int[1],
          ci.upper = x$conf.int[2],
          p.value=x$p.value)
})

#formatting table
colnames(table.C.N) <- c("JCB", "JCF", "JCM", "JCP")
C.N.Sites <- t(table.C.N)
C.N.Sites <- cbind(Site.No=c(1,2,3,4), C.N.Sites)
C.N <-as.data.frame(C.N.Sites)
colnames(C.N) <- c("Site.ID", "Mean", "CI.Lower", "CI.Upper", "p.value")

#plotting results
windows()
plotCI(C.N$Site.ID, C.N$Mean, ui=C.N$CI.Upper, li=C.N$CI.Lower, xlab="Sites",
ylab="Mean C.N", xlim=c(0.5,4.5), axes=FALSE, pch=16)
box()
axis(1, tck=-0.015, labels=NA)
axis(1, at=c(1,2,3,4), labels=c("JCB", "JCF", "JCM", "JCP"))
axis(2, tck=-0.015, las=1, labels=NA)
axis(2, lwd=0, line=-0.4, las=1)
mtext(side=3, "CN 95% Confidence Intervals", line=1, font=2, cex=1)

#LOI.Perc 0 to 10
tests <- list()
```

```
tests[[1]] <- wilcox.test(surface.data$LOI.Perc[surface.data$Site.ID=="JCB" &
surface.data$Depth.cm=="5"], conf.int=TRUE, conf.level=0.95)
tests[[2]] <- wilcox.test(surface.data$LOI.Perc[surface.data$Site.ID=="JCF" &
surface.data$Depth.cm=="5"], conf.int=TRUE, conf.level=0.95)
tests[[3]] <- wilcox.test(surface.data$LOI.Perc[surface.data$Site.ID=="JCM" &
surface.data$Depth.cm=="5"], conf.int=TRUE, conf.level=0.95)
tests[[4]] <- wilcox.test(surface.data$LOI.Perc[surface.data$Site.ID=="JCP" &
surface.data$Depth.cm=="5"], conf.int=TRUE, conf.level=0.95)
table.LOI.Perc.10 <- sapply(tests, function(x) {
        c( x$estimate[1],
          ci.lower = x$conf.int[1],
          ci.upper = x$conf.int[2],
          p.value=x$p.value)
})

#formatting table
colnames(table.LOI.Perc.10) <- c("JCB", "JCF", "JCM", "JCP")
LOI.Perc.Sites.10 <- t(table.LOI.Perc.10)
LOI.Perc.Sites.10 <- cbind(Site.No=c(1,2,3,4), LOI.Perc.Sites.10)
LOI.Perc.10 <-as.data.frame(LOI.Perc.Sites.10)
colnames(LOI.Perc.10) <- c("Site.ID", "Mean", "CI.Lower", "CI.Upper", "p.value")

#plotting results
windows()
plotCI(LOI.Perc.10$Site.ID, LOI.Perc.10$Mean, ui=LOI.Perc.10$CI.Upper,
li=LOI.Perc.10$CI.Lower, xlab="Sites", ylab="Mean LOI.Perc", xlim=c(0.5,4.5),
axes=FALSE, pch=16)
box()
axis(1, tck=-0.015, labels=NA)
axis(1, at=c(1,2,3,4), labels=c("JCB", "JCF", "JCM", "JCP"))
axis(2, tck=-0.015, las=1, labels=NA)
axis(2, lwd=0, line=-0.4, las=1)
mtext(side=3, "LOI 0 to 10 95% Confidence Intervals", line=1, font=2, cex=1)

#LOI.Perc 10 to 20
tests <- list()
tests[[1]] <- wilcox.test(surface.data$LOI.Perc[surface.data$Site.ID=="JCB" &
surface.data$Depth.cm=="15"], conf.int=TRUE, conf.level=0.95)
tests[[2]] <- wilcox.test(surface.data$LOI.Perc[surface.data$Site.ID=="JCF" &
surface.data$Depth.cm=="15"], conf.int=TRUE, conf.level=0.95)
tests[[3]] <- wilcox.test(surface.data$LOI.Perc[surface.data$Site.ID=="JCM" &
surface.data$Depth.cm=="15"], conf.int=TRUE, conf.level=0.95)
tests[[4]] <- wilcox.test(surface.data$LOI.Perc[surface.data$Site.ID=="JCP" &
surface.data$Depth.cm=="15"], conf.int=TRUE, conf.level=0.95)

table.LOI.Perc.20 <- sapply(tests, function(x) {
```

```
        c( x$estimate[1],
          ci.lower = x$conf.int[1],
          ci.upper = x$conf.int[2],
          p.value=x$p.value)
})

#formatting table
colnames(table.LOI.Perc.20) <- c("JCB", "JCF", "JCM", "JCP")
LOI.Perc.Sites.10 <- t(table.LOI.Perc.20)
LOI.Perc.Sites.10 <- cbind(Site.No=c(1,2,3,4), LOI.Perc.Sites.10)
LOI.Perc.20 <-as.data.frame(LOI.Perc.Sites.10)
colnames(LOI.Perc.20) <- c("Site.ID", "Mean", "CI.Lower", "CI.Upper", "p.value")

#plotting results
windows()
plotCI(LOI.Perc.20$Site.ID, LOI.Perc.20$Mean, ui=LOI.Perc.20$CI.Upper,
li=LOI.Perc.20$CI.Lower, xlab="Sites", ylab="Mean LOI.Perc", xlim=c(0.5,4.5),
axes=FALSE, pch=16)
box()
axis(1, tck=-0.015, labels=NA)
axis(1, at=c(1,2,3,4), labels=c("JCB", "JCF", "JCM", "JCP"))
axis(2, tck=-0.015, las=1, labels=NA)
axis(2, lwd=0, line=-0.4, las=1)
mtext(side=3, "LOI 10 to 20 95% Confidence Intervals", line=1, font=2, cex=1)

#LOI.Perc 20 to 30
tests <- list()
tests[[1]] <- wilcox.test(surface.data$LOI.Perc[surface.data$Site.ID=="JCB" &
surface.data$Depth.cm=="15"], conf.int=TRUE, conf.level=0.95)
tests[[2]] <- wilcox.test(surface.data$LOI.Perc[surface.data$Site.ID=="JCF" &
surface.data$Depth.cm=="15"], conf.int=TRUE, conf.level=0.95)
tests[[3]] <- wilcox.test(surface.data$LOI.Perc[surface.data$Site.ID=="JCM" &
surface.data$Depth.cm=="15"], conf.int=TRUE, conf.level=0.95)
tests[[4]] <- wilcox.test(surface.data$LOI.Perc[surface.data$Site.ID=="JCP" &
surface.data$Depth.cm=="15"], conf.int=TRUE, conf.level=0.95)

table.LOI.Perc.30 <- sapply(tests, function(x) {
        c( x$estimate[1],
          ci.lower = x$conf.int[1],
          ci.upper = x$conf.int[2],
          p.value=x$p.value)
})

#formatting table
colnames(table.LOI.Perc.30) <- c("JCB", "JCF", "JCM", "JCP")
LOI.Perc.Sites.10 <- t(table.LOI.Perc.30)
```

```
LOI.Perc.Sites.10 <- cbind(Site.No=c(1,2,3,4), LOI.Perc.Sites.10)
LOI.Perc.30 <-as.data.frame(LOI.Perc.Sites.10)
colnames(LOI.Perc.30) <- c("Site.ID", "Mean", "CI.Lower", "CI.Upper", "p.value")

#plotting results
windows()
plotCI(LOI.Perc.30$Site.ID, LOI.Perc.30$Mean, ui=LOI.Perc.30$CI.Upper,
li=LOI.Perc.30$CI.Lower, xlab="Sites", ylab="Mean LOI.Perc", xlim=c(0.5,4.5),
axes=FALSE, pch=16)
box()
axis(1, tck=-0.015, labels=NA)
axis(1, at=c(1,2,3,4), labels=c("JCB", "JCF", "JCM", "JCP"))
axis(2, tck=-0.015, las=1, labels=NA)
axis(2, lwd=0, line=-0.4, las=1)
mtext(side=3, "LOI 20 to 30 95% Confidence Intervals", line=1, font=2, cex=1)

############## NMDS CODE###############################################
#Making NMDS object of geochemical variables
data.MDS <-Sample.Measures[ ,-c(3,6)]

#going to check stress and see how many dimensions to use

#these lines generate a series of NMDS objects used to construct a scree plot, in order to
evaluate the appropriate dimensionality to use in the final/primary NMDS of this dataset
my.MDS.1 <- metaMDS(data.MDS, distance="euclidean", k=1, trymax=50)
my.MDS.2 <- metaMDS(data.MDS, distance="euclidean", k=2, trymax=50)
my.MDS.3 <- metaMDS(data.MDS, distance="euclidean", k=3, trymax=50)
my.MDS.4 <- metaMDS(data.MDS, distance="euclidean", k=4, trymax=50)
my.MDS.5 <- metaMDS(data.MDS, distance="euclidean", k=5, trymax=50)
my.MDS.6 <- metaMDS(data.MDS, distance="euclidean", k=6, trymax=50)
my.MDS.7 <- metaMDS(data.MDS, distance="euclidean", k=7, trymax=50)
my.MDS.8 <- metaMDS(data.MDS, distance="euclidean", k=8, trymax=50)

#constructing the scree plot with the NMDS objects
#creating a vector of dimensions
k.vector <- c(1:8)
#creating a vector of stress values
stress.vector <- c(my.MDS.1$stress, my.MDS.2$stress, my.MDS.3$stress,
my.MDS.4$stress, my.MDS.5$stress, my.MDS.6$stress, my.MDS.7$stress,
my.MDS.8$stress)
plot(k.vector, stress.vector, las=1, xlab="number of dimensions (k)", ylab="stress value")
#review of scree plot suggests the use of 2 dimensions in primary NMDS analysis

#running the NMDS
MDS.geochem <- metaMDS(data.MDS, distance="euclidean", k=2, trymax=50)
```

```
#plotting results based on site IDs
plot(MDS.geochem, las=1, main="MDS Results", type="n")
abline(v=0, col="light gray", lty=2)
abline(h=0, col="light gray", lty=2)
text(x=-2, y=-15, labels="Beaver", col="blue")
text(x=3, y=-15, labels="Non-Beaver", col="red")
points(MDS.geochem$points[which(rownames(MDS.geochem$points)%in%rownames(
Sample.Props)[Sample.Props$Site.ID=="JCB"]), ], pch=0, lwd=0.75, col="red")
points(MDS.geochem$points[which(rownames(MDS.geochem$points)%in%rownames(
Sample.Props)[Sample.Props$Site.ID=="JCP"]), ], pch=17, col="blue")
points(MDS.geochem$points[which(rownames(MDS.geochem$points)%in%rownames(
Sample.Props)[Sample.Props$Site.ID=="JCM"]), ], pch=21, col="black", bg="light
blue")
points(MDS.geochem$points[which(rownames(MDS.geochem$points)%in%rownames(
Sample.Props)[Sample.Props$Site.ID=="JCF"]), ], pch=3, lwd=1.25, col="dark red")

############## DFA CODE################################################
#extracting NMDS points
MDS.points <- MDS.geochem$points
#run DFA using NMDS points

#Making a vector of Site IDs that matches the NMDS scores (minus the JCP2 outlier)
MDS.Site.IDs <- Sample.Props$Site.ID

#Adding the column of unique Site IDs
#Site ID values... 1=JCB, 2=JCF, 3=JCM, 4=JCP
MDS.DFA.input <- cbind(MDS.points, MDS.Site.IDs)

#making it a data frame for the DFA
DFA.input <- as.data.frame(MDS.DFA.input)
Sites.DFA <- lda(MDS.Site.IDs~MDS1+MDS2, data=DFA.input)

#classification of groups using predict
Sites.Predict <- predict(Sites.DFA)

#maximum probability of classification in each group
Sites.Predict.max <- apply(Sites.Predict$posterior, MARGIN=1, FUN=max)

#plotting the DFA results
windows()
plot(Sites.DFA, dimen=1, type="both")
#spread in JCM and JCP a lot
#JCB and JCF tight, but very identical

#making a table of DFA results
Sites.DFA.table <- table(DFA.input$MDS.Site.IDs, Sites.Predict$class)
```

```
colnames(Sites.DFA.table) <- c("JCB", "JCF", "JCM", "JCP")
rownames(Sites.DFA.table) <- c("JCB", "JCF", "JCM", "JCP")
#viewing table
Sites.DFA.table

#Checking to see how many sites were classified correctly
Sites.DFA.value <-
sum(Sites.DFA.table[row(Sites.DFA.table)==col(Sites.DFA.table)])/sum(Sites.DFA.tabl
e)
#viewing maximum classification value
Sites.DFA.value

#run DFA (using all 5 geochem variables)
geochem.DFA <- Sample.Measures[ ,-c(3,6)]
DFA.Site.IDs <- Sample.Props$Site.ID
geochem.DFA.input <- cbind(geochem.DFA, DFA.Site.IDs)
DFA.input <- as.data.frame(geochem.DFA.input)
Sites.DFA <- lda(DFA.Site.IDs~Total.C+d13C+Total.N+d15N+C.N, data=DFA.input)

#classification of groups using predict
Sites.Predict <- predict(Sites.DFA)

#maximum probability of classification in each group
Sites.Predict.max <- apply(Sites.Predict$posterior, MARGIN=1, FUN=max)

#plotting the DFA results
windows()
plot(Sites.DFA, dimen=1, type="both")
#spread in JCM and JCP a lot
#JCB and JCF tight, but very identical

#making a table of DFA results
Geochem.DFA.table <- table(DFA.input$DFA.Site.IDs, Sites.Predict$class)
colnames(Geochem.DFA.table) <- c("JCB", "JCF", "JCM", "JCP")
rownames(Geochem.DFA.table) <- c("JCB", "JCF", "JCM", "JCP")
Geochem.DFA.table

#Checking to see how many sites were classified correctly
Geochem.DFA.value <-
sum(Geochem.DFA.table[row(Geochem.DFA.table)==col(Geochem.DFA.table)])/sum(
Geochem.DFA.table)
#viewing value
Geochem.DFA.value
```

```
#making an object of DFA scores for plotting
dfa.scores <-Sites.Predict$x
write.csv(dfa.scores, file="DFA.Scores.csv")
#reading in dfa scores with appropriate ID information for samples
Scores <- read.csv("DFA.results.csv", header=TRUE, sep=",")

#making DFA Score Line Figure with symbology
plot(Scores$LD1, Scores$ID, type="n", xlab="DFA Score", ylab="Site", las=1)
#need to add points in ascending order on scale bar
points(Scores$LD1[Scores$Site=="JCP"], Scores$ID[Scores$ID=="1"], pch=17,
col="blue")
points(Scores$LD1[Scores$Site=="JCM"], Scores$ID[Scores$ID=="2"], pch=21,
col="black", bg="light blue")
points(Scores$LD1[Scores$Site=="JCF"], Scores$ID[Scores$ID=="3"], pch=3,
lwd=1.25, col="dark red")
points(Scores$LD1[Scores$Site=="JCB"], Scores$ID[Scores$ID=="4"], pch=0,
lwd=0.75, col="red")
#all sites added
############## END OF CODE##############################################
```