PALEOLIMNOLOGICAL TECHNIQUES APPLIED TO AN INDIGENOUS BEOTHUK ARCHAEOLOGICAL SITE IN NEWFOUNDLAND, CANADA

By

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Land acknowledgment

We acknowledge that the lands on which Memorial University's campuses are situated are in the traditional territories of diverse Indigenous groups, and we acknowledge with respect the diverse histories and cultures of the Beothuk, Mi'kmaq, Innu, and Inuit of this province.

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List of Abbreviations and Symbols

^{14}C	-	radiocarbon
^{137}Cs	-	cesium
AMS	-	accelerator mass spectrometry
BCHRON	-	Bchronology
$CaCO_3$	-	calcium carbonate
cal. BP	-	calendar years before present
CE	-	common era
chl *a*	-	chlorophyll *a*
CRS	-	constant rate of supply
DCM	-	dichloromethane
GC	-	gas chromatography
GC-MS	-	gas chromatography-mass spectrometry
ICP-MS	-	inductively coupled plasma mass spectrometer
IRMS	-	isotope-ratio mass spectrometer
KOH	-	potassium hydroxide
PSI	-	pounds per square inch
rpm	-	revolutions per minute
SPE	-	solid phase extraction

Abstract

Obtaining human population and environmental data from a single sediment record allows us to analyze ecosystem stressors, adaptability, and elasticity in relation to human interference. Russell’s Point on Dildo Pond, Newfoundland is a Beothuk winter camp with a history of pre-European Indigenous use, Indigenous-European interaction, and a seasonal caribou migration and subsequent Indigenous hunting. Archaeological excavations established site use from ~1000 CE until abandonment in ~1650 CE, after European colonization of Newfoundland. To identify this window of Beothuk presence in the sediment record, two dated sediment cores, collected downstream of Russell’s Point, were analyzed for stable isotopes, metal(loid)s, chlorophyll *a*, macroscopic charcoal, and fecal lipids. These paleolimnological proxies are compared with archaeological information from Russell’s Point to support our understanding of environmental responses during the Beothuk period. The lipid ratio coprostanol/cholesterol shows a positive human signal at Dildo Pond at ~900 CE, increasing to its highest point around ~1000 CE. Delayed responses in As, Cd, Cu, Zn, and $\delta^{13}C$ increase and decrease to match these lipid changes. Chlorophyll *a* has elevated levels ~1100 CE until sharp declines ~1900s and drastic increases in the 2000s, with a large peak in the 1700s. Charcoal analysis show that fire events line up with lipid changes, with most occurring during the Beothuk period. The charcoal flux increases drastically after the 1900s with the establishment of the railroad in the area. Our proxies matched the human history of Dildo Pond and Newfoundland. This research is one of the first studies to utilize fecal lipid analysis in Newfoundland and the first paleolimnological study at Russell’s Point, Dildo Pond.

Chapter 1: Introduction and Overview

In this thesis, I apply a multiproxy paleolimnological approach to investigate signals of prehistoric human winter camps archived in lake sediments from in Newfoundland, Canada. In chapter 2, I quantify fecal lipid concentrations, sedimentary metal concentrations, chlorophyll *a*, and macroscopic charcoal concentrations for an ~1100-year-long sediment core from Dildo Pond, which captures the period of Indigenous Beothuk settlement, European arrival, and extensive 19^{th}-20^{th} century activity.

1.0 Background

Indigenous peoples first came to Newfoundland and Labrador 6,000 calendar years before present (cal. BP) and 10,000 cal. BP, respectively (Duggan et al., 2017). Over this time Newfoundland has experienced three distinct periods of Indigenous settlement: the Maritime Archaic, Paleoeskimo, and the Beothuk, with the Beothuk being the first Indigenous North Americans to have contact with Europeans (Duggan et al., 2017; Gilbert, 2002; Mackay et al., 2020). Beothuk interactions with Europeans were limited, due to Beothuk isolationist tendencies, before Europeans declared their extinction in 1829 CE (Gilbert, 2002; Polack, 2018; Rankin, 2018). With little remaining evidence from the Beothuk, most established knowledge of the Beothuk comes from European documentation and archaeological studies (Gilbert, 2002; Polack, 2018; Rankin, 2018). Introducing paleolimnological techniques to this research would make space for an approach to Beothuk and Newfoundland history that moves away from the racial biases often found in European documentation, particularly concerning colonization.

Over the last decade, paleolimnological techniques in conjunction with archaeological research have disproven previously foregone conclusions that anthropogenic environmental changes are a modern occurrence and prehistoric hunter-gather communities had a negligible effect on past ecosystems (e.g., reviewed in Bell & Blais, 2021; Douglas et al., 2004; Michelutti et al., 2013). These findings expand the window of potential analysis to study anthropogenic environmental change and allows for greater accuracy in projections of climate models moving forward while also providing more detailed accounts of Indigenous prehistoric communities.

From the environmental changes of the industrial revolution to the ^{137}Cs left behind by atomic bomb testing, modern humanity has left behind a lasting presence captured in lake sediments (Last & Smol, 2002). Paleolimnological approaches could provide a common ground for archaeological research to be directly compared to environmental changes (Bell & Blais, 2021). Fecal stanols are a paleolimnological proxy that is gaining in popularity due to its source-specific nature and its ability to provide population reconstructions from the same sediment cores that environmental data are obtained (Bell & Blais, 2021; White et al., 2019). Previously, archaeological population reconstructions were derived from ceramic chronologies and archaeological data sets (White et al., 2019). By obtaining population data and environmental data from the same sediment record, multiproxy approaches are more directly and reliably compared to each other (Bell & Blais, 2021). A multi-proxy paleolimnological approach using fecal stanols and sedimentary charcoal will provide a complement to archaeological research, as we are able to analyze ecosystem stressors, adaptability, and elasticity in relation to human interference in the environment (Bell & Blais, 2021). The ebb and flow of human settlement in Newfoundland has been documented archaeologically and provides an opportune research backboard to apply paleolimnology to analyze anthropogenically-driven environmental changes (Duggan et al., 2017).

1.1 Paleolimnology

Paleolimnology is the study of lakes and lake sediment as a proxy for depositional environment to understand how environmental conditions have changed throughout a lake's existence (Smol, 2008). Overtime organic and inorganic material ranging from soil runoff to plant debris to animal or human excrement to charcoal from forest fires are deposited from within the drainage basin and preserved in the lake sediment (Last & Smol, 2002; Smol, 2008). This material and its diagenetic byproducts, the physical and chemical changes that occur after sediment is deposited, are used as proxies for analyzing the environment at the time of deposition (Last & Smol, 2002). Proxies are classified as either biological, chemical, or physical and can inform on different aspects of an environment (Bell & Blais, 2021). Physical proxies can include sediment texture, magnetic properties, color, and density (Bell & Blais, 2021). Biological proxies can include arthropod assemblages, spores, charcoal, diatoms, and pollen and plant remains, and chemical proxies can include isotopes, elemental analysis, biomarkers, and biogenic silica (Bell & Blais, 2021). Most paleolimnological studies utilize a multi-proxy approach where markers that are produced independently from one another can corroborate interpretations of past environmental changes (Bell & Blais, 2021).

Sediment cores can be reliably dated using several approaches depending on the time scale being studied. Radiometric dating with natural lead isotopes (^{210}Pb, ^{214}Pb) as well as anthropogenically-produced isotopes (^{137}Cs, ^{141}Am) are used to establish a sediment core chronology for the last ~150-200 years (Appleby & Oldfield, 1978; Last & Smol, 2002). Cesium-137 (^{137}Cs) can identify the circa-1963 peak resulting from atomic bomb testing and is an independent dating marker to verify ^{210}Pb-derived dates (Hajdas et al., 2021). For longer time scales to ~50,000 years ago, ^{14}C of macrofossils and bulk sediment is commonly measured

(Hajdas et al., 2021). ^{14}C produced in the atmosphere is incorporated into organic material for tissue building until death and then begins to decay (Hajdas et al., 2021). With a half-life of 5568 years and modern human activity (i.e., burning of old carbon within fossil fuels) leading to decreased ^{14}C production), this dating method is complemented with the addition of ^{210}Pb and ^{137}Cs radioisotopes (Hajdas et al., 2021; Last & Smol, 2002). The anthropogenic-driven decrease in ^{14}C, known as the Suess effect, is corrected for with calibration curves (Hajdas et al., 2021).

1.2 Combining paleolimnology with archaeology

Contemporary archaeological research is starting to shift from the passive Indigenous extinction narrative that is largely based on European documentation and surviving artifact interpretation that reflects outdated biases towards Indigenous knowledge and agency (Polack, 2018; Rankin, 2018). While documentation, like explorer's journals or letters to employers, were useful, it is important to consider author's biases and the intended audience when understanding the Beothuk perspective (Gilbert, 2002; Polack, 2018; Rankin, 2018). Current archaeological data interpretations state that the Beothuk camp Russell's point in Newfoundland was used for 650 years, with the site abandoned in 1650 CE, soon after European contact in 1612 CE (Gilbert, 2002; Rankin, 2018). This fits with the larger narrative of Newfoundland, that the Beothuk vanished suddenly shortly after European colonization (Gilbert, 2002; Rankin, 2018). Incorporating paleolimnological techniques into archaeological research makes it possible to obtain more detailed population reconstructions that are not as susceptible to human biases and yields an interdisciplinary approach to understanding past human settlements on lakes (Bell & Blais, 2021; Gilbert, 2002; Polack, 2018).

Paleolimnological techniques are able to identify human inputs into lake environments from direct and indirect proxies, with analyses being able to account for *in situ* degradation (Bell & Blais, 2021; Bull et al., 1999; Hadley et al., 6/2010b; Michelutti et al., 2013; Stewart et al., 2018). This method is particularly useful when studying hunter-gather/nomadic communities that leave few artifacts, which are highly susceptible to weathering or in locations of high modern activity/contamination, or in environments of severe weather/climate (like the arctic) with accessibility issues. Paleolimnological techniques enable comparison of prehistoric and historic environmental and population data (Douglas et al., 2004; Hadley et al., 2010b; Stewart et al., 2018; White et al., 2019). These techniques are useful when studying "extinct" prehistoric peoples whose narrative has previously relied solely on the material record and European documentation (Polack, 2018). European documentation often displays a limited understanding of Indigenous culture with biases depending on the purpose of the documentation (Polack, 2018).

Paleolimnology techniques are becoming more commonly used in conjunction with archaeological research (Bell & Blais, 2021). As ancient humans migrated inland seasonally or permanently, lakes provided food and resources while aiding in sanitation and hygiene (Gilbert, 2002; Rankin, 2018). Prior to Indigenous-European contact, Indigenous lacustrine coastal and inland camps were used annually and/or seasonally for extended periods of time, allowing human indicative sediment to accumulate (Gilbert, 2002; Rankin, 2018). While paleolimnology and archaeology have been analyzing anthropogenically driven environmental changes separately, their respective techniques have limited the acquisition of population data and environmental data from the same source, making comparisons tenuous. Douglas et al. (2004) used changes in diatom assemblages, $\delta^{15}N$ values, total phosphorus, dissolved organic carbon, and moss substrates to show that the pond used for Indigenous whaling practices and discarding remaining whale bones had a lasting effect on the aquatic ecology. They used the beginning of the changes in water chemistry as a sign of Indigenous arrival, but because the effects are still occurring, they cannot use those proxies to identify site abandonment (Douglas et al., 2004). Hadley et al. (2010a&b) analyzed another Indigenous site that had an established history of whaling, with the bioproducts preferentially draining into one of two almost identical ponds near the settlement. With changes in diatom assemblages, $\delta^{15}N$, chlorophyll*a*, and radiocarbon dates from archaeological artifacts, they were able to establish an indirect timeline when more direct radiocarbon dating proved unreliable (Hadley et al., 2010a, b). However, these data cannot inform on population changes at the site, merely relatively changes of possible Beothuk presence. In this way, existing archaeological data becomes part of the multi-proxy approach and provides independent reconstructions to verify the veracity of paleolimnological population reconstructions and environmental data.

1.3 Stable carbon and nitrogen isotopes

Carbon and nitrogen stable isotopes ($\delta^{13}C$ and $\delta^{15}N$) are used by paleolimnological and archaeological studies in various climates as proxies to identify human presence and anthropogenic environmental changes (Bell & Blais, 2021). Arctic environments have limited documentation of human presence and provide the earliest indications of changing climates trends. To expand on current population reconstructions in Arctic environments, data must be obtained from environmental proxies. Unfortunately, studies vary on the accuracy of stable isotope proxies in Arctic environments (Gallant et al., 2020; Stewart et al., 2018). Stewart et al. (2018) analyzed a former wastewater lagoon in an Arctic climate and even though there was ~30 years of documented wastewater disposal in the lagoon, the stable nitrogen isotopes did not reflect this human input (Stewart et al., 2018). This could be a result of mediation by primary production and other components of the N-cycle or due to human excrement being only a part of municipal wastewater discharge, which also incorporates domestic waste, food scraps, and sink and tub water (Stewart et al., 2018). Gallant et al. (2020), on the other hand, did find stable nitrogen isotopes to be useful in their high Arctic study. Michelutti et al. (2013) studied five ponds with archaeological evidence of Indigenous occupation and two control ponds. Among the five ponds, three showed no changes in $\delta^{15}N$ due to the sites being seasonal or having short-term occupations, one showed a peak at what is thought to be the highest period of activity and corresponded with archaeological research and diatom assemblages, and the last one only showed one peak when archaeological research indicates multiple periods of occupation by various groups and does not correspond with diatom assemblages (Michelutti et al., 2013). This inconsistency shows a need for a more reliable population proxy that can establish robust population reconstructions that environmental data can building upon.

In paleolimnology, $\delta^{13}C$ values have been used to quantify aquatic primary productivity, to identify autochthonous and allochthonous organic inputs, local landscape development, soil and vegetation dynamics, sewage input, types of plant input, and marine vegetation input (Bull et al., 1999; Duda et al., 2022; Guo et al., 2020). In archaeology, $\delta^{13}C$ values of bone collagen and hair can identify human diet, distinguishing between marine and terrestrial food sources (Harris et al., 2019). Gallant et al. (2020) used $\delta^{13}C$ values to accompany their fecal lipid analysis of human presence through sewage input into various lakes, with input resulting in trending increases of -26‰ to -22‰. With anthropogenic climate change, $\delta^{13}C$ values show increasing magnitudes of change in modern sediment, possibly from increased aquatic primary productivity.

1.4 Fecal sterols and stanols

Fecal sterols and stanols are hydrophobic organic compounds that are biohydrogenated by anaerobic bacteria in the digestive tract and bound strongly with fecal matter (Leeming et al., 1996). These compounds are able to maintain enough of their structure to be recognizable after deposition in sediment (Leeming et al., 1996). The compounds and concentrations of a sterol profile or 'sterol fingerprint' are determined by diet (omnivore, herbivore, or carnivore), endogenous sterols biosynthesized in the digestive tract of higher animals, and the anaerobic bacteria in the digestive tract biohydrogenating sterols into stanols (Leeming et al., 1996). These three factors allow fecal sterols to be more source specific than stable isotopes (Leeming et al., 1996; Gallant et al., 2020). Their structural integrity and source specificity allows fecal sterols and stanols to support spatial and long-term temporal studies (Leeming et al., 1996; Bull et al., 2002).

The human digestive tract creates high concentrations of fecal sterols, with human feces containing approximately 4 to 5 times higher concentrations of sterols compared to other animals (Leeming et al., 1996). Even with humans on low cholesterol diets, the same concentrations of sterols and stanols are biosynthesized in the digestive tract (Leeming et al., 1996). Coprostanol, epicoprostanol, and cholesterol are the more commonly analyzed fecal sterols and stanols used to identify a human source, due to coprostanol making up 60% of the human feces stanol content (Bull et al., 2002; Gallant et al., 2020; Leeming et al., 1996). Coprostanol is produced by other mammals in significantly lower quantities, with only pigs and sheep producing significant enough concentrations to mask a human signal (Bull et al., 2002; Leeming et al., 1996). However, a recent study by Harrault et al. (2019) has shown that specific mammalian species can be distinguished with unique fecal signatures (Harrault et al., 2019). Otherwise, a multi-proxy approach can be used to differentiate between human, pig, or sheep feces (Leeming et al., 1996). Fecal sterol and stanol analysis is a technique primarily used in colder climates because that is where they are more stable (Gallant et al., 2020). When they do go through microbial breakdown, the degradation rates slow as burial depth increases, and the resulting sterols and stanols are preserved *in situ* and are traceable (Bell & Blais, 2021; Bull et al., 2002). Ratios are used to compensate for differing degradation rates through the sediment core (Gallant et al., 2020).

1.5 Charcoal

Charcoal analysis is a physical proxy that identifies evidence of fire events in lake sediment cores and can be used to indicate human presence on various scales in multiproxy studies (Bell & Blais, 2021). Charcoal is incompletely burned biomass produced between 280 and 500°C (Courtney Mustaphi, 2014; Whitlock & Larsen, 2002). Charcoal particles are typically black opaque, angular or planar fragments (Whitlock & Larsen, 2002). Particle sizes correspond to distance travelled as shown in Fig. 1.1, with microscopic pieces (<100 μm) being from extra local or regional fire events and macroscopic (>100 μm) pieces being from local fire events near or on study lakes (Long et al., 1998; Millspaugh & Whitlock, 1995). These macroscopic charcoal pieces are categorized as primary charcoal having been deposited directly from the fire into the lake via runoff/slopewash or short distance fall out from wind (Courtney Mustaphi, 2014). Microscopic charcoal is categorized as secondary charcoal, typically deposited from extra local or regional fire event fall out (Mustaphi, 2014). (Mustaphi, 2014). Millspaugh and Whitlock (1996) concluded that after a recent fire macroscopic charcoal >125 μm in diameter were common in lakes when fire events occurred within the catchment basin or in the region upwind of the lake, typically referred to as extralocal. Studies have used macroscopic charcoal in conjunction with fecal lipids to identify evidence of Indigenous or early human-derived fire at sites near study lakes (Argiriadis et al., 2018).

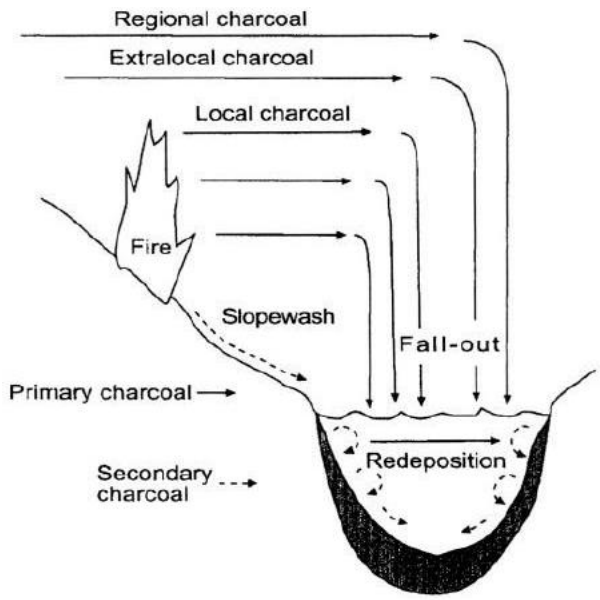

Figure 1.1. Charcoal transport and deposition into lakes (Whitlock & Larsen, 2002).

1.6 Multi-proxy paleolimnological approaches to track past cultures

With the fecal lipid analysis, population reconstructions are obtained from the same source as environmental data, allowing studies to make more robust and direct comparisons between population changes and environmental changes (D'Anjou et al., 2012; White et al., 2018, 2019). White et al. (2018 and 2019) reconstructed population changes at the largest prehistoric population site in North America using fecal lipids and independent archaeological models. The highly detailed record allowed them to make comparisons to $\delta^{18}O$ values, tree ring reconstructions, mineral content, sediment accumulation rates, and sediment grain size to show how flooding and drought lead to population decline at the settlement (White et al., 2018, 2019). D'Anjou et al. (2012) identified human arrival at a lake in northern Norway with fecal lipids that corresponded with a rise in pyrolytic polycyclic aromatic hydrocarbons from an increase in landscape fires, a change in *n*-alkane chain lengths from leaf waxes (indicating a decline in woodland), and independent tree-ring reconstructions; showing how human population increases in an area leads to changes in land-use through woodland clearing (D'Anjou et al., 2012). And because humans have a unique fecal lipid signature, D'Anjou et al. (2012) could identify the human effect on the long-term natural variations in the local environment from wider scale climate changes. Mackay et al. (2020) was able to analyze fecal lipids on a small-scale studying floor deposits inside an Iron Age roundhouse along with faunal data, entomological dung indicators, and archaeological proxies to understand its multiple uses and division of space over short periods of time. Vachula et al. (2020) used a multi-proxy approach to support the theory that humans were in Beringia during the Last Glacial period and promoted fire activity. Validating the use of these proxies in cold climates on millennial time scales, they compared radiocarbon dates, sedimentary pollen, ancient vegetation DNA, nematode assemblages, chironomid-based paleo-temperature records, organic geochemical analyses, fecal lipids, and polycyclic aromatic hydrocarbons to previous paleoecological records (Vachula et al., 2020). Schroeter et al. (2020) used fecal lipids in a high-altitude archaeological site in Central Asia to identify pre-Silk Road human occupation, migration, and adaptations to extreme environments as well as the history of grazing animals in the region. They were able to determine that human migration in the area occurred during the Bronze age, long before the Silk Road was established, and that small-scale migration was influential on larger trade and exchange networks (Schroeter et al., 2020).

Charcoal analyses have also been used in multi-proxy paleolimnological studies to identify anthropogenic fire history and land-use changes in various climates and environments. Argiriadis et al. (2018) compared macroscopic charcoal analysis with fecal and plant lipids, pollen analysis, sedimentation rate changes in two lakes to show how deforestation after the initial settlement of New Zealand documented land-use changes and fire activity. They were able to identify different types of land-use between Māori and European settlement periods as well as differences between charcoal peaks and biomarker peaks separated local sourced fire activity to wider, possibly global fire history (Argiriadis et al., 2018). Long et al. (1998) examined pollen, magnetic susceptibility, and charcoal to create a 9000-year fire history of a lake on the Oregon coast. Sediment magnetism identified changes in allochthonous sedimentation and was compared to vegetation and climate changes to identify fire frequency trends (Long et al., 1998). Kennedy and Horn (2008) compared pollen analysis, and charcoal analysis to archaeological research to identify the effects of forest clearing and maize agriculture in the rainforest of Costa Rica. Their sediment profiles were able to show the history of human land-use along with the natural forest disturbances and climate variability (Kennedy & Horn, 2007).

1.7 Newfoundland

Even though Newfoundland was first claimed by England in 1583 CE and colonized in 1610 CE, it was not until the 20th century that archaeologists began to fully understand its Indigenous history (Gilbert, 2002). In 1612 CE, an expedition into Trinity Bay led by then-Governor John Guy, came in contact with an Indigenous Beothuk settlement located at what would become known in the modern era as Russell's Point on Dildo Pond (Gilbert, 2002). According to Governor Guy's personal diary of the expedition, Russell's Point was a collection of three houses three kilometers inland from Trinity Bay and a kilometer down a fresh-water lake (Gilbert, 2002). John Guy's detailed record of this camp led to it being rediscovered and excavated in 1994 CE and 1997 CE (Gilbert, 2002). Twenty-six weeks of excavations between 1994 CE and 1997 CE found evidence of seventeen hearths, more are thought to have existed but been destroyed by site reuse after abandonment, two middens, two fire-cracked rock features, post molds, pits, greasy black deposits, red ochre stains, and organic material (variety of plants and caribou bones) (Gilbert, 2002). Seventeen caribou samples were identified at the camp; this along with accounts of caribou migration in across the pond it is suggested that Russell's Point was a winter camp established to hunt caribou migrating to the west of Dildo Pond. Radiocarbon dates of the hearths and middens indicate the camp was used by the Beothuk from approximately 1000 CE to 1650 CE (Gilbert, 2002). While there is evidence of further interactions between the Europeans and the Beothuk at Russell's Point, exchanges increased after the settlement was abandoned and forgotten (Gilbert, 2002). The surrounding area became an agricultural center as Newfoundland was being developed by European settlers. In its post-Beothuk age, there has been whaling, mink farming, and agricultural and community development around most of the pond.

Prior to the 1920s, archaeologists were only aware of one Indigenous culture in Newfoundland, the Beothuk (Gilbert, 2002). By the 1960s, surveys of the island uncovered two other Indigenous cultures that pre-dated the Beothuk, the Dorset Eskimo/Paleoeskimo and the Maritime Archaic (Gilbert, 2002). It was not until the 1980s that archaeologists began to understand how crucial the interior of the island was for survival during the winter and after

European arrival (Gilbert, 2002). Indigenous groups that relied too heavily on a single species as a food source were more vulnerable to extinction (Gilbert, 2002). Groups that moved to interior camps near the coast for the winter, to take advantage of both resources, showed longevity (Gilbert, 2002). These criteria lead to the conclusion that the settlement mentioned in John Guy's records would likely be an ideal winter base camp (Gilbert, 2002). An added bonus to this location is the seasonal caribou crossing that occurred across Dildo Pond, directly across from the settlement (Gilbert, 2002). The annual presence of the caribou likely influenced the Beothuk's decision to establish this settlement for hunting purposes (Gilbert, 2002). This drove researchers to find the settlement John Guy encountered and validate their findings (Gilbert, 2002).

Duggan et al. (2017) found that there is genetic discontinuity between the three known Indigenous settlement groups supporting three distinct periods of occupation, with one 600-year hiatus. There are indications of abandonment, severe constriction, or local extinction in their genetic record (Duggan et al., 2017). Indigenous bone collagen shows an increase in terrestrial isotopic signatures, which mirror the Beothuk's retreat to inland camps to avoid European interaction and conflict after colonization (Duggan et al., 2017).

1.8 Thesis objectives and outline

In this thesis, I investigate the local ecological and environmental impacts of human activity within a lake drainage basin from Indigenous settlement to modern human activity. In chapter 2, I collect and align two sediment cores for a 1100-year analysis of lake sediment. I add to existing local archaeological research by quantifying fecal lipid ratios to support two major periods of human presence on the study lake, Dildo Pond. Following unreliable $\delta^{15}N$ analysis to substantiate the lipid analysis, I conducted a charcoal analysis, using documented events like the construction of a railroad, evidence of Indigenous hearths on the shore, and a massive fire in the neighboring town as age markers. I built a chronology based on sediment radiocarbon dating and ^{210}Pb samples and used it track ecological and environmental changes across multiple proxies: stable carbon isotopes, metal(loid)s, chlorophyll *a*, and organic carbon.

Overall, my thesis seeks to be a part of the introduction of fecal lipids to Newfoundland and paleolimnological techniques to the archaeological research already conducted in the region. The application of these methods has shown that hunter-gather and nomadic communities in colder regions had notable effects on their local environments, some forever changing the ecology at archaeology sites (Douglas et al., 2004; Hadley et al., 2010b). By bringing this research to Newfoundland, we can better understand how the various settlement episodes affected the regional and local environment and make comparisons to the effects of modern humans. All this while also supporting the use of fecal lipids in colder climates.

My thesis objectives are to: (1) identify and date the pre-European window of human presence at Dildo Pond in the lake sediment stratigraphy; (2) to validate the use of fecal stanols and charcoal as a reliable proxy for tracking past Indigenous settlements on lakes in Newfoundland. My hypothesis is that within a multiproxy approach, fecal lipids and charcoal will identify camp occupation dates on Dildo Pond that correspond with archaeological data but will expand the window of human presence as the current occupation window is dependent on the preservation, retrieval, and adequate ^{14}C of the oldest artifacts/animal bones at Russell's Point.

1.9 References

Andrews, J. E., Greenaway, A. M., Bigg, G. R., Webber, D. F., Dennis, P. F., & Guthrie, G. A. (1999). Pollution history of a tropical estuary revealed by combined hydrodynamic modelling and sediment geochemistry. *Journal of Marine Systems*, *18*(4), 333–343. https://doi.org/10.1016/S0924-7963(98)00019-0

Antoniades, D., Michelutti, N., Quinlan, R., Blais, J. M., Bonilla, S., Douglas, M. S. V., Pienitz, R., Smol, J. P., & Vincent, W. F. (2011). Cultural eutrophication, anoxia, and ecosystem recovery in Meretta Lake, High Arctic Canada. *Limnology and Oceanography*, *56*(2), 639–650. https://doi.org/10.4319/lo.2011.56.2.0639

Appleby, P. G., & Oldfield, F. (1978). The calculation of lead-210 dates assuming a constant rate of supply of unsupported 210Pb to the sediment. *CATENA*, *5*(1), 1–8. https://doi.org/10.1016/S0341-8162(78)80002-2

Argiriadis, E., Battistel, D., McWethy, D. B., Vecchiato, M., Kirchgeorg, T., Kehrwald, N. M., Whitlock, C., Wilmshurst, J. M., & Barbante, C. (2018). Lake sediment fecal and biomass burning biomarkers provide direct evidence for prehistoric human-lit fires in New Zealand. *Springer Nature*. https://doi.org/10.1038/s41598-018-30606-3

Bartkowska, I., Tałałaj, I., & Biedka, P. (2019). Analysis of the Quality of Stabilized Municipal Sewage Sludge. *Journal of Ecological Engineering*, *20*(2), 200–208. https://doi.org/10.12911/22998993/99306

Bell, & Blais. (2021). Paleolimnology in support of archeology: A review of past investigations and a proposed framework for future study design. *Journal of Paleolimnology*, *65*(1), 1–32. https://doi.org/10.1007/s10933-020-00156-8

Bell, T., Macpherson, J. B., & Renouf, M. A. P. (2005). *Late Prehistoric Human Impact on Bass Pond, Port au Choix*. 23.

Bronk Ramsey, C. (2009). Bayesian Analysis of Radiocarbon Dates. *Radiocarbon*, *51*(1), 337–360. https://doi.org/10.1017/S0033822200033865

Bull, I. D., Lockheart, M. J., Elhmmali, M. M., Roberts, D. J., & Evershed, R. P. (2002). The origin of faeces by means of biomarker detection. *Environment International*, *27*(8), 647–654. https://doi.org/10.1016/S0160-4120(01)00124-6

Bull, I. D., Simpson, I. A., van Bergen, P. F., & Evershed, R. P. (1999). Muck 'n' molecules: Organic geochemical methods for detecting ancient manuring. *Antiquity*, *73*(279), 86–96. https://doi.org/10.1017/S0003598X0008786X

Courtney Mustaphi, C. (2014). *A Landscape-Scale Assessment of Holocene Fire Regime Controls in South-Eastern British Columbia, Canada* [Doctor of Philosophy, Carleton University]. https://doi.org/10.22215/etd/2014-10073

D'Anjou, R. M., Bradley, R. S., Balascio, N. L., & Finkelstein, D. B. (2012). Climate impacts on human settlement and agricultural activities in northern Norway revealed through sediment biogeochemistry. *Proceedings of the National Academy of Sciences*, *109*(50), 20332–20337. https://doi.org/10.1073/pnas.1212730109

Dickinson, A., & Sanger, C. (2018). *After the Basques: The whaling Stations of Newfoundland and Labrador*. DRC Publishing.

Douglas, M. S. V., Smol, J. P., Savelle, J. M., & Blais, J. M. (2004). Prehistoric Inuit whalers affected Arctic freshwater ecosystems. *Proceedings of the National Academy of Sciences*, *101*(6), 1613–1617. https://doi.org/10.1073/pnas.0307570100

Duda, M. P., Cyr, F., Robertson, G. J., Michelutti, N., Meyer-Jacob, C., Hedd, A., Montevecchi, W. A., Kimpe, L. E., Blais, J. M., & Smol, J. P. (2022). Climate oscillations drive millennial-scale changes in seabird colony size. *Global Change Biology*, *28*(14), 4292–4307. https://doi.org/10.1111/gcb.16171

Duggan, A. T., Harris, A. J. T., Marciniak, S., Marshall, I., Kuch, M., Kitchen, A., Renaud, G., Southon, J., Fuller, B., Young, J., Fiedel, S., Golding, G. B., Grimes, V., & Poinar, H. (2017). Genetic Discontinuity between the Maritime Archaic and Beothuk Populations in Newfoundland, Canada. *Current Biology*, *27*(20), 3149-3156.e11. https://doi.org/10.1016/j.cub.2017.08.053

Fattore, E., Benfenati, E., Marelli, R., Cools, E., & Fanelli, R. (1996). Sterols in sediment samples from Venice Lagoon, Italy. *Chemosphere*, *33*(12), 2383–2393. https://doi.org/10.1016/S0045-6535(96)00340-2

Finsinger, W., & Bonnici, I. (2022). *tapas: An R package to perform trend and peaks analysis* [R]. https://doi.org/10.5281/zenodo.6344463

Furtula, V., Osachoff, H., Derksen, G., Juahir, H., Colodey, A., & Chambers, P. (2012). Inorganic nitrogen, sterols and bacterial source tracking as tools to characterize water quality and possible contamination sources in surface water. *Water Research*, *46*(4), 1079–1092. https://doi.org/10.1016/j.watres.2011.12.002

Gallant, L. R., Kimpe, L. E., Hargan, K. E., & Blais, J. M. (2020). Tracking the history of 20th century cultural eutrophication in High Arctic waterbodies. *Anthropocene*, *31*, 100250. https://doi.org/10.1016/j.ancene.2020.100250

Gilbert, W. (2002). *Russell's Point (CiAj-1): A Little Passage/Beothuk site at the bottom of Trinity Bay*.

Glew, JohnR. (1988). A portable extruding device for close interval sectioning of unconsolidated core samples. *Journal of Paleolimnology*, *1*(3). https://doi.org/10.1007/BF00177769

Griffiths, K., Jeziorski, A., Antoniades, D., Beaulieu, M., Smol, J. P., & Gregory-Eaves, I. (2022). Pervasive changes in algal indicators since pre-industrial times: A paleolimnological study of changes in primary production and diatom assemblages from ~200 Canadian lakes. *Science of The Total Environment*, *838*, 155938. https://doi.org/10.1016/j.scitotenv.2022.155938

Guo, Q., Wang, C., Wei, R., Zhu, G., Cui, M., & Okolic, C. P. (2020). Qualitative and quantitative analysis of source for organic carbon and nitrogen in sediments of rivers and lakes based on stable isotopes. *Ecotoxicology and Environmental Safety*, *195*, 110436. https://doi.org/10.1016/j.ecoenv.2020.110436

Hadley, K. R., Douglas, M. S. V., Blais, J. M., & Smol, J. P. (7/2010a). Nutrient enrichment in the High Arctic associated with Thule Inuit whalers: A paleolimnological investigation from Ellesmere Island (Nunavut, Canada). *Hydrobiologia*, *649*(1), 129–138. https://doi.org/10.1007/s10750-010-0235-6

Hadley, K. R., Douglas, M. S. V., McGhee, R., Blais, J. M., & Smol, J. P. (6/2010b). Ecological influences of Thule Inuit whalers on high Arctic pond ecosystems: A comparative paleolimnological study from Bathurst Island (Nunavut, Canada). *Journal of Paleolimnology*, *44*(1), 85–93. https://doi.org/10.1007/s10933-009-9388-6

Hajdas, I., Ascough, P., Garnett, M. H., Fallon, S. J., Pearson, C. L., Quarta, G., Spalding, K. L., Yamaguchi, H., & Yoneda, M. (2021). Radiocarbon dating. *Nature Reviews Methods Primers*, *1*(1), 62. https://doi.org/10.1038/s43586-021-00058-7

Harrault, L., Milek, K., Jardé, E., Jeanneau, L., Derrien, M., & Anderson, D. G. (2019). Faecal biomarkers can distinguish specific mammalian species in modern and past environments. *PLOS ONE*, *14*(2), e0211119. https://doi.org/10.1371/journal.pone.0211119

Harris, A. J. T., Duggan, A. T., Marciniak, S., Marshall, I., Fuller, B. T., Southon, J., Poinar, H. N., & Grimes, V. (2019). Dorset Pre-Inuit and Beothuk foodways in Newfoundland, ca. AD 500-1829. *PLOS ONE*, *14*(1), e0210187. https://doi.org/10.1371/journal.pone.0210187

Kennedy, L. M., & Horn, S. P. (2007). A Late Holocene Pollen and Charcoal Record from La Selva Biological Station, Costa Rica. *Biotropica*, *0*(0), 070626194706002-??? https://doi.org/10.1111/j.1744-7429.2007.00334.x

Komada, T., Anderson, M. R., & Dorfmeier, C. L. (2008). Carbonate removal from coastal sediments for the determination of organic carbon and its isotopic signatures, δ^{13} C and Δ^{14} C: Comparison of fumigation and direct acidification by hydrochloric acid: Carbonate removal from coastal sediments. *Limnology and Oceanography: Methods*, *6*(6), 254–262. https://doi.org/10.4319/lom.2008.6.254

Last, W. M., & Smol, J. P. (2002). *Tracking Environmental Change Using Lake Sediments*. Kluwer Academic Publishers200.

Leeming, R., Ball, A., Ashbolt, N., & Nichols, P. (1996). Using faecal sterols from humans and animals to distinguish faecal pollution in receiving waters. *Water Research*, *30*(12), 2893–2900. https://doi.org/10.1016/S0043-1354(96)00011-5

Long, C. J., Whitlock, C., Bartlein, P. J., & Millspaugh, S. H. (1998). *A 9000-year fire history from the Oregon Coast Range, based on a high-resolution charcoal study*. *28*.

Mackay, H., Davies, K. L., Robertson, J., Roy, L., Bull, I. D., Whitehouse, N. J., Crone, A., Cavers, G., McCormick, F., Brown, A. G., & Henderson, A. C. G. (2020). Characterising life in settlements and structures: Incorporating faecal lipid biomarkers within a multiproxy case study of a wetland village. *Journal of Archaeological Science*, *121*, 105202. https://doi.org/10.1016/j.jas.2020.105202

Michelutti, N., Blais, J. M., Cumming, B. F., Paterson, A. M., Rühland, K., Wolfe, A. P., & Smol, J. P. (2010). Do spectrally inferred determinations of chlorophyll a reflect trends in lake trophic status? *Journal of Paleolimnology*, *43*(2), 205–217. https://doi.org/10.1007/s10933-009-9325-8

Michelutti, N., McCleary, K. M., Antoniades, D., Sutherland, P., Blais, J. M., Douglas, M. S. V., & Smol, J. P. (2013). Using paleolimnology to track the impacts of early Arctic peoples on freshwater ecosystems from southern Baffin Island, Nunavut. *Quaternary Science Reviews*, *76*, 82–95. https://doi.org/10.1016/j.quascirev.2013.06.027

Mills, K., Schillereff, D., Saulnier-Talbot, É., Gell, P., Anderson, N. J., Arnaud, F., Dong, X., Jones, M., McGowan, S., Massaferro, J., Moorhouse, H., Perez, L., & Ryves, D. B. (2017). Deciphering long-term records of natural variability and human impact as recorded in lake sediments: A palaeolimnological puzzle: A palaeolimnological puzzle. *Wiley Interdisciplinary Reviews: Water*, *4*(2), e1195. https://doi.org/10.1002/wat2.1195

Millspaugh, S. H., & Whitlock, C. (1995). A 750-year fire history based on lake sediment records in central Yellowstone National Park, USA. *The Holocene*, *5*(3), 283–292. https://doi.org/10.1177/095968369500500303

Page, G. T., & Shapiro, L. (2018). Coal in Canada | The Canadian Encyclopedia. *Historica Canada*. www.thecanadianencyclopedia.ca/en/article/coal

Pan, F., Liu, H., Guo, Z., Cai, Y., Fu, Y., Wu, J., Wang, B., & Gao, A. (2019). Metal/metalloid and phosphorus characteristics in porewater associated with manganese geochemistry: A case study in the Jiulong River Estuary, China. *Environmental Pollution*, *255*, 113134. https://doi.org/10.1016/j.envpol.2019.113134

Patton, D., & Reeves, A. D. (1999). Sterol Concentrations and Temporal Variations on the North Shore Mudflats of the Firth of Tay, Scotland. *Marine Pollution Bulletin*, *38*(7), 613–618. https://doi.org/10.1016/S0025-326X(99)00068-5

Polack, F. (Ed.). (2018). *Tracing ochre: Changing perspectives on the Beothuk*. University of Toronto Press.

Rankin, L. (2018). 8 Towards a Beothuk Archaeology: Understanding Indigenous Agency in the Material Record. In F. Polack (Ed.), *Tracing Ochre* (pp. 177–198). University of Toronto Press. https://doi.org/10.3138/9781442623859-012

Reavie, E. D., Cai, M., Meyer-Jacob, C., Smol, J. P., & Werne, J. P. (2021). Long-term primary production trends in the Laurentian Great Lakes: A comparison of geochemical methods. *Journal of Paleolimnology*, *65*(3), 299–314. https://doi.org/10.1007/s10933-020-00170-w

Reimer, P. J., Austin, W. E. N., Bard, E., Bayliss, A., Blackwell, P. G., Bronk Ramsey, C., Butzin, M., Cheng, H., Edwards, R. L., Friedrich, M., Grootes, P. M., Guilderson, T. P., Hajdas, I., Heaton, T. J., Hogg, A. G., Hughen, K. A., Kromer, B., Manning, S. W., Muscheler, R., … Talamo, S. (2020). The IntCal20 Northern Hemisphere Radiocarbon Age Calibration Curve (0–55 cal kBP). *Radiocarbon*, *62*(4), 725–757. https://doi.org/10.1017/RDC.2020.41

Renouf, >M. A. P. (1999). Prehistory of Newfoundlandhunter-gatherers: Extinctions or adaptations? *World Archaeology*, *30*(3), 403–420. https://doi.org/10.1080/00438243.1999.9980420

Rowley-Conwy, P. (1990). Settlement Patterns of the Beothuk Indians of Newfoundland: A View from Away. *Canadian Journal of Archaeology*, *14*, 21.

Schelske, C. L., & Hodell, D. A. (1995). Using carbon isotopes of bulk sedimentary organic matter to reconstruct the history of nutrient loading and eutrophication in Lake Erie. *Limnology and Oceanography*, *40*(5), 918–929. https://doi.org/10.4319/lo.1995.40.5.0918

Schroeter, N., Lauterbach, S., Stebich, M., Kalanke, J., Mingram, J., Yildiz, C., Schouten, S., & Gleixner, G. (2020). Biomolecular Evidence of Early Human Occupation of a High-Altitude Site in Western Central Asia During the Holocene. *Frontiers in Earth Science*, *8*, 20. https://doi.org/10.3389/feart.2020.00020

Shotyk, W., Cheburkin, A. K., Appleby, P. G., Fankhauser, A., & Kramers, J. D. (1996). Two thousand years of atmospheric arsenic, antimony, and lead deposition recorded in an ombrotrophic peat bog profile, Jura Mountains, Switzerland. *Earth and Planetary Science Letters*, *145*(1–4), E1–E7. https://doi.org/10.1016/S0012-821X(96)00197-5

Smol, J. P. (2008). There is no substitute for water. In *Pollution of Lakes and Rivers: A Paleoenvironmental Prespective*. Wiley and Sons.

Stewart, E. M., Hargan, K. E., Sivarajah, B., Kimpe, L. E., Blais, J. M., & Smol, J. P. (2018). A Paleoenvironmental Study Tracking Eutrophication, Mining Pollution, and Climate Change in Niven Lake, the First Sewage Lagoon of Yellowknife (Northwest Territories)

+ Supplementary Appendix 1 (See Article Tools). *ARCTIC*, *71*(2). https://doi.org/10.14430/arctic4720

Telford, J. V., Kay, M. L., Vander Heide, H., Wiklund, J. A., Owca, T. J., Faber, J. A., Wolfe, B. B., & Hall, R. I. (2021). Building upon open-barrel corer and sectioning systems to foster the continuing legacy of John Glew. *Journal of Paleolimnology*, *65*(2), 271–277. https://doi.org/10.1007/s10933-020-00162-w

Tse, T. J., Codling, G., Jones, P. D., Thoms, K., Liber, K., Giesy, J. P., Wheater, H., & Doig, L. E. (2014). Reconstructing long-term trends in municipal sewage discharge into a small lake in northern Manitoba, Canada. *Chemosphere*, *103*, 299–305. https://doi.org/10.1016/j.chemosphere.2013.12.019

Vachula, R. S., Huang, Y., Russell, J. M., Abbott, M. B., Finkenbinder, M. S., & O’Donnell, J. A. (2020). Sedimentary biomarkers reaffirm human impacts on northern Beringian ecosystems during the Last Glacial period. *Boreas*, *49*(3), 514–525. https://doi.org/10.1111/bor.12449

White, A. J., Stevens, L. R., Lorenzi, V., Munoz, S. E., Lipo, C. P., & Schroeder, S. (2018). An evaluation of fecal stanols as indicators of population change at Cahokia, Illinois. *Journal of Archaeological Science*, *93*, 129–134. https://doi.org/10.1016/j.jas.2018.03.009

White, A. J., Stevens, L. R., Lorenzi, V., Munoz, S. E., Schroeder, S., Cao, A., & Bogdanovich, T. (2019). Fecal stanols show simultaneous flooding and seasonal precipitation change correlate with Cahokia’s population decline. *Proceedings of the National Academy of Sciences*, *116*(12), 5461–5466. https://doi.org/10.1073/pnas.1809400116

Whitlock, C., & Larsen, C. (2002). Charcoal as a Fire Proxy. In J. P. Smol, H. J. B. Birks, W. M. Last, R. S. Bradley, & K. Alverson (Eds.), *Tracking Environmental Change Using Lake*

Sediments (Vol. 3, pp. 75–97). Springer Netherlands. https://doi.org/10.1007/0-306-47668-1_5

Chapter 2: Using lake sediment fecal biomarkers, charcoal, and metals to track human history over 1100 years at Dildo Pond, Newfoundland

2.1 Abstract

Over the last decade, paleolimnological techniques in conjunction with archaeological research have disproven previously foregone conclusions that anthropogenic environmental changes are a modern occurrence and prehistoric hunter-gather communities had a negligible effect on past ecosystems. To expand on this research, I used sedimentary fecal lipids and charcoal in a multiproxy approach to identify the human presence window at Russell's Point, Newfoundland, a seasonal Beothuk winter camp used to hunt caribou during their historical migration across Dildo Pond from ~1000 to 1650 CE. Additionally, I used multiple proxies to compare historical use of the lake prior to European settlement to modern use (after ~1900 CE) of the lake. I hypothesize that fecal lipid proxies will identify Beothuk presence corresponding with archaeological dating but will expand the human presence window as current dates are dependent on the ^{14}C preserved in the oldest artifacts/animal bones at Russell's Point. Sedimentary charcoal will identify small-scale fires from hearths and fires may increase after European arrival due to the government endorsed settlement in the area, then increase with the building of the trans-Newfoundland railway in the early 20th century. Two sediment cores were successfully aligned using sedimentary chlorophyll *a*, ^{210}Pb-dating, and ^{14}C-dating to yield long, high-resolution sediment records from Dildo Pond. Modeled chronologies show the oldest samples of core 01 reach to ca.1180 CE ±73 and ~900 CE ±229 in core 03. My results capture greater changes in sedimentary proxies in more recent sediments and a potential human signal as early as ~909 CE ±216 (from the high ratio of coprostanol to cholesterol), supporting our current knowledge of the Beothuk being present in the catchment at ~1000 CE. Given that our results show a human signal from the base of the core, we do not capture the Beothuk arrival to Dildo Pond. Camp abandonment at 1650 CE is obscured in the sediment record by catchment disturbances from European settlement.

Keywords: paleolimnology, archaeology, fecal lipids, charcoal, Indigenous, Newfoundland, multiproxy

2.2 Introduction

The Beothuk people of Newfoundland were the last of three periods of Indigenous settlement of Newfoundland (Duggan et al., 2017). First known contact with Europeans was made in the early 1500s, but the Beothuk kept their distance until the early 1600s when colonies were established (Gilbert, 2002; Polack, 2018; Rowley-Conwy, 1990). Beothuk people are thought to have experienced a rapid population decline shortly after European colonization, with the last surviving descendent dying in 1829 CE (Duggan et al., 2017; Gilbert, 2002; Polack, 2018). All the information currently known about the Beothuk comes from these early colonizers' diaries, letters to employers back home, and the few Beothuk artifacts that have survived (Gilbert, 2002; Polack, 2018). Starting in the early 20th century, there has been a concentrated effort by archaeologists to expand our understanding of Newfoundland's Indigenous history (Gilbert, 2002; Polack, 2018). Indigenous sites have been found using primary sources and first-hand accounts from initial colonizers (Gilbert, 2002; Polack, 2018). Expanding knowledge about Indigenous groups and the natural environment of Newfoundland raises questions about how they could have survived in such a harsh climate with limited natural food sources, particularly in winter (Duggan et al., 2017; Gilbert, 2002; Harris et al., 2019; Renouf, 1999). It was speculated that Beothuk established seasonal camps in the winter at locations that would protect them from the weather while giving them easier access to what animals were available for hunting, like seal and caribou (Gilbert, 2002; Harris et al., 2019). This idea was supported by the finding of seasonal interior camps using first-hand accounts from Europeans (Gilbert, 2002).

Within the last decade, paleolimnological techniques have been successfully combined with archaeological research by providing data that are less susceptible to modern disturbance or destruction and can be more directly compared to environmental data (Bell & Blais, 2021). Paleolimnological techniques have shown that even hunter-gather and nomadic groups, previously thought to have a negligible effect on the environment, affected their local environments through hunting practices, anthropogenic fires, waste disposal, etc. (Bell & Blais, 2021; Bell et al., 2005.; Douglas et al., 2004; Hadley et al., 2010; Michelutti et al., 2013). So, while most artifacts from historical cultures have been lost and/or preserved poorly, paleolimnology provides a way to detect human presence, interactions, and impacts on the environment, even in severe climates (Bell & Blais, 2021; Douglas et al., 2004; Hadley et al., 2010b). Paleolimnological techniques are useful when studying "extinct" prehistoric peoples whose narrative has previously relied solely on the material record and European documentation (Polack, 2018). Existing archaeological data can then provide independent information to verify the veracity of paleolimnologically-derived settlement history, population reconstructions, and environmental data.

Fecal lipids are hydrophobic organic compounds biosynthesized in a mammal's digestive tract and bound to fecal matter (Bull et al., 1999; Leeming et al., 1996). A 'sterol fingerprint' is a unique signal determined using the concentrations of the lipids found in fecal samples which is then linked to their presence in sediment samples (Harrault et al., 2019; Leeming et al., 1996). They are detectible thousands of years after deposition and are more source specific than stable isotopes (Bull et al., 1999; Gallant et al., 2020; Leeming et al., 1996). Humans produce four to five times the concentration of fecal lipids than other animals, with diagnostic amounts of the lipids coprostanol, epicoprostanol, and cholesterol representing the human 'sterol fingerprint' (Bull et al., 1999; Gallant et al., 2020; Harrault et al., 2019; Leeming et al., 1996). Ratios are used to account for differing degradation rates throughout sediment cores (Gallant et al., 2020).

Fecal lipids have been used to identify both modern and historical human presence in the environment, primarily in lower latitudes, with more recent studies successfully applying the method to colder climates (Gallant et al., 2020; Hadley et al., 2010b). Paleolimnological studies like White et al. (2018, 2019) have been able to add new information to the already extensive archaeological research at a large prehistoric population center in central North America, Cahokia in Illinois, by connecting population changes, determined using fecal lipids, to environmental issues in the region (White et al., 2018, 2019). Vachula et al. (2020) validated the use of fecal lipids in cold climates on millennial time scales using a multi-proxy approach to support the theory that humans were in Beringia during the Last Glacial period and promoted fire activity. D'Anjou et al. (2012) identified human arrival at a lake in northern Norway with fecal lipids that corresponded with a rise in pyrolytic polycyclic aromatic hydrocarbons from an increase in landscape fires, a change in *n*-alkane chain lengths from leaf waxes (indicating a decline in woodland), and independent tree-ring reconstructions; showing how human population increases in an area leads to changes in land-use through woodland clearing (D'Anjou et al., 2012).

Macroscopic charcoal has been used in multi-proxy studies to identify localized fire histories in areas with evidence of Indigenous presence. Charcoal particle sizes correspond to distance travelled, with microscopic pieces (<100 μm) being from extra-local or regional fire events and macroscopic (>100 μm) pieces being from local fire events near or on study lakes (Long et al., 1998; Millspaugh & Whitlock, 1995). Millspaugh and Whitlock (1996) concluded that after a recent fire macroscopic charcoal >125 μm in diameter were common in lakes when fire events occurred within the catchment basin or in the region upwind of the lake, typically referred to as extra-local. These macroscopic charcoal pieces are categorized as primary charcoal having been deposited directly from the fire into the lake via runoff/slopewash or short distance fall out from wind (Mustaphi, 2014; Long et al., 1998; Millspaugh & Whitlock, 1995). Differentiating between anthropogenic and natural fires poses a complex challenge that is aided by global or regional fire histories and tentative comparisons to human chronologies for the study site (Argiriadis et al., 2018; Bell & Blais, 2021; Long et al., 1998; Millspaugh & Whitlock, 1995). The combination of macroscopic charcoal and fecal lipids strengthens paleolimnological studies inferring past human settlement patterns by providing independent lines of evidence for the presence of humans in a lake catchment, including a potential Indigenous-derived fire history (Argiriadis et al., 2018; Bell & Blais, 2021).

Sedimentary metal analysis has been used in multiproxy studies to understand anthropogenic effects on lake ecosystems. Zinc, chromium, lead, and cadmium, in particular, are known to increase with human waste input (Andrews et al., 1999; Antoniades et al., 2011; Bartkowska et al., 2019; Gallant et al., 2020). Arsenic is affected by coal combustion, land clearing and changes in land use, and atmospheric emissions from mining and smelting (Shotyk et al., 1996). However, many metal(loid)s in sediment records have been shown to have a delayed response to human activity possibly due to sediment resuspension or dissolution and diffusion in sediment porewaters (Gallant et al., 2020). While we do not know if this delay is consistent throughout the chronology, analyzing metals in conjunction with fecal lipids and percent organic carbon, allows for this delayed response to be accounted for (Gallant et al., 2020). Due to certain metals preferentially attaching to available carbon, increases in percent organic carbon would decrease the chances of resuspension and thereby limit the timing of a delayed response (Pan et al., 2019).

Russell's Point is a low, grassy triangle on the west bank of Dildo Pond in Blaketown, Newfoundland (Fig. 2.1B). While there have been no structures built on it in living memory, it has been used for dumping, parking, camping, and launching boats. Natural weathering and these modern disturbances have left no visible evidence of the approximately 650 year-long presence of the Beothuk. The site was rediscovered in 1988 CE using first-hand accounts written by Newfoundland's first governor, John Guy, who was present at the first interaction with the Beothuk at this site in 1612 CE (Gilbert, 2002). The archaeological excavations done at Russell's Point (Fig. 2.1B), show that the site was used for a substantial period, if intermittently/seasonally, with middens close to the shoreline and records of man-made fires (Gilbert, 2002). Evidence of 17 hearths indicate extended man-made charcoal production. Two middens, one right next to the shoreline, are signs of various types of waste disposal and cleanliness practices at the site. These two factors at Russell's Point support the use of fecal lipid analysis and charcoal analysis in our study.

Analyzing how aquatic ecosystems responded to the small-scale interference of ancient humans by correlating paleolimnological records with archaeological records will provide a multi-disciplinary understanding of environmental responses (Bell & Blais, 2021). The objectives of this study were to: (1) identify and date the pre-European, Beothuk window of human presence at Dildo Pond in the lake sediment stratigraphy; (2) to validate the use of fecal stanols and charcoal as reliable proxies for tracking past Indigenous settlements on lakes in Newfoundland, including within larger and deeper bodies of water; and (3) to place 20th century human impacts to the region within a long-term context. We predicted that together fecal stanols and charcoal within a multi-proxy study would identify camp occupation dates on Dildo Pond that corresponded with archaeological data, but would expand the window of human presence as the current occupation window was dependent on the preservation, retrieval, and adequate ^{14}C of the oldest artifacts/animal bones at Russell's Point. As Dildo Pond has had a continuous human presence since Beothuk arrival, we anticipated that sediment proxies may more closely track the arrival and growth of the Beothuk presence on Dildo Pond rather than the abandonment of the winter camp, as the abandonment coincided with European arrival and settlement around Dildo Pond. It is also important to note the size of Dildo Pond; being a 4 km long lake with depths up to 21.3 m; this large volume of water may have resulted in the dilution of proxies and may affect our study's results. To achieve our objectives, we collected three sediment cores downstream from the Russell's Point, aligning two cores with ^{210}Pb and radiocarbon dates, to yield a continuous chronology of the pond going a hundred years further back than the accepted age of Beothuk site establishment (~1000 CE).

2.3 Methods

2.3.1 Study Site Description

The Beothuk winter camp, named Russell's Point (47.4940923, -53.5509094) after the Russell's Service Station that it is situated behind, is located on the western shore of Dildo Pond ~2.4 km south of Dildo Arm in Trinity Bay, NL (Fig. 2.1) (Gilbert, 2002). The site juts into the pond for 34 meters, ending in a medium to fine gravel beach and a panoramic view of the entire pond (Gilbert, 2002). Dildo Pond formed during the Pleistocene as glaciers receded northward through a pre-glacial river valley (Gilbert, 2002). This formation gave the pond a long (4 km) and narrow (0.67 km wide) geomorphology, with an average depth of 10 meters and a maximum depth of 21.3 meters (Gilbert, 2002). Even though by limnological definitions Dildo Pond is classified as a lake, Newfoundland tradition uses 'pond' more commonly and thus this lake is named ‘Dildo Pond’. It should also be noted that Google Maps identifies Dildo Pond as Blaketown Pond, and some residents of Blaketown follow suit. However, previous research, namely Gilbert (2002), local development projects, and provincial records refer to it as Dildo Pond. This study will follow the Newfoundland tradition to match previous research and provincial records. There are two small islands in the southern end of Dildo Pond visible from Russell’s Point (Gilbert, 2002). The pond sits at 30.5 meters above sea level and the drainage basin is approximately 41 square kilometers (Gilbert, 2002). The main tributary input comes from the southern end through a north flowing river that forms a series of small ponds before reaching Dildo Pond (Gilbert, 2002). Output is at a marshy area in the northern tip which then flows a kilometer and a half and deposits into Dildo Arm and Trinity Bay (Gilbert, 2002). The prevailing theory is that this location was chosen by the Beothuk for its visibility and proximity to the annual caribou migration that crossed Dildo Pond (Gilbert, 2002). After colonization and development, a railroad was established and disrupted the caribou migration patterns in the area (Table 2.1). The land around Dildo Pond was designated as an agricultural center in the late 1800s and in the 1900s there was whaling and mink farming within the drainage basin. The whaling station in South Dildo was one of the last to close in Newfoundland in 1972 (Dickinson & Sanger, 2018). The former whaling premises are now used for other marine-related purposes, primarily processing and curing harp seal pelts (Dickinson & Sanger, 2018).

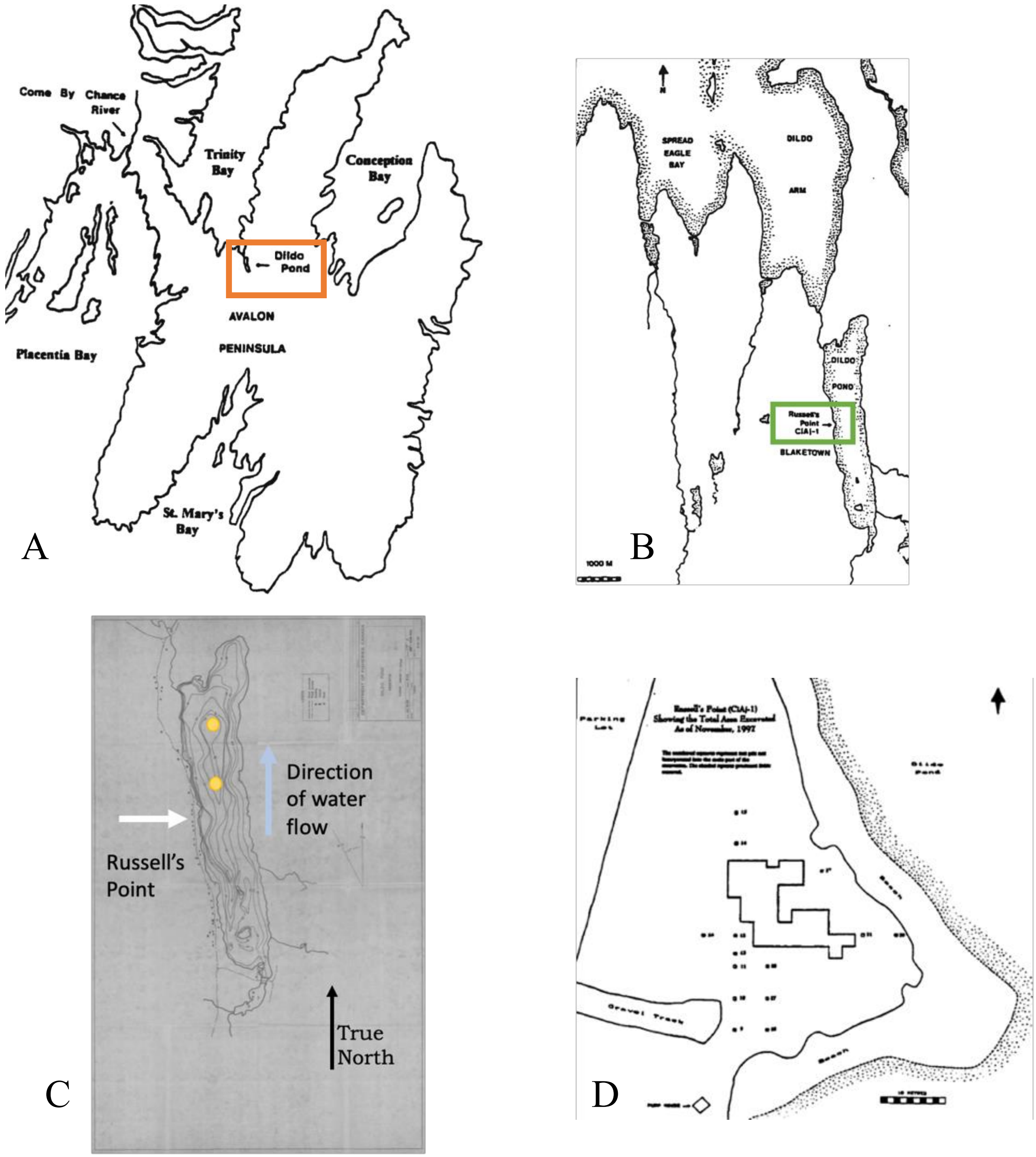

Figure 2.1. (A, B, C, D). Maps of Russell's Point on Dildo Pond. A – The Avalon Peninsula with Dildo Pond indicated by the orange box. B - Green box indicates location of Russell's Point. C - White arrow points to Russell's Point, blue arrow indicates direction of water flow, and yellow dots identify coring locations. D - Zoomed in view of Russell's Point showing the excavation site from 1997. Maps from Gilbert, 2002.

Table 2.1. Dildo Pond regional historical timeline from 1000 to 2021 CE.

Year (CE)	Events
1000 -1650	Beothuk utilization of winter camp on Dildo Pond to hunt caribou[1]
1612	Beothuk-European contact at Russell's Point[1]
1884	Railway line along Dildo Pond completed – end of caribou migration[1]
1886	Road built along Dildo Pond completed
1888	Blaketown established around Dildo Pond as an agricultural district
1889-1896	Cod hatchery established on Dildo Island[2]
1892	Blaketown burns down and is rebuilt
early 1900s – 1972	Dildo Whaling period – predominantly Pot Head whales
1947-1966	Arctic Fishery Products Co.; whaling & export of marine oils[2]
1967-1972	East Coast Whaling Co. (takeover Arctic Fishery Products Co.); 1035 whales taken[2]
~1955 - ~1981	Mink farming in Dildo Pond catchment[2]
1994	1st excavation of Russell's Point[1]
1997	2nd excavation of Russell's Point[1]
2021	Hargan Lab core Dildo Pond

[1]Gilbert, 2002
[2]Dickinson & Sanger, 2018

2.3.2 Sample collection

Three cores were collected with a gravity corer downstream from Russell's Point, Dildo Pond (Fig. 2.1C). Dildo 01 and Dildo 02 were taken with a Glew gravity corer with an internal diameter of 7.62 cm (Glew, 1988) on June 5, 2021, at a depth of 20.4 m and sectioned with a Glew vertical extruder (Glew, 1988) at 0.5 cm resolution; sediment samples were placed into individual WhirlPak® sample bags. Dildo 01 was 57 cm long and Dildo 02 was 58 cm long (Fig. 2.2A). There were no distinguishing features between collection and visual inspection of these two cores; therefore, Dildo 01 samples were freeze dried to prepare for subsampling and Dildo 02 samples were stored frozen for future use.

Dildo 03 was collected with a longer coring tube than Dildo 01 and 02 to ensure the window of Beothuk presence at Russell's Point (currently established based on archaeological research; Gilbert, 2002) was captured in its entirety. The core was collected October 7, 2021, from a sailboat with a UWITEC gravity corer and a modified bung system at a depth of 21.3 m. The UWITEC auto bunging system was not utilized. Dildo 03 was 85 cm long (Fig. 2.2 B) and sectioned with a Telford sectioner (Telford et al., 2021) at 0.5 cm resolution. Each interval was freeze dried to prepare for subsampling.

Figure 2.2 Pictures of the two focus cores from Dildo Pond. A-Dildo Pond 01 core prior to sectioning. B-Dildo Pond 03 core prior to sectioning.

2.3.3 Chronologies

Gamma tubes for ^{210}Pb dating were prepared for Dildo 01 and Dildo 03 every 2 cm from 0-10 cm and every 4 cm from 10-28 cm. Approximately 0.5 grams (equivalent to a height of 1.5-2.0 cm within the gamma tube) of dried sediment was used for each gamma tube and sealed with 2-ton epoxy (50:50 epoxy resin and polyamine hardener). Prepared samples were sent to the Paleoecological Environmental Assessment and Research Lab (PEARL) at Queen's University for low-background gamma counting analysis. A constant rate of supply (CRS) model was applied to assign sediment chronologies to both cores (Appleby & Oldfield, 1978). The sediment chronology reports for each core were made using the software ScienTissiME and the CHRONO toolbox (http://www.scientissime.net/). The historic 1963 CE ^{137}Cs peak, signaling the height of nuclear weapons testing, was used as an independent date marker for all chronologies.

Bulk sediment and organic material from Dildo 01 and Dildo 03 were sent to the André E. Lalonde AMS Laboratory at the University of Ottawa for ^{14}C dating. Calibrations were done with the model OxCal v4.4 (Bronk Ramsey, 2009) and IntCal20 calibration curve (Reimer et al., 2020). Macrofossil mass proved insufficient for ^{14}C dating, so only bulk sediment ^{14}C dates were obtained. A compound Poisson-Gamma model (Haslett and Parnell 2008) was used to calculate continuous chronologies with the function 'Bchronology' in the R package 'Bchron' v 4.7.6 (Haslett and Parnell 2008).

2.3.4 Elemental and Bulk Stable Isotopes

For stable isotope analysis, between 7-8 mg of freeze-dried sediment was subsampled every 4 cm from Dildo 03 into 7x7 mm tin capsules and analyzed at the Earth Resources Research and Analysis (TERRA) facility at MUN, with duplicate samples sent to Ján Veizer Stable Isotope Lab at the University of Ottawa. Samples at TERRA were analyzed with a Carlo

Erba Elemental Analyser coupled to a Delta V Plus Isotope-Ratio Mass Spectrometer (Thermo Scientific) via a ConFlo III interface. The duplicates were analyzed with a Vario El III Elemental Analyzer (Elementar, Germany) coupled with an isotope ratio mass spectrometer (Delta Advantage, Thermo, Germany). The combustion reactor (chromium oxide and silvered cobaltous oxide) was held at 1050ºC, while the reduction reactor (Cu) was at 600ºC. For elemental analysis, a calibration curve for %C and %N was prepared using acetanilide. For isotopic analysis, scale calibration for $\delta^{13}C$ was performed with $CaCO_3$ ($\delta^{13}C$ = -40.11± 0.15‰) and D-fructose ($\delta^{13}C$ = -10.53±0.11‰). Scale calibration for $\delta^{15}N$ was performed using IAEA-N-2 ($(NH_4)_2SO_4$; $\delta^{15}N$ = +20.32 ± 0.09‰) and USGS25 ($(NH_4)_2SO_4$; $\delta^{15}N$ = -30.25 ± 0.38‰). A high organic sediment B2151: 7.45 ± 0.14 % C; 0.52 ± 0.02 %N; $\delta^{13}C$ = -28.90 ± 0.10‰; $\delta^{15}N$ = 4.35 ± 0.20‰), acquired from Elemental Microanalysis, was analyzed several times during a run as a quality control sample. Isotope data were normalized using these previously calibrated internal standards, and analytical precision was ±0.2‰. Modern stable carbon isotope results were Suess-corrected to account for depletion of $\delta^{13}C$ in the atmosphere due to the burning of fossil fuels (Schelske & Hodell, 1995). This correction was applied to samples from 1840 to 2017 CE, during which ~70% of carbon depletion has occurred and allows for relatively small trends from the last 60 years to be properly presented. Without the correction, productivity decreases during this period are overestimated and present productivity is underestimated (Schelske & Hodell, 1995).

To isolate organic carbon from the sediments, 20-50 mg of Dildo 03 sediment was subsampled into glass scintillation vials. This sediment was dampened with a small amount of deionized (DI) water and placed within the desiccator with concentrated HCl for 48 hrs (Komada et al., 2008). Acidified samples were rinsed repeatedly with DI water until a near neutral pH was reached. Dried samples were weighed out into tins and sent to the Ján Veizer Stable Isotope Lab at the University of Ottawa for % organic carbon analysis.

2.3.5 Metal(loid)s

Bulk sediment samples were sent to SGS Inc. (Lakefield, Ontario) for geochemical analysis using inductively coupled plasma mass spectrometry (ICP-MS). Samples were prepared by weighing approximately 0.5 g of freeze-dried sediment over four-centimeter intervals for the surface of Dildo 01 (0, 1, 4, 8, 12 cm) and all of Dildo 03 (0-85 cm). The subsampled sediment was ground with mortar and pestle before being placed in plastic scintillation vials. The 32-target metal(loid)s and their respective detection limits are found in Table 2. Arsenic, cadmium, copper, and zinc were chosen as our focus metals because their presence in lake sediments is a result of human activity (Andrews et al., 1999; Antoniades et al., 2011; Bartkowska et al., 2019; Gallant et al., 2020).

Table 2.2. Metal(loid)s and detection limits analyzed for Dildo Pond 01 and 03

Metal(loid)s (limit of detection μg/g)			
Aluminum (0.2)	Calcium (0.01)	Magnesium (0.01)	Thallium (0.002)
Antimony (0.01)	Chromium (1)	Manganese (2)	Tin (0.02)
Arsenic (0.001)	Cobalt (1)	Molybdenum (1)	Titanium (0.02)
Barium (0.05)	Copper (1)	Nickel (1)	Uranium (0.002)
Beryllium (0.05)	Iron (0.01)	Selenium (0.001)	Vanadium (0.01)
Bismuth (5)	Lead (2)	Sodium (0.01)	Yttrium (0.0005)
Cadmium (1)	Lithium (1)	Strontium (0.0005)	Zinc (0.002)

2.3.6 Charcoal

Macroscopic charcoal was analyzed for all of Dildo 01 and the bottom of Dildo 03 (44.0-85.0 cm), starting where extrapolated dates indicated overlap between the two cores, to create a continuous fire history. The method was modified from Whitlock and Larsen (2001) and

Musaphi (2014). Dried sediment samples were weighed out to 0.4 g for each interval (~ 1 cm^3 when wet) and soaked in 20 mL of 10% KOH for 48 hr, stirring once after 24 hr. Samples were then rinsed in 125 µm sieves with DI water until runoff was clear and soaked in 10% bleach for 24 hr to help differentiate between charcoal and dark organic matter. To rinse and sieve samples simultaneously, samples were wet sieved through 125 µm sieves using DI water. Samples were stored in 50 mL centrifuge tubes until charcoal counting was conducted. Charcoal was counted using an S-tray (Bogorov chamber), tweezers, and a compound/stereo microscope with over-head lighting attachment. Bleaching helped lighten most non-charcoal particles, but some still displayed opaquely. To increase visibility, the S-tray was filled with a small amount of sample and diluted with DI water to spread out the particles. Over-head lighting provided the best conditions to identify charcoal from dark organic matter post-bleaching. To identify pieces of charcoal from black organic material that resisted bleaching, I looked for pieces with sharp, distinct edges that were opaquely black or dark throughout the piece and would sometimes have a shine or be iridescent. For pieces with softer edges or inconsistent color or varying opaqueness, I gently pressed it with the tip of my tweezers. Organic material would mash and look mushy, and it would be possible to see a light brown color inside the piece. Charcoal would fracture and would be consistently black and opaque throughout. The charcoal shape guide in Musaphi (2014) was followed to identify distinct shapes when possible. When a charcoal piece was identified, it was tallied and the shape was noted. While a majority of the pieces were subangular or rounded, the next common piece was typically a rectangular grid with varying shades of gray to black.

The R package 'Tapas' (Finsinger & Bonnici, 2022) which builds on CharAnalysis (Higuera et al., 2009), was used to determined background charcoal and significant peaks of interest in the fire history. The program converts the count data to an accumulation rate – number of pieces per cm^2 per year, and thus is highly reliant on the core chronology. We compared different smoothing methods (i.e. method used to model low-frequency trends in the charcoal record) for identifying significant fire events, including a moving median, moving average, and Lowess smoothing. However, we also expected that during a continuous occupation period of Russell's Point by Beothuk that hearth fires would not necessarily yield significant fire events and may rather, be incorporated as part of the 'background' signal.

2.3.7 Chlorophyll *a*

To estimate whole-lake production changes throughout both cores, visible reflectance spectroscopy (VRS) was used to reconstruct sedimentary chl *a* (including its main diagenetic products) (Michelutti et al., 2010). Freeze-dried sediment was sieved through a 125 µm screen onto weigh paper to equalize sediment grain size and the influence of water. Sediment-filled vials were run through a spectroradiometer using the visible portion of the electromagnetic spectrum to infer chl *a* and its derivatives (i.e., chlorophyll *a* + all chlorophyll *a* isomers + pheophytin *a*+ pheophorbide *a)*. Details of the method and the equation used to infer chl *a* and its derivatives are given in Michelutti et al. (2010).

2.3.8 Stanol and Sterols

For Dildo 03, 27 samples were analyzed for seven stanols and sterols: cholesterol (cholest-5-en-3β-ol), cholestanol (5α-cholestan-3β-ol), sitosterol (β-sitosterol), stigmastanol (5α-stigmastan-3β-ol), campesterol, coprostanol, and epicoprostanol. To start, 10 mL dichloromethane (DCM) was added to 100 milligrams (mg) of copper (Cu; Fisher) in ashed scintillation vials and sonicated for 10 minutes. The DCM was discarded after the first sonication, fresh DCM was added, and sonicated again. This step was repeated for a total of three times. The Cu was air dried in a fume hood, then 100 mg of freeze-dried material was added to each vial. Sediment was subsampled every 4 cm (*n* = 27) for Dildo Pond 03. Each sample was spiked with 100 µL of 50 ppm (3α)-Allopregnanolone. Blanks containing only cleaned copper were spiked with 50 ppm 9 standard mix. Samples were evaporated to dryness and refrigerated for 12 hr at 4°C. To extract lipids from samples, 10 mL of 10% Ethyl acetate and 90% Dichloromethane (DCM high-grade Optima ® brand) was added to each vial and samples were sonicated for 10 minutes. The solvent mixture was pipetted into 50 mL centrifuge tubes three times. Samples were centrifuged at 3000 rpm for 20 minutes then transferred to solvent washed Turbovap tubes and evaporated to 2 mL under a gentle nitrogen stream. The remaining sample was transferred to a Solid Phase Extraction (SPE) column with 1.0 g of Si (Millipore), which was pre-conditioned with 6 mL of DCM ahead of time. The Turbovap tube was rinsed with 0.3 mL DCM then transferred to the columns and samples were eluted with a total of 40 mL DCM. Vacuum pressure was used to remove all DCM from the columns. The samples were transferred to solvent washed Turbovap tubes and evaporated to 1 mL under a gentle nitrogen stream. The 1 mL samples were transferred to GC vials and evaporated to dryness under a gentle nitrogen stream. At this step, 100 µL of internal standard, 50 ppm (3α)-Allopregnanolone, was also evaporated dry. Once dry, 100µL of 99% N,O-bis(trimethylsilyl)trifluoroacetamide) + 1% trimethylchlorosilane was added, samples were vortexed and then heated at 70°C for 2 hr. Samples were cooled for 15 minutes and 890 µL of toluene (high-grade Optima brand) and 10 µL of 250 ppm p-terphenyl-d_{14} were added to each sample. Samples were vortexed again and analyzed on the GC-MS.

Lipid analyses were carried out using an Agilent Technologies 6890 GC (G1530A) coupled to an Agilent Technologies 5973A MSD (G1098A) using an HP5MS-UI column from

Agilent Technologies (19091S-433-UI; 30m x 250 µm x 0.25 µm). Helium was the carrier gas at a constant flow of 1 mL min-1, resulting in a pressure of 10.5 PSI. Injections were performed using an Agilent Technologies 7683 series injector in triplicate for each sample, with a 1.0 µL injection volume. Injections were made using a pulsed spitless mode with the injector heater set at 280°C, and injection pulse pressure of 16.26 PSI for 1.0 min. The oven was heated through the following sequence for a total runtime of 39.00 min: maintained at 100°C for 1 minute, ramp of 12°C/min to 265°C, ramp of 0.5°C to 275°C, ramp 20°C/min to 320°C and held for 2 min. The mass selective detector was operated in selected ion monitoring (SIM) mode with a collision energy of -70 eV, the transfer line was heated to 280°C. All quantifier ions were monitored with a dwell time of 100 ms while the qualifiers were measured for 40 ms. The low mass filtering setting was used (+/- 0.7-0.9 m/z). Lipid values are reported in mg L^{-1} and µg g^{-1} of dry weight sediment and were corrected to the internal standard, (3α)-Allopregnanolone added to each sample when applicable. Sterol and stanol values are reported in µg$(gOC)^{-1}$.

We utilized the lipid ratios coprostanol/cholesterol and epicoprostanol/coprostanol to identify a human presence. Epicoprostanol/coprostanol accounts for *in situ* degradation of coprostanol to epicoprostanol (Stewart et al., 2018). Values less than 0.2 are interpreted as a positive human signal and values greater than 0.8 are interpreted as a negative human signal (Stewart et al., 2018). Coprostanol/cholesterol is used to identify human fecal presence (Fattore et al., 1996; Patton & Reeves, 1999; Stewart et al., 2018; Tse et al., 2014). Values above 0.5 indicate a positive human signal and values below 0.3 are a negative human signal, with values between being inconclusive (Fattore et al., 1996; Patton & Reeves, 1999; Stewart et al., 2018; Tse et al., 2014).

2.4 Results

2.4.1 Core descriptions

Dildo 01, Dildo 02, and Dildo 03 were fine grained, homogenous, dark brown sediment cores that were visually identical to each other (Table 2.3). Dildo 01 and Dildo 02 were cored at the same location at a depth of 20.4 m. Dildo 01 was 57 cm long and Dildo 02 was 58 cm long. Dildo 03 was cored at 21.3 m, the deepest part of the pond, and was 85 cm long. The water-sediment interface of Dildo Pond was evident in the top of Dildo 01 and Dildo 02 by the presence of living algae and active microorganisms. Dildo 01 and Dildo 03 had 78% and 80% water content respectively.

Table 2.3. Sampling date, coring depth (m), core length (cm), and latitude and longitude coordinates for all three Dildo Pond cores.

Core Name	Sampling Date	Coring Depth (m)	Core Length (cm)	Latitude	Longitude
Dildo Pond 01	Jun. 5, 2021	20.4	57	47.5004628	-53.5473482
Dildo Pond 02	Jun. 5, 2021	20.4	58	47.5004628	-53.5473482
Dildo Pond 03	Oct. 7, 2021	21.3	85	47.5061491	-53.5478339

2.4.2 Core Chronologies

Dildo 01

^{210}Pb decay follows a steep decline from the surface of the core at 0 cm until 1916 CE (14.0 cm) then there is a slower decay trend until background levels are reached at 1859 CE (22 cm) (Figure 2.3). Surface ^{210}Pb activity in Dildo 01 is ten times that in Dildo 03 even though they were collected within ~9 m of each other. There is a strong ^{137}Cs peak, which based on the CRS-dates, begins at 1968 CE (10.0 cm), peaks at 1992 CE (6.0 cm), and trails off through ~2003 CE (4.0 cm). Bulk sediment was used to obtain two ^{14}C dates for Dildo 01: 46.0 cm was dated to 690 ±18 yr BP with the range being 674 – 646 (77.0%) cal BP and 584 – 568 (18.4%) cal BP, and

56.5 cm dated as 851±19 yr BP with the range being 789-721 (92.2%) cal BP and 706 – 694 (3.3%) cal BP (Table 2.4).

Dildo 03

Based on surface ^{210}Pb activity and the depth of the ^{137}Cs peak in Dildo 03, we believe that the top of Dildo 03 did not capture the surface sediments of the pond; thus, Dildo 01 and Dildo 03 were aligned to provide a complete chronology. ^{210}Pb increases from the surface until 2006 CE (4.0 cm), followed by a steep decline until 1977 CE (8.0 cm), ending with a gradual decline until it reaches background levels at 1861 CE (18.0 cm) (Figure 2.3). There is a small ^{137}Cs peak starting at 1963 CE (10.0 cm), reaching its height at approximately 2006 CE (4.0 cm), and trailing off to the top of the core. Bulk sediment was used to obtain three ^{14}C dates for Dildo 03: 50.0 cm dating at 976 ±25 yr BP with a range of 896-930 (29.2%) cal BP and 793-887 (66.3%) cal BP, 58.0 cm dating at 736 ±12 yr BP with a range of 683 – 665 (95.4%) cal BP, and 70.0 cm dating at 944 ±12 yr BP with a range of 896-913 (13.3%) cal BP and 793-888 (82.2%) cal BP (Table 2.4). The ^{14}C date at 50.0 cm was excluded from the BCHRON model (Figure 2.4) because it did not align with the other two dates and is considered an age inversion.

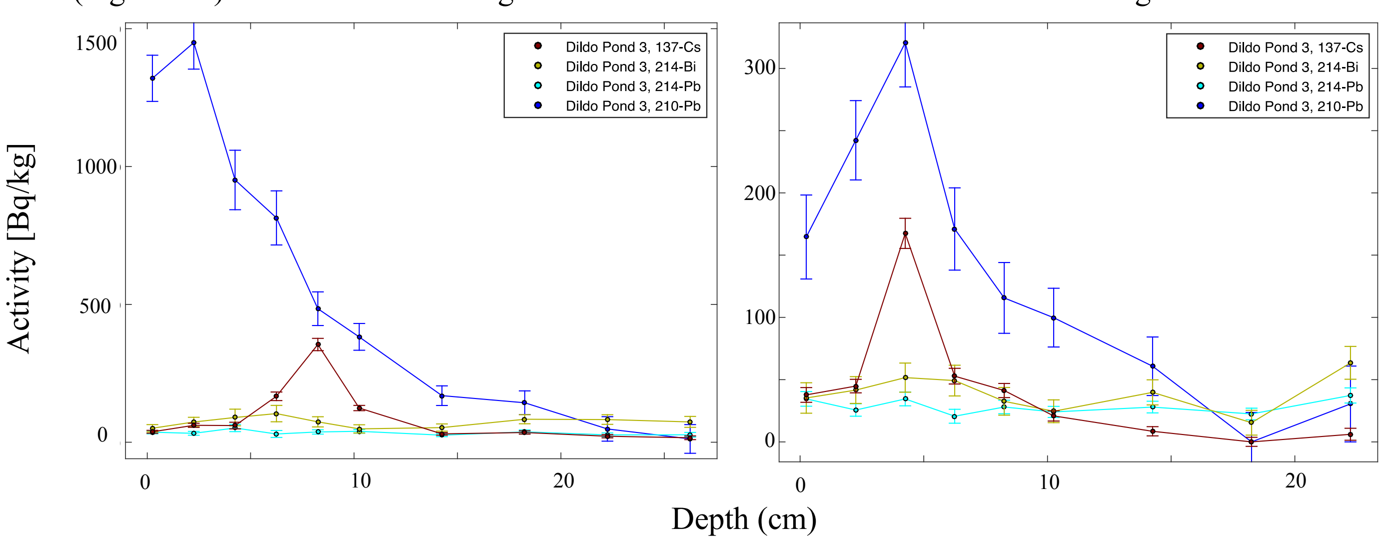

Figure 2.3 ^{210}Pb and ^{137}Cs curves for Dildo 01 (left) and Dildo 03 (right). The distinct ^{137}Cs peaks (red), along with ^{14}C-dating were used to align both cores and create a continuous chronology for Dildo Pond. Note that the y-axis scale (for radioisotope activity) is different for each plot. The cyan color is ^{214}Pb activity and yellow is ^{214}Bi, two markers used to estimate if ^{210}Pb activities have reached background.

Table 2.4. Accelerator mass spectrometry (AMS) radiocarbon dates from Dildo Pond 01 and 03 cores provided as ^{14}C years before present (^{14}C yr BP), Common Era (CE) years, and Cal BP age ranges.

UOC-Lab ID	Core ID	Depth (cm)	Conventional ^{14}C age ($^{14}C \pm$ error yr BP)	Year (CE)	Cal BP age range	Material dated
18692	Dildo 01	46.0-46.5	690±18	1260	674 - 646 (77.0%) 584 - 568 (18.4%)	Organic material
18691	Dildo 01	56.5-57.0	851±19	1099	789 - 721 (92.2%) 706 - 694 (3.3%)	Macrofossils
17255	Dildo 03	50.0-50.5	976±25	974	930-896 (29.2%) 887-793 (66.3%)	Bulk sediment
20432	Dildo 03	58.0-58.5	736 ±12	1214	683 - 665 (95.4%)	Bulk sediment
20431	Dildo 03	70.0-70.5	944 ±12	1006	913 - 896 (13.3%) 888 - 793 (82.2%)	Bulk sediment

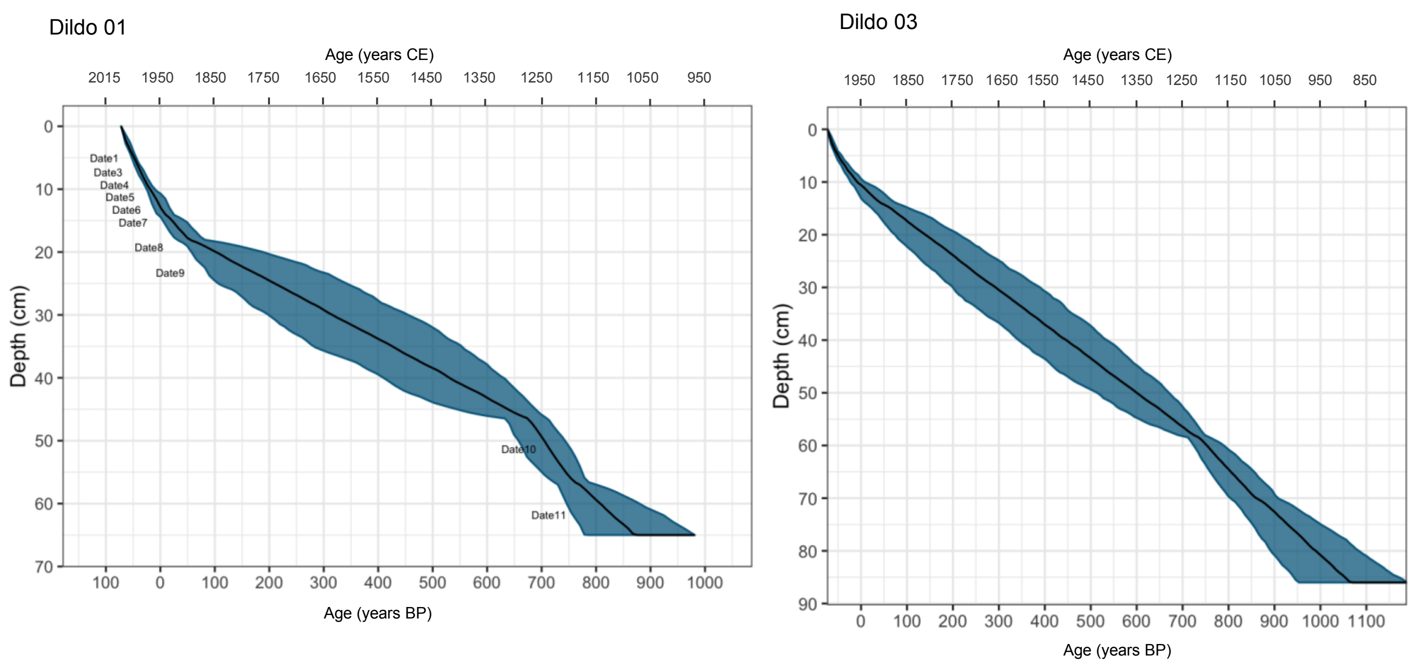

Figure 2.4. BCHRON dating models for Dildo 01 (left) and Dildo 03 (right); includes radiocarbon dates and 210Pb dates based on the CRS model for each core. The shaded blue regions represent margin of error.

2.4.3 Elemental and Bulk Stable Isotopes

At the bottom of the core, the $\delta^{15}N$ values for Dildo 01 show increased values from 6.5 to 10.2‰ starting at 1200 CE until 1382 CE followed by a decrease to 6.3‰ then 4.3‰ from 1424 to 1552 CE. Then there is the largest increase in the $\delta^{15}N$ values for the bottom half of the core to 10.1‰ at 1595 CE. After the early ~1600s, there is a decrease to 6.4‰ and 4.6‰ from 1637 to 1680 CE followed by an increase to 8.8‰ and 10.4‰ from 1720 to 1917 CE, which are the highest $\delta^{15}N$ values in the core. Following this, $\delta^{15}N$ values decline to the lowest value of the core, 3.5‰ in 1940 CE followed by an increase to 10.1‰ at 1982 CE, a decrease to 5.6‰ at 1994 CE, and an increase to 9.7‰ at the core surface. The intervals in the 20th century demonstrate greater fluctuation extremes over shorter periods of time than the rest of the core.

Here, we report the trends in the $\delta^{15}N$ values for Dildo 03; however, we do not have confidence in these values relative to those measured for Dildo 01; because it is likely that the % nitrogen content in the sediments of Dildo 03 was lower than Dildo 01 and not enough sediment was weighed into the tins for Dildo 03. This yielded small peaks on the IRMS that were difficult to quantify and resulted in greater error around the $\delta^{15}N$ values. As we already had $\delta^{15}N$ values for Dildo 01, we did not repeat the $\delta^{15}N$ measurements on Dildo 03 with greater sediment mass. The trend of $\delta^{15}N$ values for Dildo 03 was highly erratic throughout the core with a maximum of 6.1‰ at 1113 CE, a minimum of -10.6‰ at 1258 CE, and an average of -2.7‰. At least three fourths of the Dildo 03 samples analyzed have negative $\delta^{15}N$ values; however, 20th and 21st century samples are positive and show a large increase. During the early part of the chronology, the $\delta^{15}N$ values show erratic peaks in quick succession with only five samples being positive: 934 CE, 1058 CE, 1091 CE, 1113 CE, and 1226 CE. After the early 1500s, there is one peak in 1505 CE followed by a decrease from 1566 to 1627 CE and a slow increase to modern samples.

The Suess-corrected $\delta^{13}C$ values for the Dildo Pond sediment record show regular fluctuations until 1329 CE (Fig. 2.6), with the trend all but stopping at ~1669 CE. The early part of the chronology until the ~1600s shows fluctuations between -27.2‰ and -26.5‰ and three periods of more positive values: -27.1 to -26.7‰ from 983 to 1008 CE, -27.1 to -26.6‰ from 1058 CE to 1091 CE, and -27.0 to -26.5‰ from 1498 to 1584 CE. The highest $\delta^{13}C$ value during the Beothuk period is -26.5‰ at 1584 CE. After the 1600s, there is the largest decrease in $\delta^{13}C$ values from -26.5‰ in 1584 CE to -27.2‰ in 1669 CE followed by a sustained increase from -27.2‰ in 1669 to -27.0‰ in 1913 CE. After 1913 CE, the modern samples increase drastically, surpassing all of the $\delta^{13}C$ values in the bottom of the chronology and reaching the highest value of the core, -23.4‰ in 2000 CE. The average $\delta^{13}C$ for the chronology is -26.8‰.

Percent organic carbon was analyzed for Dildo 03 to account for any changes in organic matter flux to the lake overtime that may have influenced lipid attenuation to the sediments. Overall, %OC showed a general declining trend from the base of the core to modern samples. The minimum was 8.5% in 1113 CE and 2007 CE, the maximum was 16.3% in 1383 CE, and the core had an average OC of 12.0%. The variations prior to the 1500s show larger changes over shorter periods of time with ranges between 8.5% and 16.3%. After the 1500s, the range is between 10.5% and 13.9% until the low of 8.5% in 2007 CE and changes occur over longer periods than the bottom of the core.

2.4.4 Metal(loid)s

All metal results were reported in µg/g and normalized against titanium to account for sediment erosion changes over time (Duda et al., 2020; Gallant et al., 2020). Metal(loid) analysis was done at intervals of 4 cm for all of Dildo 03 and the top of Dildo 01 to provide a continuous window of analysis. However, this resulted in large metal concentration differences between Dildo 01 surface sediments and Dildo 03. We cannot know for sure if these differences in metal concentrations in the surface of Dildo 01 are from an increase in 21st century anthropogenic impacts from the catchment or differences in the sediment focusing between coring locations. For our continuous chronology, we have chosen to focus on four metal ratios, As/Ti, Cu/Ti, Cd/Ti, and Zn/Ti, that are typically used to identify human activities, particularly waste input in aquatic environments (Gallant et al., 2020). Overall, there is a large decrease at ~1000 CE, followed by the largest increase if the core at ~1200 CE (Fig. 2.6). For Cd, Cu, and Zn, the rest of the core follows a declining trend. Arsenic shows more activity leading up to modern samples.

Zinc shows a downward trend from its highest point at 1196 CE until its lowest point at 1505 CE followed by a small extended peak until 1688 CE and an increase to the top of the core. Arsenic, a proxy for human land use or atmospheric trace metals from industrialization (Mills et al., 2017), is at its second highest point at the bottom of the core, 909 CE, followed by a stilted decline at 1008 CE, two sustained peaks from 1155 to 1258 CE and 1183 to 1444 CE, followed by its lowest and highest points at 1505 CE and 1688 CE. From the mid-1700s to the late 1800s there is a slow decline then a sharp increase in the 20th century. At the bottom of the core, copper starts at a peak, 959 CE, then decreases to its lowest point at 1113 CE, followed by an increase to another peak at 1196 CE. Following this peak there is a stilted decline until 1566 CE and an increase until its highest point at 2007 CE. At the bottom of the core cadmium increases to one of two major peaks from 909 CE to 1008 CE. It then decreases from 1113 to 1155 CE and increases to its second major peak at 1319 CE. From this peak until an increase in 2007 CE, there is a sustained trough with smaller peaks that increase in magnitude in the 1800s.

2.4.5 Charcoal

Raw macroscopic charcoal counts (Figure 2.5) show major peaks in the Dildo 01 core at ~15 cm, corresponding to the early 1900s, and a depth of ~37 cm, corresponding to the mid to early 1400s. In the Dildo 03 core there are smaller, but distinct peaks at ~1226 CE and ~ 1124 CE. Charcoal analysis with TAPAS and using a LOESS smoother, found eight significant major fire events in the area (outside the 95% confidence interval of the smoother), seven of which occur before the 1600s (Figure 2.6). The first event at ~ 909 CE is the smallest of chronology. There is a second larger fire event at ~1033 CE and a third of the roughly the same magnitude at 1050 CE. The fourth event is the second smallest and occurs at ~1250 CE. The fifth, at ~1375 CE, is slightly larger than the 1250 CE event. The sixth and seventh events are the largest of this period and occur very close to each other at ~1430 CE and 1450 CE. Overall, the inset panel for the charcoal flux diagram (Figure 2.6) emphasizes that there was substantial fire activity from ~1450-1500 CE. The last fire event is in the early 1900s at ~1920 CE and is over five times the magnitude of the next highest event. Modern samples, starting at this 1920s fire event, also show much higher magnitudes and frequencies of fire activity (Figure 2.6).

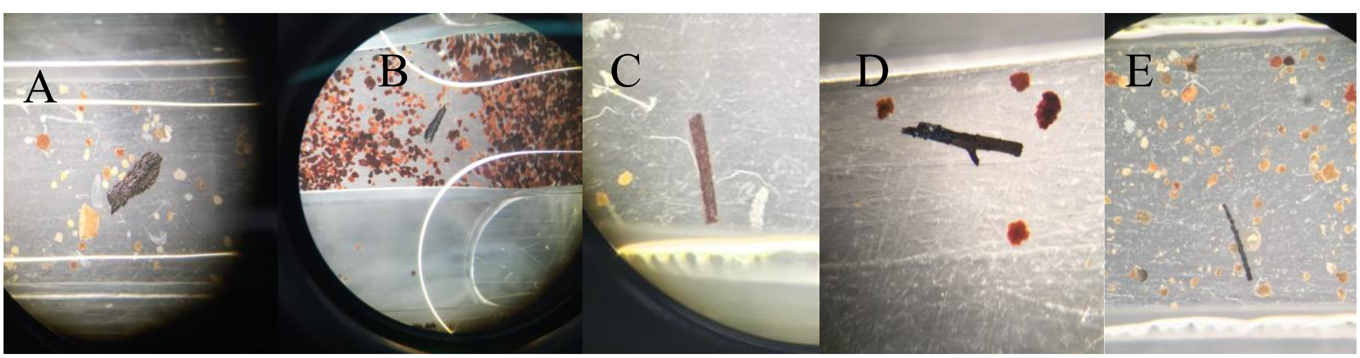

Figure 2.5. A-E Five pictures show a few common charcoal types found in the Dildo Pond samples. Many were elongated with distinct features, such as A and B with distinct structures, C has a mesh pattern, D has an embranchment, and E is built of repetitive pieces.

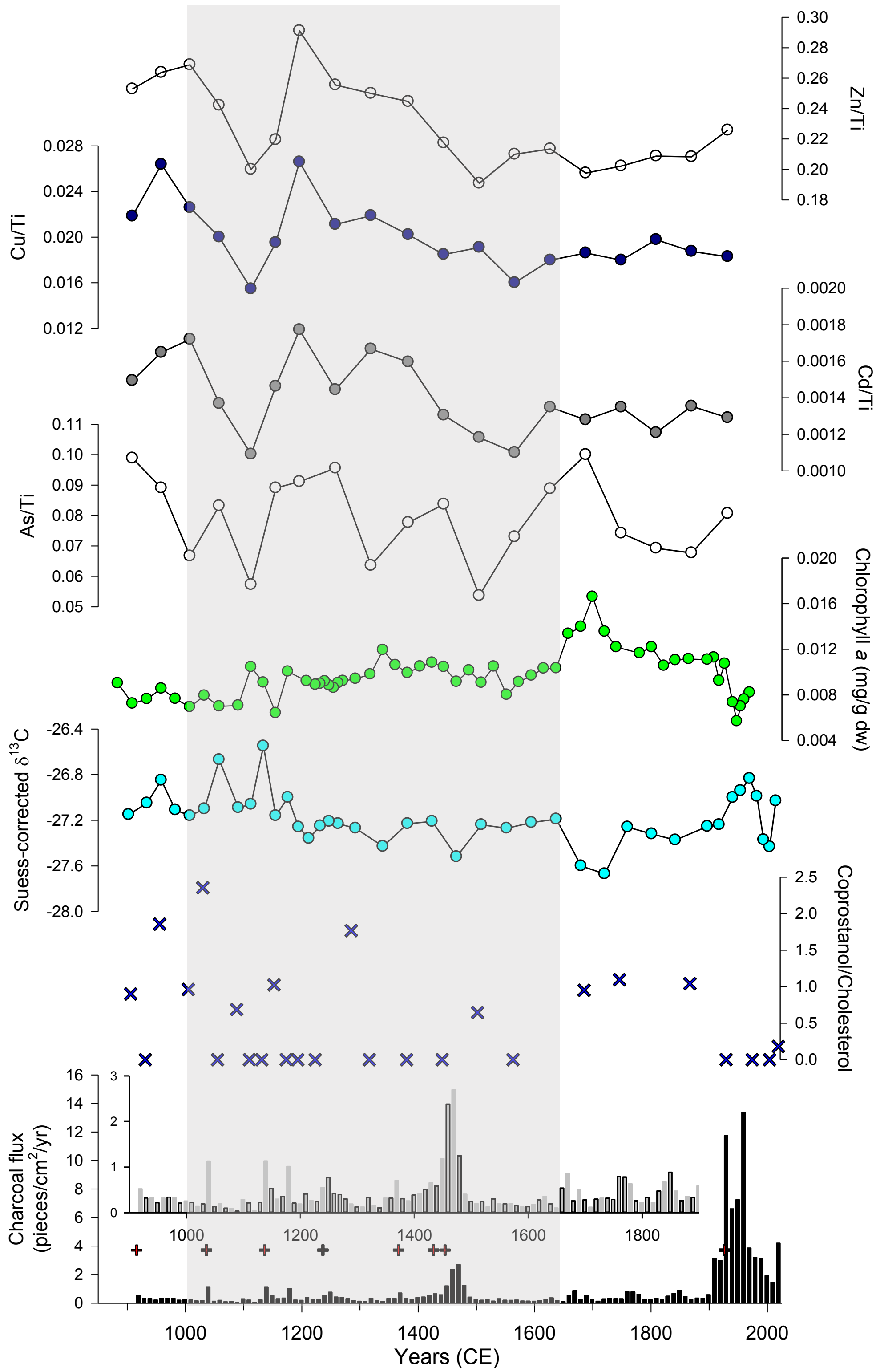

Figure 2.6. Metals standardized to Ti, chlorophyll a, Suess-corrected d[13]C, coprostanol/cholesterol, and charcoal flux graphed by year in common era on the x-axis. The known Beothuk period ~1000-1612 CE (Gilbert, 2002) is indicated by the grey box across all proxies. The coprostanol/cholesterol ratio is indicated by the blue 'x's and values over 0.5 are positive for human presence. The grey scale and black scale bar graphs show the charcoal flux, with fire events indicated by purple '+'s. This figure excludes modern samples to better display signals from the rest of the core.

2.4.6 Chlorophyll *a*

Chlorophyll *a* in Dildo 01 oscillates between 0.008 and 0.012 mg/g d.w. for the bottom half of the core. The top half of the core shows a wider range of variation between 0.005 and 0.30 mg/g d.w., with the two largest peaks of the core 0.016 mg/g d.w. at 1700 CE and 0.033 mg/g d.w. at 2004 CE. During the first half of the chronology, the chl *a* is flat until an increase at 1339 CE, the highest reading before the ~1600s. This is followed by a slight decrease from 1361 to 1382 CE, elevated levels from 1403 to 1444 CE, and two peaks at 1488 CE and 1530 CE. After a decrease in 1552 CE, there is a gradual increase leading into the 1600s. After the early 1600s, chl *a* levels become elevated exceeding previous peaks for most samples. There is a decline from 1927 to 1948 CE, the second lowest reading for the core. This is followed by a steep increase until 2004 CE and a steep decline from 2009 CE to 2021 CE, the lowest reading for the core.

Dildo 03 displays more chl *a* activity than Dildo 01, in a general increase towards the modern area. Chlorophyll *a* in the bottom half of Dildo 03, 1000 to 1650 CE, ranges between 0.005 and 0.010 mg/g d.w. with short intervals between multiple peaks and most samples being below 0.008. The top half of Dildo 03, after the early 1600s, has a range of 0.005 to 0.011 mg/g d.w. with fewer peaks and intervals, and most samples above 0.08 mg/g d.w. Prior to ~1000 CE, the chl *a* has highs and lows between 0.009 and 0.007 mg/g d.w. over 30-to-20-year intervals in a downward trend. After 1000 CE, the highs and lows are between 0.0104 and 0.005 mg/g d.w. From the bottom of the chronology until ~1600s, there are peaks and troughs in quick succession from 909 to 1319 CE. After 1319 CE, the peaks occur over longer periods of time until the early 1600s shows a dramatic increase. Chl *a* levels increase to the highest reading for the core in 1749 CE. There is a decline from 1778 to 1840 CE, but the values are still comparable with the pre-

1600 CE peaks. Then there is an increase from 1870 to 1932 CE, followed by a steep decline from 1959 to 1993 CE, the second lowest reading of the core. From 2007 to 2022 CE there is an increase to the same level as the highest peaks quantified from 1155 to 1226 CE.

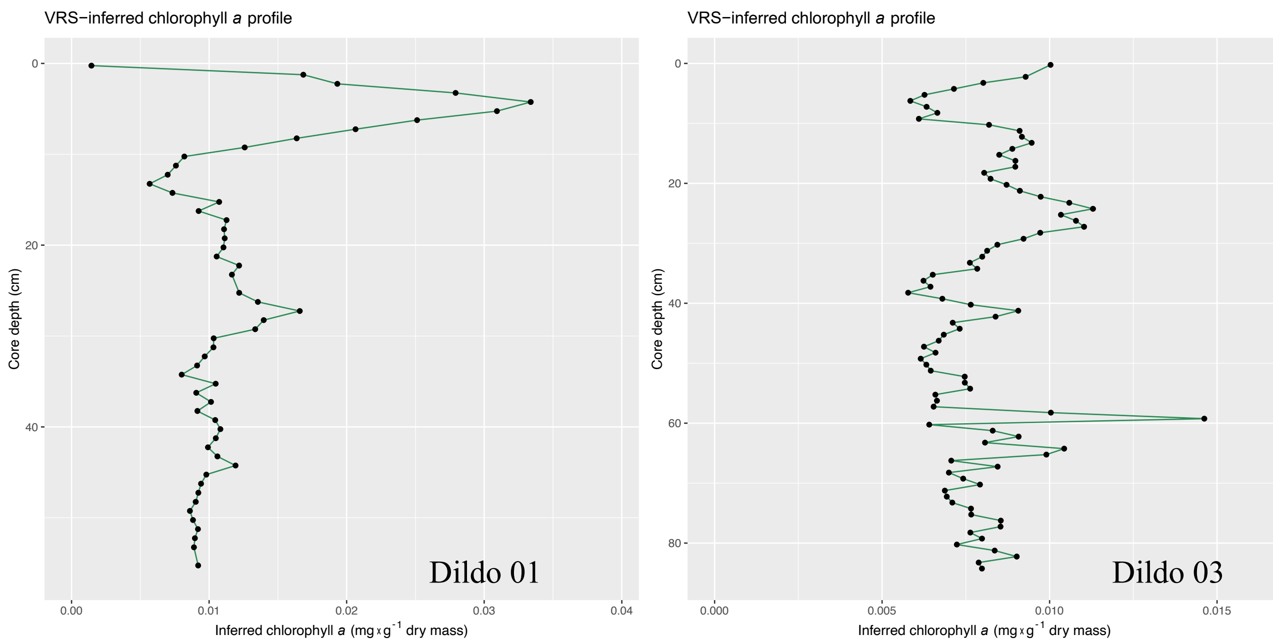

Figure 2.7. Inferred chlorophyll a profiles for Dildo 01 (left) and Dildo 03 (right) shown in mg g-1 dry weight and plotted by sediment core depth (cm).

2.4.7 Human fecal lipids

Overall, roughly half (11/25) of the samples analyzed for lipids captured a human signature (Fig. 2.6). We were unable to detect epicoprostanol, thus limiting the use of certain ratios. Plant sterols, sitosterol and stigmastanol, typically accounted for a minimum of 50% of the total lipid concentrations (Fig. 2.8). Around 1000 CE, coprostanol shows a very slight increase for 100 years followed by its highest peak during the Beothuk presence and a slow decline until European arrival (Fig. 2.8). After the early 1600s, coprostanol concentrations show significant increases with the highest values for the whole core. Cholesterol decreases after 909 CE and is followed by increasing levels until the 1650s CE: from 1058-1091 CE, 1155-1196 CE, and the highest peak during this period 1319-1505 CE. There is a decrease in cholesterol prior to the ~1600s and after the mid-1600s there are increases to the highest levels throughout the core. The coprostanol/cholesterol ratio shows short intervals of varied peaks prior to the mid-1600s and a more sustained lipid signal in the late 1600s (Fig. 2.7). Ratio values above 0.5 indicate human presence and values below 0.3 indicate no human presence (Fattore et al., 1996; Furtula et al., 2012; Patton & Reeves, 1999; Stewart et al., 2018; Tse et al., 2014). The highest ratio for the whole core is at 1033 CE.

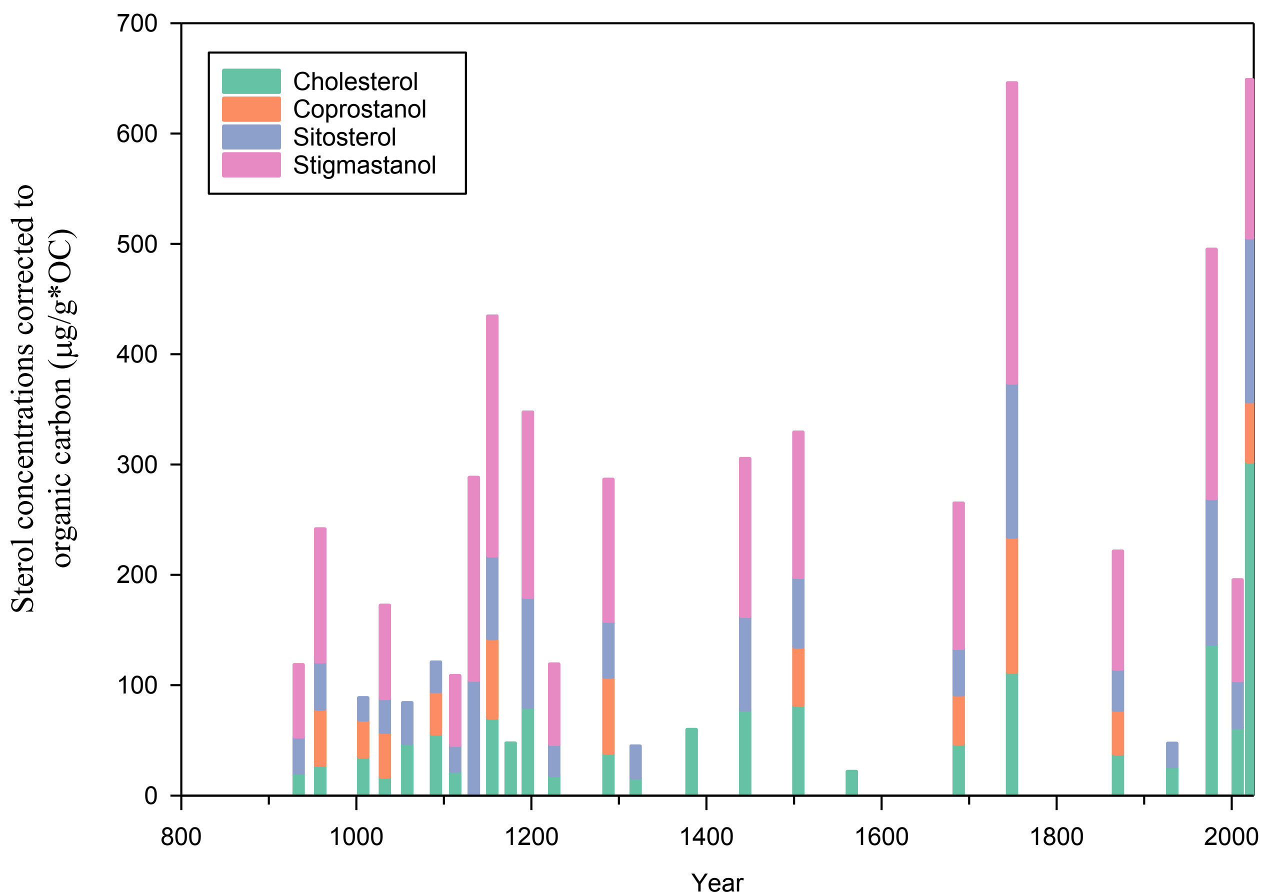

Figure 2.8. Lipid concentrations corrected to organic carbon (µg/g*OC) for Dildo Pond. Cholesterol (teal) and coprostanol (orange) are the main indicators of human presence. Sitosterol (purple) and stigmastanol (pink) are sourced from both aquatic and terrestrial plants.

2.5 Discussion

We found a positive human lipid signal throughout our chronology for Dildo Pond. Therefore, our data do not indicate a human free period in our sediment record that we can use to compare our proxies. We instead compare our proxies relative to each other and the human settlement periods within our sediment record: the Beothuk period (base of the core to ~1600s CE), after European arrival (~1600s to ~1900s CE), and the industrial revolution or 'modern period' (~1900s CE to present). The coprostanol/cholesterol ratio indicated a positive human signal from the base of the chronology (~900 CE) to the modern period, which is supported by concurrent increases in $\delta^{13}C$ values. The varying changes recorded in geochemical, biological, and ecological proxies between the different phases of human history at Dildo Pond support that the presence and activities of the Beothuk can be tracked in the sedimentary record. Below the changes in the Dildo Pond history are discussed.

The Beothuk period at Dildo Pond (~1000 to ~1650 CE)

We found evidence of human occupation at the base of our core, suggesting that we did not capture the period of initial arrival of Beothuk to the study area. With the coprostanol/cholesterol ratio, widely used to register human sewage entering lakes (Patton & Reeves, 1999; Stewart et al., 2018; Tse et al., 2014), we detected human presence to the base of the sediment chronology, 909 CE ±108 years. Thus, we most likely do not capture human arrival at Dildo Pond. While our sediment cores were not able to identify Beothuk arrival to Dildo Pond, the first sample with a positive human signal at the base of the core supported the archaeological findings that the Beothuk were present at Russell's Point at ~1000 CE (Gallant et al., 2020; Gilbert, 2002). The bottom of Dildo 01 dated to 1183 CE with an error of ±37 and the bottom of

Dildo 03 dated to 896 CE with an error of ±115. With such sizable margins of error and only three samples before ~1000 CE, using the fecal lipid analysis and the lipid ratio coprostanol/cholesterol, we cannot definitively say that the Beothuk arrived earlier than ~1000 CE. Multiple other proxies showed similar trends with lipids, suggesting that humans have driven many of the changes we observed throughout the chronology. Metals are known to have a delayed response to fecal input due to sediment resuspension or dissolution and diffusion in sediment porewaters, suggesting that increases at the bottom of the chronology may support that we did not capture the Beothuk arrival to the pond (Gallant et al., 2020). The degree of this delayed response may vary throughout the chronology as higher amounts of organic carbon can limit resuspension due to certain metals preferentially attaching to it (Pan et al., 2019). Our charcoal analysis indicated that there was a significant fire event at the very base of the chronology and around or shortly after the heightened human-lipid signal at 1033 CE, possibly supporting the use of hearths at this time. However, given that our analysis went to just before ~1000 CE and did not definitely capture the arrival of Beothuk, this posits the possibility of an earlier arrival time than currently thought. With a positive human presence indicated by the fecal lipid analysis to the bottom of the core, dated to potentially just before the previously proposed Beothuk arrival and supported by metals and charcoal analysis, the Beothuk arrival date to Dildo Pond may be earlier than currently thought.

Our findings indicate that the delayed response typically found in sedimentary metals analysis lessens during the first identified period of human activity at Dildo Pond compared to the rest of the chronology. From ~1000 to ~1300 CE, the lipid ratio and the metals experienced a sharp decline and, while the lipid ratio showed a slow increase, the metals quickly peaked to their highest values in the chronology. The sharp decline reached its minimum value for these proxies at ~1100 CE and coincided with a peak in chl *a* and a decline $\delta^{13}C$ values. For the metals, given their delayed responses, this decline may have been reflective of an event that predated our chronology and the ensuing peak could correspond with the 1033 CE lipid ratio peak (Andrews et al., 1999; Antoniades et al., 2011; Bartkowska et al., 2019; Gallant et al., 2020; Shotyk et al., 1996). The metals peaked at ~1200 CE, at which time the lipid ratio was slowly increasing, chl *a* began maintaining elevated levels and $\delta^{13}C$ values declined. The elevated chl *a* as the lipid ratio increased could suggest nutrient input from Beothuk presence, in particular from their waste disposal and hunting activities (Hadley et al., 2010). Charcoal flux increased around this period as well, possibly from increased hearth use at the camp. Previous studies, like Reavie et al, (2021) at the Great Lakes, have shown that $\delta^{13}C$ values and chl *a* have a fairly direct relationship with matching increases and decreases (Reavie et al., 2021). However, beginning at ~1200 CE, our $\delta^{13}C$ values and chl *a* differed from these trends and instead mostly changed asynchronously to each other. Given that Reavie et al. (2021) studied the Great Lakes, which are bigger and deeper than Dildo Pond, it seems unlikely that this diverging trend resulted from dilution. Instead, this could indicate that there was another unknown factor that had a stronger effect on the $\delta^{13}C$ values at Dildo Pond. The large peak in all four metals commonly associated with human activity may be a delayed response to the coprostanol/cholesterol peak in 1033 CE (Andrews et al., 1999; Antoniades et al., 2011; Bartkowska et al., 2019). However, greater organic matter in lakes can contribute to metal attenuation to sediments and lessened the delayed response by limiting resuspension (Pan et al., 2019). During this ~1000-1300 CE period, there were peaks in percent organic carbon just after ~1000 CE, 1100 CE, and in early and mid 1200s. These peaks aligned with the lowest values for all for four metals, Zn/Ti, Cu/Ti, Cd/Ti, and

As/Ti, and with the highest values for Zn/Ti, Cu/Ti, and Cd/Ti. This suggests that the metals values have less of a delayed response to human activity than other periods in the chronology.

Our proxies potentially showed changes in land use and expansion of human activities in the area after European arrival to the area. Over the last half of the Beothuk period, ~1300 to ~1650, there were declines in Zn/Ti, Cu/Ti, Cd/Ti, $\delta^{13}C$ values and increases in As/Ti, chl *a*, and charcoal flux. There was only one lipid ratio positive for human presence during this period and it showed a significant decrease from the previous positive lipid ratio at ~1288 CE. After its ~1200 CE increase, chl *a* remained at an elevated level until ~1927 CE (Hadley et al., 2010), possibly indicating nutrient input from a more regular human presence and subsequent expansion of human activities in the area. Concurrent with the chl *a* increasing trend, $\delta^{13}C$ values exhibited sustained substantial decreases from ~1200 to ~1927 CE, never becoming more positive than -27.2‰. As/Ti increased steadily to its highest point of the chronology from ~1500 CE until ~1700 CE, possibly due to increased land clearing and/or coal use after European arrival to Newfoundland in the late ~1500s and the Dildo Pond area in the early ~1600s (Gilbert, 2002; Shotyk et al., 1996). Zn/Ti and Cu/Ti began to decrease after their ~1200 CE peak, while Cd/Ti had a short decline followed by increases before decreasing until European arrival. The coprostanol/cholesterol ratio at the end of 1200s, showed its final peak for the chronology. After this peak, Cu/Ti and Cd/Ti increased slightly, possibly as their delayed response to the steady increase in the lipid ratio. Charcoal input during this period showed a slight decrease during the 1300s followed by a substantial increase in the late 1400s. This increase was large enough to potentially be from a wildfire in the area rather than just Indigenous hearth use. Even with limited fecal lipid analysis during this period, the human presence as documented archaeologically and through first-hand accounts corresponds with the continued elevation of chl *a,* and increases in As/Ti and charcoal to show the beginning of the environmental effects of European arrival in the Dildo Pond area.

After European arrival: 1612 to 1900 CE

Our findings showed very subtle changes, particularly in $\delta^{13}C$, after European arrival and Beothuk departure, and changes in land use with the new occupants. After European arrival at Dildo Pond in 1612 CE, all metals and chl *a* experienced a small increase, while $\delta^{13}C$ values started to decline and charcoal flux remained the same. Zn/Ti and Cu/Ti began to decline by the mid-1600s, but Cd/Ti showed elevated levels into the 1700s. As/Ti reached its highest peak at ~1700 CE, which coincided with the highest peak in chl *a* thus far and the lowest $\delta^{13}C$ value for the chronology. By this point, the Beothuk had abandoned Russell's Point, which could explain the more negative values in $\delta^{13}C$ at this time, decreasing to the lowest of the chronology (Bull et al., 1999; Duda et al., 2022; Gallant et al., 2020). Gallant et al. (2020) used $\delta^{13}C$ to accompany fecal lipid analysis in the identification of human wastewater input, with more negative values indicating less input. The more negative $\delta^{13}C$ values coinciding with the accepted departure date of the Beothuk, could support a relationship between them (Gallant et al., 2020). The coprostanol/cholesterol ratio still showed a positive human signal after camp abandonment, possibly indicating Europeans were actively in the area (Fattore et al., 1996; Furtula et al., 2012; Stewart et al., 2018). This suggests that there may have been nutrient inputs possibly from land clearing by Europeans in the area (Hadley et al., 2010; Shotyk et al., 1996). Land clearing would also have affected the $\delta^{13}C$ values with certain allochthonous organic inputs causing it to decline (Bull et al., 1999; Duda et al., 2022). The As/Ti peak could also be caused by coal combustion in the province by Europeans or atmospheric arsenic from mining and smelting (Shotyk et al., 1996). Charcoal accumulation rates did sharply decline after the late 1400s until the mid-1600s where there was a slight increase, but input after the 1600s remained more consistent than prior to European arrival. There were no significant fire events indicated by the TAPAS model, suggesting a consistent background rate of fires in the catchment. Our proxies showed subtle changes as the Beothuk left Russell's Point and the beginnings of the changes the European presence effected in the area before the modern period.

The smaller changes as our proxies begin to near the 20^{th} century could reflect modernization in the area and changing forms of fire control, sanitation, or fuel resources. From the 1700s to the 1900s, Zn/Ti and Cu/Ti remained relatively stable, Cd/Ti showed a slight decline, and As/Ti decreased significantly. Chl *a* declined and plateaued, which is mirrored by $\delta^{13}C$ values becoming more positive and remaining constant until the early 1900s. During this period, we have two lipid samples that were positive for human presence and showed little change between them. Charcoal input increased, but there are no significant fire events, suggesting more consistent rates of charcoal input to the Dildo Pond (Argiriadis et al., 2018). These declines and stability for most of our proxies could be reflective of the window between camp abandonment and the concerted development effort by the colonial government (Table 2.1). In the late 1800s, the road and railroad were built in the area and Dildo Pond was established as an agricultural center (Gilbert, 2002). This new infrastructure foreshadowed the technological advancements of the 20^{th} and 21^{st} century, including their effects on the local ecosystem.

Modern period: 1900 CE to Present

The modern period captured significantly large changes in the catchment of Dildo Pond, recorded by unprecedented changes across most of the study's proxies. Our modern samples did not show evidence of human presence, possibly due to the establishment of sanitation infrastructure or differences in sanitation practices (Gallant et al., 2020). We were able to use cultural records to compare environmental data with population changes and activity during this period (Table 2.1). For instance, a railway line was built along Dildo Pond in 1884 CE, a road in 1886 CE, and the surrounding area was established as an agricultural district in 1888 CE (Gilbert, 2002). These four years of drastic change were evident in large and continued increases in charcoal accumulation rates, and slight increases in Zn and As, which could be the beginning of their delayed responses to increased land clearing, coal use in the area, and more concentrated human migration to the Dildo Pond region (Andrews et al., 1999; Shotyk et al., 1996). There are records that Blaketown burnt down in 1892 CE, meanwhile the only indication of a fire event was in the early 1900s ±30 years. This large fire event in 1892 is likely not detected by the smoothing analysis of the tapas model because it was surrounded by high charcoal input to the lake at the time to the effect that this event does not exceed the 95% confidence threshold (i.e., the fire event falls within the normal range of probability for fire events at the time). There was also a significant increase in $\delta^{13}C$ values in the beginning of the 1900s, which could be due to an influx of settlers (Gallant et al., 2020). By the mid 1900s there was a sharp decline in $\delta^{13}C$ values followed by an increase in the 2000s, possibly a result of anthropogenic climate change (Duda et al., 2022; Gallant et al., 2020). These substantial changes seen in most of our proxies are a reflection of the modernization of the area and show the effects of global trends, like the Industrial Revolution, on the local environment.

High $\delta^{15}N$ values beginning in ~1700s, which corresponded with significant increases in chl *a*, may indicate that it was more directly affected by chl *a* than fecal lipids, as some studies have shown (Stewart et al., 2018). Some studies showed $\delta^{15}N$ values as a proxy for human-derived waste input into aquatic environments like (Stewart et al. 2018). However, given the lack of human fecal lipids in the core surficial sediments, our results suggest that was not the case in the Dildo Pond environment. These high $\delta^{15}N$ values and chl *a* may be a sign of anoxic events due to nutrient overload from agriculture, nearby whaling, and mink farming and its byproducts in the area (Dickinson & Sanger, 2018; Furtula et al., 2012; Gilbert, 2002; Michelutti et al., 2010).

The 20th and 21st century of our chronology show the effects of rapid technological advancements in Canada and globally, as well clear indications of climate change. In the later 1900s, Cu/Ti and Cd/Ti showed only slight declines, while Zn/Ti and As/Ti increased, possibly as a sign that their delayed response from the infrastructure development was just beginning to be captured. In the second half of the 20th century and into the 21st century, there was a decline in charcoal accumulation rates, which could be due to the change from coal to oil heating in Newfoundland by the 1950s (Page & Shapiro, 2018). As well, the Dildo whaling station was one of the last to close in NL in the 1970s and any "guanoification" of the bones (Dickinson & Sanger, 2018) would have produced regional charcoal, likely capture in the pond over the operation period of the station. In the second half of the 21st century, chl *a* saw a 10-fold increase and in more recent years a decline. Across many lakes in the northern hemisphere, modern warming has caused increases in lake primary production, captured with corresponding increases in sedimentary chl *a* (Griffiths et al., 2022). Here, in Dildo Pond, modern sedimentary chl *a* samples increased beyond any historical levels and obscured past trends when plotted together;

thus, it appears that within the ~1100-year sedimentary record for Dildo Pond, global warming and possibly increased nutrient delivery from humans has led to unprecedented primary production levels in Dildo Pond. Our modern samples demonstrate how directly affected the remote regions of Newfoundland and Dildo Pond are by global climate trends as well as local economic practices.

2.6 References

Andrews, J. E., Greenaway, A. M., Bigg, G. R., Webber, D. F., Dennis, P. F., & Guthrie, G. A. (1999). Pollution history of a tropical estuary revealed by combined hydrodynamic modelling and sediment geochemistry. *Journal of Marine Systems*, *18*(4), 333–343. https://doi.org/10.1016/S0924-7963(98)00019-0

Antoniades, D., Michelutti, N., Quinlan, R., Blais, J. M., Bonilla, S., Douglas, M. S. V., Pienitz, R., Smol, J. P., & Vincent, W. F. (2011). Cultural eutrophication, anoxia, and ecosystem recovery in Meretta Lake, High Arctic Canada. *Limnology and Oceanography*, *56*(2), 639–650. https://doi.org/10.4319/lo.2011.56.2.0639

Appleby, P. G., & Oldfield, F. (1978). The calculation of lead-210 dates assuming a constant rate of supply of unsupported 210Pb to the sediment. *CATENA*, *5*(1), 1–8. https://doi.org/10.1016/S0341-8162(78)80002-2

Argiriadis, E., Battistel, D., McWethy, D. B., Vecchiato, M., Kirchgeorg, T., Kehrwald, N. M., Whitlock, C., Wilmshurst, J. M., & Barbante, C. (2018). Lake sediment fecal and biomass burning biomarkers provide direct evidence for prehistoric human-lit fires in New Zealand. *Springer Nature*. https://doi.org/10.1038/s41598-018-30606-3

Bartkowska, I., Tałałaj, I., & Biedka, P. (2019). Analysis of the Quality of Stabilized Municipal Sewage Sludge. *Journal of Ecological Engineering*, *20*(2), 200–208. https://doi.org/10.12911/22998993/99306

Bell, & Blais. (2021). Paleolimnology in support of archeology: A review of past investigations and a proposed framework for future study design. *Journal of Paleolimnology*, *65*(1), 1–32. https://doi.org/10.1007/s10933-020-00156-8

Bell, T., Macpherson, J. B., & Renouf, M. A. P. (2005). *Late Prehistoric Human Impact on Bass Pond, Port au Choix*. 23.

Bronk Ramsey, C. (2009). Bayesian Analysis of Radiocarbon Dates. *Radiocarbon*, *51*(1), 337–360. https://doi.org/10.1017/S0033822200033865

Bull, I. D., Lockheart, M. J., Elhmmali, M. M., Roberts, D. J., & Evershed, R. P. (2002). The origin of faeces by means of biomarker detection. *Environment International*, *27*(8), 647–654. https://doi.org/10.1016/S0160-4120(01)00124-6

Bull, I. D., Simpson, I. A., van Bergen, P. F., & Evershed, R. P. (1999). Muck 'n' molecules: Organic geochemical methods for detecting ancient manuring. *Antiquity*, *73*(279), 86–96. https://doi.org/10.1017/S0003598X0008786X

Courtney Mustaphi, C. (2014). *A Landscape-Scale Assessment of Holocene Fire Regime Controls in South-Eastern British Columbia, Canada* [Doctor of Philosophy, Carleton University]. https://doi.org/10.22215/etd/2014-10073

D'Anjou, R. M., Bradley, R. S., Balascio, N. L., & Finkelstein, D. B. (2012). Climate impacts on human settlement and agricultural activities in northern Norway revealed through sediment biogeochemistry. *Proceedings of the National Academy of Sciences*, *109*(50), 20332–20337. https://doi.org/10.1073/pnas.1212730109

Dickinson, A., & Sanger, C. (2018). *After the Basques: The whaling Stations of Newfoundland and Labrador*. DRC Publishing.

Douglas, M. S. V., Smol, J. P., Savelle, J. M., & Blais, J. M. (2004). Prehistoric Inuit whalers affected Arctic freshwater ecosystems. *Proceedings of the National Academy of Sciences*, *101*(6), 1613–1617. https://doi.org/10.1073/pnas.0307570100

Duda, M. P., Cyr, F., Robertson, G. J., Michelutti, N., Meyer-Jacob, C., Hedd, A., Montevecchi, W. A., Kimpe, L. E., Blais, J. M., & Smol, J. P. (2022). Climate oscillations drive millennial-scale changes in seabird colony size. *Global Change Biology*, *28*(14), 4292–4307. https://doi.org/10.1111/gcb.16171

Duggan, A. T., Harris, A. J. T., Marciniak, S., Marshall, I., Kuch, M., Kitchen, A., Renaud, G., Southon, J., Fuller, B., Young, J., Fiedel, S., Golding, G. B., Grimes, V., & Poinar, H. (2017). Genetic Discontinuity between the Maritime Archaic and Beothuk Populations in Newfoundland, Canada. *Current Biology*, *27*(20), 3149-3156.e11. https://doi.org/10.1016/j.cub.2017.08.053

Fattore, E., Benfenati, E., Marelli, R., Cools, E., & Fanelli, R. (1996). Sterols in sediment samples from Venice Lagoon, Italy. *Chemosphere*, *33*(12), 2383–2393. https://doi.org/10.1016/S0045-6535(96)00340-2

Finsinger, W., & Bonnici, I. (2022). *tapas: An R package to perform trend and peaks analysis* [R]. https://doi.org/10.5281/zenodo.6344463

Furtula, V., Osachoff, H., Derksen, G., Juahir, H., Colodey, A., & Chambers, P. (2012). Inorganic nitrogen, sterols and bacterial source tracking as tools to characterize water quality and possible contamination sources in surface water. *Water Research*, *46*(4), 1079–1092. https://doi.org/10.1016/j.watres.2011.12.002

Gallant, L. R., Kimpe, L. E., Hargan, K. E., & Blais, J. M. (2020). Tracking the history of 20th century cultural eutrophication in High Arctic waterbodies. *Anthropocene*, *31*, 100250. https://doi.org/10.1016/j.ancene.2020.100250

Gilbert, W. (2002). *Russell's Point (CiAj-1): A Little Passage/Beothuk site at the bottom of Trinity Bay*.

Glew, JohnR. (1988). A portable extruding device for close interval sectioning of unconsolidated core samples. *Journal of Paleolimnology*, *1*(3). https://doi.org/10.1007/BF00177769

Griffiths, K., Jeziorski, A., Antoniades, D., Beaulieu, M., Smol, J. P., & Gregory-Eaves, I. (2022). Pervasive changes in algal indicators since pre-industrial times: A paleolimnological study of changes in primary production and diatom assemblages from ~200 Canadian lakes. *Science of The Total Environment*, *838*, 155938. https://doi.org/10.1016/j.scitotenv.2022.155938

Guo, Q., Wang, C., Wei, R., Zhu, G., Cui, M., & Okolic, C. P. (2020). Qualitative and quantitative analysis of source for organic carbon and nitrogen in sediments of rivers and lakes based on stable isotopes. *Ecotoxicology and Environmental Safety*, *195*, 110436. https://doi.org/10.1016/j.ecoenv.2020.110436

Hadley, K. R., Douglas, M. S. V., Blais, J. M., & Smol, J. P. (7/2010a). Nutrient enrichment in the High Arctic associated with Thule Inuit whalers: A paleolimnological investigation from Ellesmere Island (Nunavut, Canada). *Hydrobiologia*, *649*(1), 129–138. https://doi.org/10.1007/s10750-010-0235-6

Hadley, K. R., Douglas, M. S. V., McGhee, R., Blais, J. M., & Smol, J. P. (6/2010b). Ecological influences of Thule Inuit whalers on high Arctic pond ecosystems: A comparative paleolimnological study from Bathurst Island (Nunavut, Canada). *Journal of Paleolimnology*, *44*(1), 85–93. https://doi.org/10.1007/s10933-009-9388-6

Hajdas, I., Ascough, P., Garnett, M. H., Fallon, S. J., Pearson, C. L., Quarta, G., Spalding, K. L., Yamaguchi, H., & Yoneda, M. (2021). Radiocarbon dating. *Nature Reviews Methods Primers*, *1*(1), 62. https://doi.org/10.1038/s43586-021-00058-7

Harrault, L., Milek, K., Jardé, E., Jeanneau, L., Derrien, M., & Anderson, D. G. (2019). Faecal biomarkers can distinguish specific mammalian species in modern and past environments. *PLOS ONE*, *14*(2), e0211119. https://doi.org/10.1371/journal.pone.0211119

Harris, A. J. T., Duggan, A. T., Marciniak, S., Marshall, I., Fuller, B. T., Southon, J., Poinar, H. N., & Grimes, V. (2019). Dorset Pre-Inuit and Beothuk foodways in Newfoundland, ca. AD 500-1829. *PLOS ONE*, *14*(1), e0210187. https://doi.org/10.1371/journal.pone.0210187

Kennedy, L. M., & Horn, S. P. (2007). A Late Holocene Pollen and Charcoal Record from La Selva Biological Station, Costa Rica. *Biotropica*, *0*(0), 070626194706002-??? https://doi.org/10.1111/j.1744-7429.2007.00334.x

Komada, T., Anderson, M. R., & Dorfmeier, C. L. (2008). Carbonate removal from coastal sediments for the determination of organic carbon and its isotopic signatures, $\delta^{13}C$ and $\Delta^{14}C$: Comparison of fumigation and direct acidification by hydrochloric acid: Carbonate removal from coastal sediments. *Limnology and Oceanography: Methods*, *6*(6), 254–262. https://doi.org/10.4319/lom.2008.6.254

Last, W. M., & Smol, J. P. (2002). *Tracking Environmental Change Using Lake Sediments*. Kluwer Academic Publishers200.

Leeming, R., Ball, A., Ashbolt, N., & Nichols, P. (1996). Using faecal sterols from humans and animals to distinguish faecal pollution in receiving waters. *Water Research*, *30*(12), 2893–2900. https://doi.org/10.1016/S0043-1354(96)00011-5

Long, C. J., Whitlock, C., Bartlein, P. J., & Millspaugh, S. H. (1998). *A 9000-year fire history from the Oregon Coast Range, based on a high-resolution charcoal study*. *28*.

Mackay, H., Davies, K. L., Robertson, J., Roy, L., Bull, I. D., Whitehouse, N. J., Crone, A., Cavers, G., McCormick, F., Brown, A. G., & Henderson, A. C. G. (2020). Characterising life in settlements and structures: Incorporating faecal lipid biomarkers within a multiproxy case study of a wetland village. *Journal of Archaeological Science*, *121*, 105202. https://doi.org/10.1016/j.jas.2020.105202

Michelutti, N., Blais, J. M., Cumming, B. F., Paterson, A. M., Rühland, K., Wolfe, A. P., & Smol, J. P. (2010). Do spectrally inferred determinations of chlorophyll a reflect trends in lake trophic status? *Journal of Paleolimnology*, *43*(2), 205–217. https://doi.org/10.1007/s10933-009-9325-8

Michelutti, N., McCleary, K. M., Antoniades, D., Sutherland, P., Blais, J. M., Douglas, M. S. V., & Smol, J. P. (2013). Using paleolimnology to track the impacts of early Arctic peoples on freshwater ecosystems from southern Baffin Island, Nunavut. *Quaternary Science Reviews*, *76*, 82–95. https://doi.org/10.1016/j.quascirev.2013.06.027

Mills, K., Schillereff, D., Saulnier-Talbot, É., Gell, P., Anderson, N. J., Arnaud, F., Dong, X., Jones, M., McGowan, S., Massaferro, J., Moorhouse, H., Perez, L., & Ryves, D. B. (2017). Deciphering long-term records of natural variability and human impact as recorded in lake sediments: A palaeolimnological puzzle: A palaeolimnological puzzle. *Wiley Interdisciplinary Reviews: Water*, *4*(2), e1195. https://doi.org/10.1002/wat2.1195

Millspaugh, S. H., & Whitlock, C. (1995). A 750-year fire history based on lake sediment records in central Yellowstone National Park, USA. *The Holocene*, *5*(3), 283–292. https://doi.org/10.1177/095968369500500303

Page, G. T., & Shapiro, L. (2018). Coal in Canada | The Canadian Encyclopedia. *Historica Canada*. www.thecanadianencyclopedia.ca/en/article/coal

Pan, F., Liu, H., Guo, Z., Cai, Y., Fu, Y., Wu, J., Wang, B., & Gao, A. (2019). Metal/metalloid and phosphorus characteristics in porewater associated with manganese geochemistry: A case study in the Jiulong River Estuary, China. *Environmental Pollution*, *255*, 113134. https://doi.org/10.1016/j.envpol.2019.113134

Patton, D., & Reeves, A. D. (1999). Sterol Concentrations and Temporal Variations on the North Shore Mudflats of the Firth of Tay, Scotland. *Marine Pollution Bulletin*, *38*(7), 613–618. https://doi.org/10.1016/S0025-326X(99)00068-5

Polack, F. (Ed.). (2018). *Tracing ochre: Changing perspectives on the Beothuk*. University of Toronto Press.

Rankin, L. (2018). 8 Towards a Beothuk Archaeology: Understanding Indigenous Agency in the Material Record. In F. Polack (Ed.), *Tracing Ochre* (pp. 177–198). University of Toronto Press. https://doi.org/10.3138/9781442623859-012

Reavie, E. D., Cai, M., Meyer-Jacob, C., Smol, J. P., & Werne, J. P. (2021). Long-term primary production trends in the Laurentian Great Lakes: A comparison of geochemical methods. *Journal of Paleolimnology*, *65*(3), 299–314. https://doi.org/10.1007/s10933-020-00170-w

Reimer, P. J., Austin, W. E. N., Bard, E., Bayliss, A., Blackwell, P. G., Bronk Ramsey, C., Butzin, M., Cheng, H., Edwards, R. L., Friedrich, M., Grootes, P. M., Guilderson, T. P., Hajdas, I., Heaton, T. J., Hogg, A. G., Hughen, K. A., Kromer, B., Manning, S. W., Muscheler, R., … Talamo, S. (2020). The IntCal20 Northern Hemisphere Radiocarbon Age Calibration Curve (0–55 cal kBP). *Radiocarbon*, *62*(4), 725–757. https://doi.org/10.1017/RDC.2020.41

Renouf, >M. A. P. (1999). Prehistory of Newfoundlandhunter-gatherers: Extinctions or adaptations? *World Archaeology*, *30*(3), 403–420. https://doi.org/10.1080/00438243.1999.9980420

Rowley-Conwy, P. (1990). Settlement Patterns of the Beothuk Indians of Newfoundland: A View from Away. *Canadian Journal of Archaeology*, *14*, 21.

Schelske, C. L., & Hodell, D. A. (1995). Using carbon isotopes of bulk sedimentary organic matter to reconstruct the history of nutrient loading and eutrophication in Lake Erie. *Limnology and Oceanography*, *40*(5), 918–929. https://doi.org/10.4319/lo.1995.40.5.0918

Schroeter, N., Lauterbach, S., Stebich, M., Kalanke, J., Mingram, J., Yildiz, C., Schouten, S., & Gleixner, G. (2020). Biomolecular Evidence of Early Human Occupation of a High-Altitude Site in Western Central Asia During the Holocene. *Frontiers in Earth Science*, *8*, 20. https://doi.org/10.3389/feart.2020.00020

Shotyk, W., Cheburkin, A. K., Appleby, P. G., Fankhauser, A., & Kramers, J. D. (1996). Two thousand years of atmospheric arsenic, antimony, and lead deposition recorded in an ombrotrophic peat bog profile, Jura Mountains, Switzerland. *Earth and Planetary Science Letters*, *145*(1–4), E1–E7. https://doi.org/10.1016/S0012-821X(96)00197-5

Smol, J. P. (2008). There is no substitute for water. In *Pollution of Lakes and Rivers: A Paleoenvironmental Prespective*. Wiley and Sons.

Stewart, E. M., Hargan, K. E., Sivarajah, B., Kimpe, L. E., Blais, J. M., & Smol, J. P. (2018). A Paleoenvironmental Study Tracking Eutrophication, Mining Pollution, and Climate Change in Niven Lake, the First Sewage Lagoon of Yellowknife (Northwest Territories) + Supplementary Appendix 1 (See Article Tools). *ARCTIC*, *71*(2). https://doi.org/10.14430/arctic4720

Telford, J. V., Kay, M. L., Vander Heide, H., Wiklund, J. A., Owca, T. J., Faber, J. A., Wolfe, B. B., & Hall, R. I. (2021). Building upon open-barrel corer and sectioning systems to foster the continuing legacy of John Glew. *Journal of Paleolimnology*, *65*(2), 271–277. https://doi.org/10.1007/s10933-020-00162-w

Tse, T. J., Codling, G., Jones, P. D., Thoms, K., Liber, K., Giesy, J. P., Wheater, H., & Doig, L. E. (2014). Reconstructing long-term trends in municipal sewage discharge into a small lake in northern Manitoba, Canada. *Chemosphere*, *103*, 299–305. https://doi.org/10.1016/j.chemosphere.2013.12.019

Vachula, R. S., Huang, Y., Russell, J. M., Abbott, M. B., Finkenbinder, M. S., & O'Donnell, J. A. (2020). Sedimentary biomarkers reaffirm human impacts on northern Beringian ecosystems during the Last Glacial period. *Boreas*, *49*(3), 514–525. https://doi.org/10.1111/bor.12449

White, A. J., Stevens, L. R., Lorenzi, V., Munoz, S. E., Lipo, C. P., & Schroeder, S. (2018). An evaluation of fecal stanols as indicators of population change at Cahokia, Illinois. *Journal of Archaeological Science*, *93*, 129–134. https://doi.org/10.1016/j.jas.2018.03.009

White, A. J., Stevens, L. R., Lorenzi, V., Munoz, S. E., Schroeder, S., Cao, A., & Bogdanovich, T. (2019). Fecal stanols show simultaneous flooding and seasonal precipitation change correlate with Cahokia's population decline. *Proceedings of the National Academy of Sciences*, *116*(12), 5461–5466. https://doi.org/10.1073/pnas.1809400116

Whitlock, C., & Larsen, C. (2002). Charcoal as a Fire Proxy. In J. P. Smol, H. J. B. Birks, W. M. Last, R. S. Bradley, & K. Alverson (Eds.), *Tracking Environmental Change Using Lake Sediments* (Vol. 3, pp. 75–97). Springer Netherlands. https://doi.org/10.1007/0-306-47668-1_5

Chapter 3: Summary and conclusions

This study has shown that fecal lipid analysis is successful in Newfoundland and is able to connect the modern and Indigenous human history of Newfoundland to changes in the immediate environment. Our study was able to identify human-sourced lipids that could be potentially attributed to the Indigenous Beothuk and correlated with notable changes in multiple environmental paleolimnological proxies. Coprostanol is the dominant stanol produced by humans. It can be produced by other animals, typically omnivores and carnivores, but in lesser amounts (Harrault et al., 2019; Leeming et al., 1996). Historically, before European settlement, these animals may have largely been wolf, fox, otter, lynx, and martin, all relatively depauperate relative to the size of human settlements, found directly on the lake's shoreline. After European settlement, livestock, largely pig may have introduced coprostanol, and later the establishment of mink farms in the lake's catchment. Our study utilized limited ecological proxies, primarily chl *a*, and found its trends matched those of the lipid, metals, and stable carbon isotope proxies that support future ecological work at Dildo Pond to understand the relationship between the Indigenous presence and their impact on Newfoundland's aquatic environment.

Our research also allowed us to analyze how Newfoundland's colonial history has affected its environment. Spikes in chl *a* correspond with nutrient input due to Dildo's establishment as an agriculture center for the region in the 1800s and run off from whaling and mink farming in the catchment. Increases in As/Ti signal changes in land use for farming, construction of the road and railroad, or building and establishment of the community. Decreases in $\delta^{13}C$, i.e. values become more negative, shortly after European arrival could be signs of changes in the vegetation or waste input into the pond. In the early 1900s, $\delta^{13}C$ values increase, i.e. become less negative, possibly due to more people moving into the area, contributing more waste, more vegetation input from land clearing, or increased aquatic primary productivity (Bull et al., 1999; Duda et al., 2022). We have also shown that modern human activity and climate change are having incredible changes on an island that often feels isolated from the rest of the world. Most modern results show such significant increases that they muted signals for the rest of the cores, with drastically large increases in chl *a* and charcoal accumulation rates. These samples had to be graphed separately to properly analyze pre-modern results. In conclusion, our study was able to place humans in the Dildo Pond drainage basin in the timeframe archaeological research has indicated the Beothuk established the Russell's Point camp.

Future work at Dildo Pond

Our study has shown that humans were present at Dildo Pond during the window purposed by the independent archaeological research at Russell's Point (Gilbert, 2002) and that there were changes in the environment commonly attributed to human activity. More radiocarbon dates could be obtained to reduce chronology errors and address the age inversion our study received from one ^{14}C dating result. This would also be helpful given that our study relied on radiocarbon dates from bulk sediment, which has a greater error than macrofossils (Hajdas et al., 2021). While we used limited ecology proxies, future studies could further analyze the ecological effects of the Beothuk's presence through pollen or diatom analysis. Future studies could also obtain longer sediment cores, with the help of coring platforms, to capture the entire Holocene chronology. Researchers could then identify the Beothuk arrival to Dildo and previous settlement periods like the Dorset Palaeoeskimo, the Groswater Palaeoeskimo, and the Maritime Archaic, all of which have been shown to be in this area at various times over Newfoundland's human history (Duggan et al., 2017). This would provide better context for the environmental changes our study noted during Newfoundland's colonization, modern human activity, and climate change. Future studies could also utilize the fecal lipid method's ability to differentiate between native mammal species and attempt to identify the caribou migration in the sediment record. With data on the caribou migration and the Beothuk arrival, it would be interesting to identify any affects the Beothuk's hunting practices could have had on the caribou. Another possible avenue of future study would be to build a more comprehensive fire history of the area. Pollen slides could be used to conduct a more thorough charcoal analysis and expand on our macroscopic charcoal record. With this more detailed fire history, future studies would have a better understanding of the human impact on Dildo Pond to compare with further fecal and plant sterol analysis and paleoclimate data (Argiriadis et al., 2018; Whitlock & Larsen, 2002).

Future work in Newfoundland

While Dildo Pond did provide some challenges with its size and depth, Newfoundland is plentiful in shallower and smaller ponds and wetlands that would limit the dilution of proxies while still providing a window into a complex slice of human history. A variety of cores could be appropriate for future studies, such as soil cores at archaeological sites for more focused Indigenous analysis, marine or embayment cores to expand the scope of human and environmental data for the region, peatland cores or even just longer cores obtained with drilling platforms to capture Newfoundland's various settlement periods. Peat cores in particular are already used for this type of research in both archaeology and paleolimnology (Bell & Blais, 2021). By combining techniques, like lipid analysis, macrofossil plants, or human trampling analysis, from both fields when analyzing peat cores, it could expand their potential at sites which early human history, like L'Anse Aux Meadows, which is near peatlands (Bell & Blais, 2021). With these types of cores, more fecal lipid analysis, which has been shown to work in Newfoundland's colder climate, could be done to fill out Newfoundland's Indigenous history and development population reconstructions. With more lipid analysis, more lipid ratios could be utilized to provide a multifaceted approach to human data. Charcoal along with lipids showed promise to aide in the understanding of local fire histories and identify human activities. This study has shown that the Indigenous of Newfoundland had traceable effects on their immediate environments. With this in mind, future work could explore these effects to expand our understanding of climate change on Newfoundland's environment and ecology, while expanding its human history.

Future work with paleolimnology and archaeology

This study, in agreement with previous research, demonstrated the successful application of paleolimnological techniques to archaeological research and sites. Our multi-proxy approach showed that Newfoundland's rich Indigenous history is prime for the intersection of these two fields. Given the fact that ancient humans often settled near water, particularly as they moved inland, and that these paleolimnological techniques can be utilized in various climates, this structure has been applied to research all over the world with good reason. Together these two fields can potentially broaden the window of anthropogenic climate and environmental changes while also adding to the records of human history.

3.1 References

Andrews, J. E., Greenaway, A. M., Bigg, G. R., Webber, D. F., Dennis, P. F., & Guthrie, G. A. (1999). Pollution history of a tropical estuary revealed by combined hydrodynamic modelling and sediment geochemistry. *Journal of Marine Systems*, *18*(4), 333–343. https://doi.org/10.1016/S0924-7963(98)00019-0

Antoniades, D., Michelutti, N., Quinlan, R., Blais, J. M., Bonilla, S., Douglas, M. S. V., Pienitz, R., Smol, J. P., & Vincent, W. F. (2011). Cultural eutrophication, anoxia, and ecosystem recovery in Meretta Lake, High Arctic Canada. *Limnology and Oceanography*, *56*(2), 639–650. https://doi.org/10.4319/lo.2011.56.2.0639

Appleby, P. G., & Oldfield, F. (1978). The calculation of lead-210 dates assuming a constant rate of supply of unsupported 210Pb to the sediment. *CATENA*, *5*(1), 1–8. https://doi.org/10.1016/S0341-8162(78)80002-2

Argiriadis, E., Battistel, D., McWethy, D. B., Vecchiato, M., Kirchgeorg, T., Kehrwald, N. M., Whitlock, C., Wilmshurst, J. M., & Barbante, C. (2018). Lake sediment fecal and biomass burning biomarkers provide direct evidence for prehistoric human-lit fires in New Zealand. *Springer Nature*. https://doi.org/10.1038/s41598-018-30606-3

Bartkowska, I., Tałałaj, I., & Biedka, P. (2019). Analysis of the Quality of Stabilized Municipal Sewage Sludge. *Journal of Ecological Engineering*, *20*(2), 200–208. https://doi.org/10.12911/22998993/99306

Bell, & Blais. (2021). Paleolimnology in support of archeology: A review of past investigations and a proposed framework for future study design. *Journal of Paleolimnology*, *65*(1), 1–32. https://doi.org/10.1007/s10933-020-00156-8

Bell, T., Macpherson, J. B., & Renouf, M. A. P. (2005). *Late Prehistoric Human Impact on Bass Pond, Port au Choix*. 23.

Bronk Ramsey, C. (2009). Bayesian Analysis of Radiocarbon Dates. *Radiocarbon*, *51*(1), 337–360. https://doi.org/10.1017/S0033822200033865

Bull, I. D., Lockheart, M. J., Elhmmali, M. M., Roberts, D. J., & Evershed, R. P. (2002). The origin of faeces by means of biomarker detection. *Environment International*, *27*(8), 647–654. https://doi.org/10.1016/S0160-4120(01)00124-6

Bull, I. D., Simpson, I. A., van Bergen, P. F., & Evershed, R. P. (1999). Muck 'n' molecules: Organic geochemical methods for detecting ancient manuring. *Antiquity*, *73*(279), 86–96. https://doi.org/10.1017/S0003598X0008786X

Courtney Mustaphi, C. (2014). *A Landscape-Scale Assessment of Holocene Fire Regime Controls in South-Eastern British Columbia, Canada* [Doctor of Philosophy, Carleton University]. https://doi.org/10.22215/etd/2014-10073

D'Anjou, R. M., Bradley, R. S., Balascio, N. L., & Finkelstein, D. B. (2012). Climate impacts on human settlement and agricultural activities in northern Norway revealed through sediment biogeochemistry. *Proceedings of the National Academy of Sciences*, *109*(50), 20332–20337. https://doi.org/10.1073/pnas.1212730109

Dickinson, A., & Sanger, C. (2018). *After the Basques: The whaling Stations of Newfoundland and Labrador*. DRC Publishing.

Douglas, M. S. V., Smol, J. P., Savelle, J. M., & Blais, J. M. (2004). Prehistoric Inuit whalers affected Arctic freshwater ecosystems. *Proceedings of the National Academy of Sciences*, *101*(6), 1613–1617. https://doi.org/10.1073/pnas.0307570100

Duda, M. P., Cyr, F., Robertson, G. J., Michelutti, N., Meyer-Jacob, C., Hedd, A., Montevecchi, W. A., Kimpe, L. E., Blais, J. M., & Smol, J. P. (2022). Climate oscillations drive millennial-scale changes in seabird colony size. *Global Change Biology*, *28*(14), 4292–4307. https://doi.org/10.1111/gcb.16171

Duggan, A. T., Harris, A. J. T., Marciniak, S., Marshall, I., Kuch, M., Kitchen, A., Renaud, G., Southon, J., Fuller, B., Young, J., Fiedel, S., Golding, G. B., Grimes, V., & Poinar, H. (2017). Genetic Discontinuity between the Maritime Archaic and Beothuk Populations in Newfoundland, Canada. *Current Biology*, *27*(20), 3149-3156.e11. https://doi.org/10.1016/j.cub.2017.08.053

Fattore, E., Benfenati, E., Marelli, R., Cools, E., & Fanelli, R. (1996). Sterols in sediment samples from Venice Lagoon, Italy. *Chemosphere*, *33*(12), 2383–2393. https://doi.org/10.1016/S0045-6535(96)00340-2

Finsinger, W., & Bonnici, I. (2022). *tapas: An R package to perform trend and peaks analysis* [R]. https://doi.org/10.5281/zenodo.6344463

Furtula, V., Osachoff, H., Derksen, G., Juahir, H., Colodey, A., & Chambers, P. (2012). Inorganic nitrogen, sterols and bacterial source tracking as tools to characterize water quality and possible contamination sources in surface water. *Water Research*, *46*(4), 1079–1092. https://doi.org/10.1016/j.watres.2011.12.002

Gallant, L. R., Kimpe, L. E., Hargan, K. E., & Blais, J. M. (2020). Tracking the history of 20th century cultural eutrophication in High Arctic waterbodies. *Anthropocene*, *31*, 100250. https://doi.org/10.1016/j.ancene.2020.100250

Gilbert, W. (2002). *Russell's Point (CiAj-1): A Little Passage/Beothuk site at the bottom of Trinity Bay*.

Glew, JohnR. (1988). A portable extruding device for close interval sectioning of unconsolidated core samples. *Journal of Paleolimnology*, *1*(3). https://doi.org/10.1007/BF00177769

Griffiths, K., Jeziorski, A., Antoniades, D., Beaulieu, M., Smol, J. P., & Gregory-Eaves, I. (2022). Pervasive changes in algal indicators since pre-industrial times: A paleolimnological study of changes in primary production and diatom assemblages from ~200 Canadian lakes. *Science of The Total Environment*, *838*, 155938. https://doi.org/10.1016/j.scitotenv.2022.155938

Guo, Q., Wang, C., Wei, R., Zhu, G., Cui, M., & Okolic, C. P. (2020). Qualitative and quantitative analysis of source for organic carbon and nitrogen in sediments of rivers and lakes based on stable isotopes. *Ecotoxicology and Environmental Safety*, *195*, 110436. https://doi.org/10.1016/j.ecoenv.2020.110436

Hadley, K. R., Douglas, M. S. V., Blais, J. M., & Smol, J. P. (7/2010a). Nutrient enrichment in the High Arctic associated with Thule Inuit whalers: A paleolimnological investigation from Ellesmere Island (Nunavut, Canada). *Hydrobiologia*, *649*(1), 129–138. https://doi.org/10.1007/s10750-010-0235-6

Hadley, K. R., Douglas, M. S. V., McGhee, R., Blais, J. M., & Smol, J. P. (6/2010b). Ecological influences of Thule Inuit whalers on high Arctic pond ecosystems: A comparative paleolimnological study from Bathurst Island (Nunavut, Canada). *Journal of Paleolimnology*, *44*(1), 85–93. https://doi.org/10.1007/s10933-009-9388-6

Hajdas, I., Ascough, P., Garnett, M. H., Fallon, S. J., Pearson, C. L., Quarta, G., Spalding, K. L., Yamaguchi, H., & Yoneda, M. (2021). Radiocarbon dating. *Nature Reviews Methods Primers*, *1*(1), 62. https://doi.org/10.1038/s43586-021-00058-7

Harrault, L., Milek, K., Jardé, E., Jeanneau, L., Derrien, M., & Anderson, D. G. (2019). Faecal biomarkers can distinguish specific mammalian species in modern and past environments. *PLOS ONE*, *14*(2), e0211119. https://doi.org/10.1371/journal.pone.0211119

Harris, A. J. T., Duggan, A. T., Marciniak, S., Marshall, I., Fuller, B. T., Southon, J., Poinar, H. N., & Grimes, V. (2019). Dorset Pre-Inuit and Beothuk foodways in Newfoundland, ca. AD 500-1829. *PLOS ONE*, *14*(1), e0210187. https://doi.org/10.1371/journal.pone.0210187

Kennedy, L. M., & Horn, S. P. (2007). A Late Holocene Pollen and Charcoal Record from La Selva Biological Station, Costa Rica. *Biotropica*, *0*(0), 070626194706002-??? https://doi.org/10.1111/j.1744-7429.2007.00334.x

Komada, T., Anderson, M. R., & Dorfmeier, C. L. (2008). Carbonate removal from coastal sediments for the determination of organic carbon and its isotopic signatures, $\delta^{13}C$ and $\Delta^{14}C$: Comparison of fumigation and direct acidification by hydrochloric acid: Carbonate removal from coastal sediments. *Limnology and Oceanography: Methods*, *6*(6), 254–262. https://doi.org/10.4319/lom.2008.6.254

Last, W. M., & Smol, J. P. (2002). *Tracking Environmental Change Using Lake Sediments*. Kluwer Academic Publishers200.

Leeming, R., Ball, A., Ashbolt, N., & Nichols, P. (1996). Using faecal sterols from humans and animals to distinguish faecal pollution in receiving waters. *Water Research*, *30*(12), 2893–2900. https://doi.org/10.1016/S0043-1354(96)00011-5

Long, C. J., Whitlock, C., Bartlein, P. J., & Millspaugh, S. H. (1998). *A 9000-year fire history from the Oregon Coast Range, based on a high-resolution charcoal study*. *28*.

Mackay, H., Davies, K. L., Robertson, J., Roy, L., Bull, I. D., Whitehouse, N. J., Crone, A., Cavers, G., McCormick, F., Brown, A. G., & Henderson, A. C. G. (2020). Characterising life in settlements and structures: Incorporating faecal lipid biomarkers within a multiproxy case study of a wetland village. *Journal of Archaeological Science*, *121*, 105202. https://doi.org/10.1016/j.jas.2020.105202

Michelutti, N., Blais, J. M., Cumming, B. F., Paterson, A. M., Rühland, K., Wolfe, A. P., & Smol, J. P. (2010). Do spectrally inferred determinations of chlorophyll a reflect trends in lake trophic status? *Journal of Paleolimnology*, *43*(2), 205–217. https://doi.org/10.1007/s10933-009-9325-8

Michelutti, N., McCleary, K. M., Antoniades, D., Sutherland, P., Blais, J. M., Douglas, M. S. V., & Smol, J. P. (2013). Using paleolimnology to track the impacts of early Arctic peoples on freshwater ecosystems from southern Baffin Island, Nunavut. *Quaternary Science Reviews*, *76*, 82–95. https://doi.org/10.1016/j.quascirev.2013.06.027

Mills, K., Schillereff, D., Saulnier-Talbot, É., Gell, P., Anderson, N. J., Arnaud, F., Dong, X., Jones, M., McGowan, S., Massaferro, J., Moorhouse, H., Perez, L., & Ryves, D. B. (2017). Deciphering long-term records of natural variability and human impact as recorded in lake sediments: A palaeolimnological puzzle: A palaeolimnological puzzle. *Wiley Interdisciplinary Reviews: Water*, *4*(2), e1195. https://doi.org/10.1002/wat2.1195

Millspaugh, S. H., & Whitlock, C. (1995). A 750-year fire history based on lake sediment records in central Yellowstone National Park, USA. *The Holocene*, *5*(3), 283–292. https://doi.org/10.1177/095968369500500303

Page, G. T., & Shapiro, L. (2018). Coal in Canada | The Canadian Encyclopedia. *Historica Canada*. www.thecanadianencyclopedia.ca/en/article/coal

Pan, F., Liu, H., Guo, Z., Cai, Y., Fu, Y., Wu, J., Wang, B., & Gao, A. (2019). Metal/metalloid and phosphorus characteristics in porewater associated with manganese geochemistry: A case study in the Jiulong River Estuary, China. *Environmental Pollution*, *255*, 113134. https://doi.org/10.1016/j.envpol.2019.113134

Patton, D., & Reeves, A. D. (1999). Sterol Concentrations and Temporal Variations on the North Shore Mudflats of the Firth of Tay, Scotland. *Marine Pollution Bulletin*, *38*(7), 613–618. https://doi.org/10.1016/S0025-326X(99)00068-5

Polack, F. (Ed.). (2018). *Tracing ochre: Changing perspectives on the Beothuk*. University of Toronto Press.

Rankin, L. (2018). 8 Towards a Beothuk Archaeology: Understanding Indigenous Agency in the Material Record. In F. Polack (Ed.), *Tracing Ochre* (pp. 177–198). University of Toronto Press. https://doi.org/10.3138/9781442623859-012

Reavie, E. D., Cai, M., Meyer-Jacob, C., Smol, J. P., & Werne, J. P. (2021). Long-term primary production trends in the Laurentian Great Lakes: A comparison of geochemical methods. *Journal of Paleolimnology*, *65*(3), 299–314. https://doi.org/10.1007/s10933-020-00170-w

Reimer, P. J., Austin, W. E. N., Bard, E., Bayliss, A., Blackwell, P. G., Bronk Ramsey, C., Butzin, M., Cheng, H., Edwards, R. L., Friedrich, M., Grootes, P. M., Guilderson, T. P., Hajdas, I., Heaton, T. J., Hogg, A. G., Hughen, K. A., Kromer, B., Manning, S. W., Muscheler, R., … Talamo, S. (2020). The IntCal20 Northern Hemisphere Radiocarbon Age Calibration Curve (0–55 cal kBP). *Radiocarbon*, *62*(4), 725–757. https://doi.org/10.1017/RDC.2020.41

Renouf, >M. A. P. (1999). Prehistory of Newfoundlandhunter-gatherers: Extinctions or adaptations? *World Archaeology*, *30*(3), 403–420. https://doi.org/10.1080/00438243.1999.9980420

Rowley-Conwy, P. (1990). Settlement Patterns of the Beothuk Indians of Newfoundland: A View from Away. *Canadian Journal of Archaeology*, *14*, 21.

Schelske, C. L., & Hodell, D. A. (1995). Using carbon isotopes of bulk sedimentary organic matter to reconstruct the history of nutrient loading and eutrophication in Lake Erie. *Limnology and Oceanography*, *40*(5), 918–929. https://doi.org/10.4319/lo.1995.40.5.0918

Schroeter, N., Lauterbach, S., Stebich, M., Kalanke, J., Mingram, J., Yildiz, C., Schouten, S., & Gleixner, G. (2020). Biomolecular Evidence of Early Human Occupation of a High-Altitude Site in Western Central Asia During the Holocene. *Frontiers in Earth Science*, *8*, 20. https://doi.org/10.3389/feart.2020.00020

Shotyk, W., Cheburkin, A. K., Appleby, P. G., Fankhauser, A., & Kramers, J. D. (1996). Two thousand years of atmospheric arsenic, antimony, and lead deposition recorded in an ombrotrophic peat bog profile, Jura Mountains, Switzerland. *Earth and Planetary Science Letters*, *145*(1–4), E1–E7. https://doi.org/10.1016/S0012-821X(96)00197-5

Smol, J. P. (2008). There is no substitute for water. In *Pollution of Lakes and Rivers: A Paleoenvironmental Prespective*. Wiley and Sons.

Stewart, E. M., Hargan, K. E., Sivarajah, B., Kimpe, L. E., Blais, J. M., & Smol, J. P. (2018). A Paleoenvironmental Study Tracking Eutrophication, Mining Pollution, and Climate Change in Niven Lake, the First Sewage Lagoon of Yellowknife (Northwest Territories) + Supplementary Appendix 1 (See Article Tools). *ARCTIC*, *71*(2). https://doi.org/10.14430/arctic4720

Telford, J. V., Kay, M. L., Vander Heide, H., Wiklund, J. A., Owca, T. J., Faber, J. A., Wolfe, B. B., & Hall, R. I. (2021). Building upon open-barrel corer and sectioning systems to foster the continuing legacy of John Glew. *Journal of Paleolimnology*, *65*(2), 271–277. https://doi.org/10.1007/s10933-020-00162-w

Tse, T. J., Codling, G., Jones, P. D., Thoms, K., Liber, K., Giesy, J. P., Wheater, H., & Doig, L. E. (2014). Reconstructing long-term trends in municipal sewage discharge into a small lake in northern Manitoba, Canada. *Chemosphere*, *103*, 299–305. https://doi.org/10.1016/j.chemosphere.2013.12.019

Vachula, R. S., Huang, Y., Russell, J. M., Abbott, M. B., Finkenbinder, M. S., & O'Donnell, J. A. (2020). Sedimentary biomarkers reaffirm human impacts on northern Beringian ecosystems during the Last Glacial period. *Boreas*, *49*(3), 514–525. https://doi.org/10.1111/bor.12449

White, A. J., Stevens, L. R., Lorenzi, V., Munoz, S. E., Lipo, C. P., & Schroeder, S. (2018). An evaluation of fecal stanols as indicators of population change at Cahokia, Illinois. *Journal of Archaeological Science*, *93*, 129–134. https://doi.org/10.1016/j.jas.2018.03.009

White, A. J., Stevens, L. R., Lorenzi, V., Munoz, S. E., Schroeder, S., Cao, A., & Bogdanovich, T. (2019). Fecal stanols show simultaneous flooding and seasonal precipitation change correlate with Cahokia's population decline. *Proceedings of the National Academy of Sciences*, *116*(12), 5461–5466. https://doi.org/10.1073/pnas.1809400116

Whitlock, C., & Larsen, C. (2002). Charcoal as a Fire Proxy. In J. P. Smol, H. J. B. Birks, W. M. Last, R. S. Bradley, & K. Alverson (Eds.), *Tracking Environmental Change Using Lake Sediments* (Vol. 3, pp. 75–97). Springer Netherlands. https://doi.org/10.1007/0-306-47668-1_5

Appendix A – Raw Charcoal Counts

Core	Depth	Year (CE)	Margin of error	Sediment weight (g)	Raw Charcoal Count
01	0.5-1.0	2019	2.5	0.4371	40
01	1.0-1.5	2017	2.0	0.2086	89
01	1.5-2.0	2016	2.5	0.4030	22
01	2.0-2.5	2015	2.5	0.4114	8
01	2.5-3.0	2012	4.0	0.4165	3
01	3.0-3.5	2009	4.5	0.4301	16
01	3.5-4.0	2007	4.5	0.4185	15
01	4.0-4.5	2004	4.0	0.4264	2
01	4.5-5.0	2000	3.5	0.4032	9
01	5.0-5.5	1998	4.5	0.4186	5
01	5.5-6.0	1996	4.5	0.4054	19
01	6.0-6.5	1994	5.0	0.4164	9
01	6.5-7.0	1990	5.0	0.4053	48
01	7.0-7.5	1987	5.5	0.4135	17
01	7.5-8.0	1985	6.0	0.4157	34
01	8.0-8.5	1982	5.5	0.4060	9
01	8.5-9.0	1978	6.5	0.4035	14
01	9.0-9.5	1975	6.5	0.4056	28
01	9.5-10.0	1973	6.5	0.4015	42
01	10.0-10.5	1970	7.0	0.4437	32
01	10.5-11.0	1964	9.5	0.4176	71
01	11.0-11.5	1960	11.5	0.4236	65
01	11.5-12.0	1957	12.5	0.4153	109
01	12.0-12.5	1954	13.5	0.4403	115
01	12.5-13.0	1951	14.5	0.4300	173
01	13.0-13.5	1948	15.0	0.4046	62
01	13.5-14.0	1944	14.5	0.4103	74
01	14.0-14.5	1940	14.5	0.4052	109
01	14.5-15.0	1933	16.5	0.4122	142
01	15.0-15.5	1927	18.5	0.4244	261
01	15.5-16.0	1922	21.0	0.4378	47
01	16.0-16.5	1917	23.5	0.4015	24
01	16.5-17.0	1913	24.0	0.4191	49
01	17.0-17.5	1908	25.0	0.4129	54
01	17.5-18.0	1903	25.5	0.4103	39
01	18.0-18.5	1897	26.5	0.4031	16
01	18.5-19.0	1880	41.0	0.3997	15
01	19-19.5	1865	53.5	0.4035	6
01	19.5-20.0	1853	61.5	0.4306	30
01	20.0-20.5	1842	71.5	0.4224	20
01	20.5-21.0	1832	81.5	0.2206	17

Core	Depth	Year (CE)	Margin of error	Sediment weight (g)	Raw Charcoal Count
01	21.0-21.5	1822	86.0	0.4160	5
01	21.5-22.0	1812	90.5	0.4193	11
01	22-22.5	1801	97.1	0.4251	7
01	22.5-23	1791	102.0	0.4040	5
01	23-23.5	1781	104.0	0.4344	17
01	23.5-24	1771	107.1	0.4123	24
01	24-24.5	1760	116.0	--	--
01	24.5-25	1750	117.0	0.4059	8
01	25.0-25.5	1740	121.5	0.4288	9
01	25.5-26	1730	123.5	0.4052	9
01	26.0-26.5	1720	125.5	0.4141	9
01	26.5-27.0	1710	129.5	0.4063	3
01	27.0-27.5	1700	127.0	0.4038	7
01	27.5-28.0	1690	128.0	0.4187	15
01	28.0-28.5	1680	128.1	0.4106	8
01	28.5-29.0	1669	128.6	0.4165	27
01	29.0-29.5	1658	131.5	0.4121	14
01	29.5-30.0	1648	137.0	0.4147	2
01	30.0-30.5	1637	136.0	0.4135	7
01	30.5-31	1626	139.5	0.4359	12
01	31.0-31.5	1616	139.0	0.4241	7
01	31.5-32.0	1605	140.6	0.4029	4
01	32.0-32.5	1595	140.6	0.4382	4
01	32.5-33.0	1584	143.0	--	--
01	33.0-33.5	1573	143.1	0.4124	6
01	33.5-34	1562	145.0	0.4008	
01	34.0-34.5	1552	146.1	0.4195	5
01	34.5-35.0	1541	142.6	0.4019	10
01	35.0-35.5	1530	142.6	0.4057	4
01	35.5-36	1519	142.5	0.4068	7
01	36.0-36.5	1509	141.5	0.4101	6
01	36.5-37	1498	140.5	0.4129	7
01	37.0-37.5	1488	136.0	0.4031	13
01	37.5-38	1477	133.0	0.4057	45
01	38.0-38.5	1466	130.5	0.4075	100
01	38.5-39	1455	129.0	**0.4063**	**56**
01	39.0-39.5	1444	126.5	0.4035	14
01	39.5-40.0	1434	120.5	0.4171	19
01	40.0-40.5	1424	120.0	0.4058	18
01	40.5-41.0	1414	116.5	0.2369	12
01	41.0-41.5	1403	109.5	0.4015	13
01	41.5-42	1393	106.6	0.4318	9

Core	Depth	Year (CE)	Margin of error	Sediment weight (g)	Raw Charcoal Count
01	42.0-42.5	1382	101.5	0.4167	6
01	42.5-43	1371	99.0	0.4143	23
01	43.0-43.5	1361	92.0	0.4119	10
01	43.5-44	1350	90.0	0.4247	10
01	44.0-44.5	1339	83.0	0.4174	3
01	44.5-45	1329	76.5	0.4229	5
01	45.0-45.5	1318	71.1	0.4027	11
01	45.5-46	1307	63.0	0.4104	3
01	46.0-46.5	1293	52.0	0.4047	9
01	46.5-47	1276	39.5	0.3931	3
01	47.0-47.5	1271	39.5	0.4365	6
01	47.5-48	1266	40.0	0.4217	6
01	48.0-48.5	1263	41.0	0.4094	2
01	48.5-49	1259	41.5	0.4249	8
01	49.0-49.5	1255	42.5	0.4182	2
01	49.5-50	1251	42.0	0.4276	4
01	50.0-50.5	1247	42.0	0.4111	12
01	50.5-51	1243	42.0	0.4069	6
01	51.0-51.5	1240	41.0	0.4044	5
01	51.5-52	1236	40.5	0.4265	8
01	52.0-52.5	1232	40.0	0.4138	5
01	52.5-53	1228	39.5	0.4095	2
01	53.0-53.5	1224	40.5	0.4058	3
01	53.5-54	1220	38.5	--	--
01	54-54.5	1216	38.5	--	--
01	54.5-55	1212	37.5	0.4185	3
01	55.0-55.5	1208	36.5	0.4315	5
01	55.5-56	1204	35.0	0.4176	5
01	56-56.5	1200	32.5	0.2206	4
03	44.0-44.5	1444	91.0	0.4088	8
03	44.5-45	1437	91.6	0.4268	2
03	45.0-45.5	1429	93.0	0.4051	2
03	45.5-46	1422	93.0	0.4114	6
03	46.0-46.5	1414	93.0	0.4179	3
03	46.5-47	1406	91.0	0.4184	5
03	47.0-47.5	1398	91.5	0.4239	3
03	47.5-48	1391	91.0	0.4253	6
03	48.0-48.5	1383	90.0	0.4107	0
03	48.5-49	1376	87.5	0.4202	7
03	49.0-49.5	1368	84.1	0.4251	2
03	49.5-50	1360	81.0	0.4197	1
03	50.0-50.5	1353	78.0	0.4249	6

Core	Depth	Year (CE)	Margin of error	Sediment weight (g)	Raw Charcoal Count
03	50.5-51	1342	75.5	0.4020	1
03	51.0-51.5	1334	73.0	0.4264	3
03	51.5-52	1326	70.5	0.4209	1
03	52.0-52.5	1319	69.1	0.4140	0
03	52.5-53	1312	66.0	0.4329	2
03	53.0-53.5	1304	64.6	0.4147	2
03	53.5-54	1296	63.0	0.4114	0
03	54.0-54.5	1288	60.5	0.4033	5
03	54.5-55	1280	57.5	0.4040	11
03	55.0-55.5	1273	53.5	0.4211	5
03	55.5-56	1265	51.0	0.4273	10
03	56.0-56.5	1258	46.5	--	--
03	56.5-57	1251	43.5	0.4135	1
03	57.0-57.5	1243	40.0	0.4025	3
03	57.5-58.0	1235	35.0	0.4273	8
03	58.0-58.5	1226	31.0	0.4008	16
03	58.5-59.0	1214	27.5	0.4347	100
03	59.0-59.5	1208	31.0	0.4166	44
03	59.5-60.0	1202	33.5	0.3828	30
03	60.0-60.5	1196	35.5	0.4012	37
03	60.5-61.0	1191	38.0	--	--
03	61.0-61.5	1186	40.0	0.4212	5
03	61.5-62	1181	42.0	0.4211	7
03	62.0-62.5	1176	42.0	0.4216	8
03	62.5-63.0	1171	43.5	0.4071	6
03	63.0-63.5	1166	46.0	0.4108	6
03	63.5-64.0	1161	45.5	0.4174	2
03	64.0-64.5	1155	48.0	0.4253	6
03	64.5-65.0	1150	49.0	0.4209	7
03	65.0-65.5	1145	51.0	0.4243	7
03	65.5-66.0	1140	52.0	0.4128	13
03	66.0-66.5	1134	52.5	0.4147	22
03	66.5-67.0	1129	55.0	0.4088	5
03	67.0-67.5	1124	54.0	0.4063	2
03	67.5-68.0	1118	54.0	0.4122	1
03	68.0-68.5	1113	54.0	0.4325	0
03	68.5-69.0	1108	55.0	0.4201	5
03	69.0-69.5	1103	54.5	0.4204	2
03	69.5-70.0	1097	53.5	0.4045	8
03	70.0-70.5	1091	53.0	0.4191	1
03	70.5-71.0	1080	55.5	0.4154	2
03	71.0-71.5	1073	59.5	0.4053	2

Core	Depth	Year (CE)	Margin of error	Sediment weight (g)	Raw Charcoal Count
03	71.5-72.0	1065	59.5	0.4033	2
03	72.0-72.5	1058	60.5	0.4123	4
03	72.5-73.0	1052	64.0	0.4096	3
03	73.0-73.5	1045	65.0	0.4166	2
03	73.5-74.0	1039	69.5	0.4165	32
03	74.0-74.5	1033	70.0	0.4132	3
03	74.5-75.0	1026	72.5	0.4188	4
03	75.0-75.5	1020	74.0	0.4139	1
03	75.5-76.0	1014	77.0	0.4169	4
03	76.0-76.5	1008	80.5	0.4211	4
03	76.5-77.0	1002	83.5	0.4062	4
03	77.0-77.5	995	85.5	0.4262	5
03	77.5-78.0	989	89.0	0.4137	2
03	78.0-78.5	983	91.0	0.4258	6
03	78.5-79.0	977	90.5	0.4165	5
03	79.0-79.5	971	93.0	0.4079	7
03	79.5-80.0	965	93.6	0.4163	5
03	80.0-80.5	959	96.0	0.4146	5
03	80.5-81.0	953	97.6	0.4014	6
03	81.0-81.5	947	99.6	0.4084	3
03	81.5-82.0	940	100.5	0.4229	8
03	82.0-82.5	934	103.0	0.4141	3
03	82.5-83.0	928	105.5	0.4131	4
03	83.0-83.5	922	106.6	0.4252	10
03	83.5-84.0	915	107.0	0.4095	9
03	84.0-84.5	909	108.1	0.4272	16
03	84.5-85.0	903	109.6	0.4283	12

Appendix B – Raw Metals Data

Core	Depth	Year (CE)	Margin of error	Arsenic	Cadmium	Copper	Titanium	Zinc	Units
03	4.0-4.5	2007	4.5	81	1.4	23	860	250	µg/g
03	12.0-12.5	1932	27.5	75	1.2	17	930	210	µg/g
03	16.0-16.5	1870	49.0	65	1.3	18	960	200	µg/g
03	20.0-20.5	1809	70.0	63	1.1	18	910	190	µg/g
03	24.0-24.5	1749	80.0	66	1.2	16	890	180	µg/g
03	28.0-28.5	1688	90.5	86	1.1	16	860	170	µg/g
03	32.0-32.5	1627	96.5	79	1.2	16	890	190	µg/g
03	36.0-36.5	1566	97.0	73	1.1	16	1000	210	µg/g
03	40.0-40.5	1505	96.0	59	1.3	21	1100	210	µg/g
03	44.0-44.5	1444	91.0	77	1.2	17	920	200	µg/g
03	48.0-48.5	1383	90.0	73	1.5	19	940	230	µg/g
03	52.0-52.5	1319	69.1	61	1.6	21	960	240	µg/g
03	56.0-56.5	1258	46.5	86	1.3	19	900	230	µg/g
03	60.0-60.5	1196	35.5	72	1.4	21	790	230	µg/g
03	64.0-64.5	1155	48.0	73	1.2	16	820	180	µg/g
03	68.0-68.5	1113	54.0	63	1.2	17	1100	220	µg/g
03	72.0-72.5	1058	60.5	79	1.3	19	950	230	µg/g
03	76.0-76.5	1008	80.5	62	1.6	21	930	250	µg/g
03	80.0-80.5	959	96.0	81	1.5	24	910	240	µg/g
03	84.0-84.5	909	108.1	86	1.3	19	870	220	µg/g

Appendix C – Raw Lipid Data

Core	Depth	Coprostanol	Cholesterol	Sitosterol	Stigmastanol
03	0.0-0.5	4.36	24.23	11.89	11.46
03	4.0-4.5	--	7.27	5.04	10.75
03	8.0-8.5	--	13.36	12.86	21.98
03	12.0-12.5	--	2.29	1.80	--
03	16.0-16.5	3.78	3.63	3.55	10.19
03	24.0-24.5	9.12	8.33	10.38	20.23
03	28.0-28.5	3.81	4.01	3.58	11.21
03	36.0-36.5	--	2.07	--	--
03	40.0-40.5	4.56	7.07	5.44	11.34
03	44.0-44.5	--	7.34	8.03	13.51
03	48.0-48.5	--	3.67	--	--
03	52.0-52.5	--	1.40	2.49	--
03	54.0-54.5	4.74	2.68	3.50	8.85
03	58.0-58.5	--	1.80	2.77	7.14
03	60.0-60.5	--	8.46	10.51	17.68
03	62.0-62.5	--	3.92	--	--
03	64.0-64.5	5.63	5.51	5.86	17.00
03	66.0-66.5	--	--	8.19	14.37
03	68.0-68.5	--	2.59	2.80	7.42
03	70.0-70.5	2.47	3.61	1.73	--
03	72.0-72.5	--	3.87	3.00	--
03	74.0-74.5	3.36	1.43	2.55	7.01
03	76.0-76.5	3.06	3.18	1.82	--
03	80.0-80.5	3.62	1.95	3.04	8.52
03	82.0-82.5	--	1.64	2.62	5.21
03	84.0-84.5	3.29	3.66	2.19	--

Appendix D – Chronology Output

Core	Depth (cm)	Minimum	Median	Mean	Max	Year
01	0.0-0.5	-72.00	-71.00	-71.22	-69.00	2021.22
01	0.5-1.0	-71.00	-69.00	-68.65	-66.00	2018.65
01	1.0-1.5	-69.00	-67.00	-67.28	-65.00	2017.28
01	1.5-2.0	-69.00	-66.00	-66.10	-64.00	2016.10
01	2.0-2.5	-68.00	-65.00	-64.71	-63.00	2014.71
01	2.5-3.0	-65.00	-62.00	-61.79	-57.00	2011.79
01	3.0-3.5	-63.00	-59.00	-59.10	-54.00	2009.10
01	3.5-4.0	-62.00	-56.00	-56.70	-53.00	2006.70
01	4.0-4.5	-59.03	-54.00	-54.03	-51.00	2004.03
01	4.5-5.0	-53.00	-51.00	-50.47	-46.00	2000.47
01	5.0-5.5	-52.00	-48.00	-48.07	-43.00	1998.07
01	5.5-6.0	-51.00	-46.00	-46.05	-41.98	1996.04
01	6.0-6.5	-49.00	-44.00	-43.64	-39.00	1993.64
01	6.5-7.0	-44.00	-40.00	-39.95	-34.00	1989.95
01	7.0-7.5	-42.00	-38.00	-37.25	-31.00	1987.25
01	7.5-8.0	-41.00	-35.00	-34.91	-29.00	1984.91
01	8.0-8.5	-38.03	-32.00	-32.12	-27.00	1982.12
01	8.5-9.0	-34.00	-28.00	-27.94	-21.00	1977.94
01	9.0-9.5	-31.00	-25.00	-25.06	-18.00	1975.06
01	9.5-10.0	-29.00	-23.00	-22.52	-15.98	1972.52
01	10.0-10.5	-27.00	-20.00	-19.62	-13.00	1969.62
01	10.5-11.0	-22.00	-15.00	-14.32	-3.00	1964.32
01	11.0-11.5	-20.00	-11.00	-10.39	3.00	1960.39
01	11.5-12.0	-18.00	-8.00	-7.05	7.03	1957.05
01	12.0-12.5	-16.00	-5.00	-4.03	11.03	1954.03
01	12.5-13.0	-14.03	-1.00	-0.98	15.00	1950.98
01	13.0-13.5	-12.00	2.00	2.18	18.03	1947.82
01	13.5-14.0	-8.00	6.00	5.58	21.00	1944.42
01	14.0-14.5	-5.00	9.00	9.53	24.00	1940.47
01	14.5-15.0	2.00	16.00	17.23	35.03	1932.77
01	15.0-15.5	7.00	22.00	23.16	44.00	1926.84
01	15.5-16.0	10.00	27.00	28.12	52.03	1921.88
01	16.0-16.5	13.00	31.00	32.70	60.00	1917.31
01	16.5-17.0	16.00	36.00	37.13	64.00	1912.87
01	17.0-17.5	20.00	40.00	41.70	70.00	1908.30
01	17.5-18.0	24.00	46.00	46.72	75.00	1903.28
01	18.0-18.5	28.00	52.00	52.87	81.00	1897.13

Core	Depth (cm)	Minimum	Median	Mean	Max	Year
01	18.5-19.0	38.98	67.00	70.12	121.03	1879.88
01	19-19.5	45.00	80.00	84.83	152.03	1865.17
01	19.5-20.0	50.00	91.50	96.87	173.00	1853.13
01	20.0-20.5	56.00	101.00	107.84	199.13	1842.16
01	20.5-21.0	58.98	111.00	117.89	222.03	1832.12
01	21.0-21.5	62.00	121.00	127.62	234.05	1822.38
01	21.5-22.0	64.98	132.00	138.14	246.03	1811.86
01	22-22.5	72.93	142.00	148.54	267.03	1801.46
01	22.5-23	79.00	154.00	158.79	283.05	1791.21
01	23-23.5	85.00	164.00	169.21	293.05	1780.79
01	23.5-24	90.00	174.00	179.38	304.13	1770.63
01	24-24.5	95.00	185.00	190.18	327.05	1759.83
01	24.5-25	101.95	194.00	199.87	336.03	1750.13
01	25.0-25.5	105.98	203.50	209.53	349.00	1740.47
01	25.5-26	113.00	213.00	219.52	360.05	1730.48
01	26.0-26.5	120.00	222.00	229.59	371.03	1720.41
01	26.5-27.0	124.00	232.50	239.73	383.03	1710.27
01	27.0-27.5	136.00	245.00	250.10	390.03	1699.90
01	27.5-28.0	140.95	257.00	260.00	397.03	1690.01
01	28.0-28.5	151.00	267.50	270.14	407.13	1679.86
01	28.5-29.0	160.00	278.00	281.11	417.13	1668.89
01	29.0-29.5	173.00	288.00	291.82	436.03	1658.18
01	29.5-30.0	179.95	299.00	302.46	454.00	1647.54
01	30.0-30.5	189.98	310.00	312.73	462.00	1637.27
01	30.5-31	196.00	322.00	323.60	475.03	1626.40
01	31.0-31.5	202.95	333.00	334.41	481.03	1615.59
01	31.5-32.0	209.95	345.00	345.07	491.08	1604.93
01	32.0-32.5	219.93	355.00	355.32	501.08	1594.68
01	32.5-33.0	230.98	365.00	366.44	517.05	1583.56
01	33.0-33.5	237.98	374.00	376.93	524.08	1573.07
01	33.5-34	251.98	384.00	387.57	542.00	1562.43
01	34.0-34.5	257.95	395.50	397.79	550.05	1552.21
01	34.5-35.0	273.90	405.50	409.04	559.08	1540.96
01	35.0-35.5	279.98	417.00	420.00	565.08	1530.00
01	35.5-36	289.00	427.00	430.56	574.03	1519.44
01	36.0-36.5	298.98	440.00	441.08	582.03	1508.92
01	36.5-37	308.98	452.00	452.29	590.03	1497.71
01	37.0-37.5	322.00	463.00	462.48	594.03	1487.52

Core	Depth (cm)	Minimum	Median	Mean	Max	Year
01	37.5-38	332.98	475.00	472.88	599.03	1477.12
01	38.0-38.5	345.98	484.50	484.00	607.00	1466.00
01	38.5-39	356.98	497.50	495.35	615.00	1454.65
01	39.0-39.5	370.00	510.00	505.86	623.03	1444.14
01	39.5-40.0	387.00	519.00	515.92	628.00	1434.09
01	40.0-40.5	397.00	527.50	525.91	637.00	1424.09
01	40.5-41.0	408.00	541.00	536.38	641.03	1413.62
01	41.0-41.5	426.98	551.00	546.54	646.03	1403.46
01	41.5-42	440.93	563.00	557.41	654.03	1392.59
01	42.0-42.5	455.00	574.50	568.17	658.03	1381.83
01	42.5-43	463.98	585.00	578.72	662.03	1371.28
01	43.0-43.5	482.98	595.00	589.06	667.00	1360.94
01	43.5-44	491.98	605.00	599.97	672.00	1350.04
01	44.0-44.5	509.95	616.00	610.58	676.03	1339.42
01	44.5-45	527.95	628.00	621.09	681.00	1328.91
01	45.0-45.5	541.88	638.00	631.89	684.03	1318.11
01	45.5-46	562.98	649.00	643.12	689.00	1306.88
01	46.0-46.5	593.00	662.00	657.40	697.00	1292.60
01	46.5-47	631.00	676.00	673.60	710.00	1276.40
01	47.0-47.5	636.98	681.00	679.18	716.00	1270.82
01	47.5-48	640.00	686.00	683.59	720.03	1266.41
01	48.0-48.5	644.98	689.00	687.37	727.03	1262.63
01	48.5-49	648.98	693.00	691.34	732.03	1258.67
01	49.0-49.5	651.98	696.00	695.24	737.00	1254.76
01	49.5-50	655.98	699.00	699.08	740.00	1250.92
01	50.0-50.5	660.00	704.00	702.98	744.00	1247.02
01	50.5-51	663.00	707.00	706.64	747.00	1243.36
01	51.0-51.5	668.95	711.00	710.36	751.00	1239.64
01	51.5-52	672.98	715.00	714.10	754.00	1235.90
01	52.0-52.5	676.00	719.00	718.17	756.00	1231.83
01	52.5-53	679.98	723.00	722.30	759.00	1227.70
01	53.0-53.5	681.98	727.00	726.38	763.00	1223.62
01	53.5-54	689.00	730.00	730.20	766.03	1219.80
01	54-54.5	692.98	734.00	733.97	770.00	1216.03
01	54.5-55	697.00	738.00	737.74	772.00	1212.27
01	55.0-55.5	702.00	742.00	741.56	775.00	1208.44
01	55.5-56	707.00	747.00	745.68	777.03	1204.32
01	56-56.5	714.98	753.00	750.01	780.00	1199.99

Core	Depth (cm)	Minimum	Median	Mean	Max	Year
03	0.0-0.5	-73.00	-72.00	-71.76	-70.00	2021.76
03	0.5-1.0	-71.00	-69.00	-69.37	-67.00	2019.37
03	1.0-1.5	-70.00	-68.00	-68.35	-66.00	2018.35
03	1.5-2.0	-70.00	-67.00	-67.44	-65.00	2017.44
03	2.0-2.5	-69.00	-66.00	-66.39	-64.00	2016.39
03	2.5-3.0	-67.00	-64.00	-63.85	-59.00	2013.85
03	3.0-3.5	-65.00	-62.00	-61.38	-56.00	2011.38
03	3.5-4.0	-64.00	-59.00	-59.10	-54.00	2009.10
03	4.0-4.5	-61.00	-57.00	-56.58	-52.00	2006.58
03	4.5-5.0	-57.00	-53.00	-52.31	-46.00	2002.31
03	5.0-5.5	-55.00	-49.00	-49.03	-42.00	1999.03
03	5.5-6.0	-53.00	-46.00	-46.07	-38.98	1996.07
03	6.0-6.5	-50.00	-43.00	-42.68	-35.00	1992.68
03	6.5-7.0	-46.00	-38.00	-37.62	-29.00	1987.62
03	7.0-7.5	-42.00	-34.00	-33.89	-24.00	1983.89
03	7.5-8.0	-39.03	-31.00	-30.64	-20.98	1980.64
03	8.0-8.5	-37.00	-27.00	-27.07	-16.00	1977.07
03	8.5-9.0	-33.00	-21.50	-21.28	-8.00	1971.28
03	9.0-9.5	-29.00	-17.00	-16.94	-2.98	1966.94
03	9.5-10.0	-26.03	-13.00	-13.17	1.00	1963.17
03	10.0-10.5	-24.00	-9.00	-8.68	8.00	1958.68
03	10.5-11.0	-18.00	-1.00	-0.41	20.00	1950.41
03	11.0-11.5	-13.03	6.00	6.39	32.00	1943.61
03	11.5-12.0	-10.00	11.00	12.23	40.03	1937.77
03	12.0-12.5	-7.00	17.00	17.92	48.00	1932.09
03	12.5-13.0	-4.00	23.00	23.74	54.00	1926.26
03	13.0-13.5	-1.00	29.00	29.42	60.03	1920.58
03	13.5-14.0	3.98	35.50	35.38	67.00	1914.62
03	14.0-14.5	9.98	43.00	42.38	76.03	1907.62
03	14.5-15.0	18.00	55.50	55.23	92.00	1894.78
03	15.0-15.5	24.00	65.00	64.37	105.00	1885.63
03	15.5-16.0	28.98	72.00	72.11	118.03	1877.89
03	16.0-16.5	36.00	79.00	79.99	134.00	1870.01
03	16.5-17.0	39.00	87.00	87.83	145.03	1862.17
03	17.0-17.5	44.00	95.00	95.42	158.00	1854.58
03	17.5-18.0	48.00	101.00	102.57	164.00	1847.43
03	18.0-18.5	52.98	109.00	109.85	173.03	1840.15
03	18.5-19.0	57.98	116.00	117.49	182.03	1832.51

Core	Depth (cm)	Minimum	Median	Mean	Max	Year
03	19-19.5	61.98	124.00	125.07	193.00	1824.93
03	19.5-20.0	66.98	132.00	133.01	205.03	1817.00
03	20.0-20.5	73.98	140.00	141.00	214.00	1809.00
03	20.5-21.0	76.98	148.00	148.72	222.00	1801.28
03	21.0-21.5	84.00	156.00	156.51	233.00	1793.49
03	21.5-22.0	90.00	163.00	164.10	241.00	1785.90
03	22-22.5	96.98	172.00	171.59	247.00	1778.41
03	22.5-23	102.98	180.00	179.12	261.00	1770.88
03	23-23.5	109.98	187.00	186.36	265.03	1763.64
03	23.5-24	116.98	194.00	193.69	274.00	1756.31
03	24-24.5	121.98	202.00	201.16	282.03	1748.84
03	24.5-25	128.00	209.00	208.67	293.03	1741.33
03	25.0-25.5	132.98	215.00	216.20	302.08	1733.80
03	25.5-26	138.98	223.00	223.84	311.00	1726.17
03	26.0-26.5	146.98	231.00	231.52	316.00	1718.48
03	26.5-27.0	153.00	238.00	239.14	323.03	1710.86
03	27.0-27.5	163.00	245.00	246.66	336.05	1703.34
03	27.5-28.0	168.00	252.00	254.44	346.00	1695.56
03	28.0-28.5	173.98	260.00	262.34	355.05	1687.66
03	28.5-29.0	179.00	268.00	269.98	362.00	1680.02
03	29.0-29.5	184.95	275.50	277.65	370.03	1672.35
03	29.5-30.0	194.95	285.00	285.29	380.08	1664.71
03	30.0-30.5	200.00	293.00	293.17	390.00	1656.83
03	30.5-31	202.98	300.00	300.85	396.03	1649.15
03	31.0-31.5	208.95	308.00	308.48	405.00	1641.52
03	31.5-32.0	214.00	316.00	315.81	413.03	1634.20
03	32.0-32.5	223.98	324.00	323.01	417.05	1626.99
03	32.5-33.0	226.98	331.00	330.26	430.03	1619.74
03	33.0-33.5	238.88	339.00	337.77	437.00	1612.23
03	33.5-34	246.93	346.50	345.61	442.00	1604.39
03	34.0-34.5	253.95	355.00	353.32	446.03	1596.68
03	34.5-35.0	262.00	362.00	360.99	452.00	1589.01
03	35.0-35.5	268.98	368.50	368.72	460.03	1581.28
03	35.5-36	275.00	377.50	376.26	470.03	1573.74
03	36.0-36.5	286.00	386.00	384.37	480.03	1565.63
03	36.5-37	295.93	392.00	391.73	488.05	1558.27
03	37.0-37.5	305.00	399.00	399.21	496.00	1550.79
03	37.5-38	309.95	407.00	406.61	503.05	1543.39

Core	Depth (cm)	Minimum	Median	Mean	Max	Year
03	38.0-38.5	318.00	416.00	414.27	509.03	1535.73
03	38.5-39	324.98	423.00	421.50	514.00	1528.50
03	39.0-39.5	330.00	429.00	429.16	521.03	1520.84
03	39.5-40.0	335.95	437.00	436.93	526.00	1513.07
03	40.0-40.5	342.95	447.00	444.59	535.03	1505.41
03	40.5-41.0	350.00	454.00	452.61	544.00	1497.39
03	41.0-41.5	357.93	462.00	460.62	553.00	1489.39
03	41.5-42	366.98	471.00	468.64	559.00	1481.36
03	42.0-42.5	371.00	479.00	475.96	565.05	1474.04
03	42.5-43	378.98	485.00	483.01	570.00	1466.99
03	43.0-43.5	389.93	493.00	490.79	577.03	1459.21
03	43.5-44	398.90	501.00	498.32	584.00	1451.68
03	44.0-44.5	406.95	508.00	505.81	589.00	1444.19
03	44.5-45	411.95	516.00	513.34	595.05	1436.66
03	45.0-45.5	417.93	523.00	520.77	604.00	1429.23
03	45.5-46	423.93	530.00	528.25	610.00	1421.76
03	46.0-46.5	430.00	537.00	536.03	616.03	1413.97
03	46.5-47	443.00	545.00	543.77	625.05	1406.23
03	47.0-47.5	450.98	554.00	551.59	634.00	1398.41
03	47.5-48	459.00	561.00	559.46	641.03	1390.54
03	48.0-48.5	467.98	569.00	566.74	648.03	1383.26
03	48.5-49	479.98	577.00	574.26	655.03	1375.74
03	49.0-49.5	490.90	585.00	582.06	659.00	1367.94
03	49.5-50	503.00	593.00	589.54	665.03	1360.46
03	50.0-50.5	513.95	600.00	597.30	670.03	1352.70
03	50.5-51	529.93	611.00	608.31	681.00	1341.69
03	51.0-51.5	539.00	619.00	616.00	685.03	1334.00
03	51.5-52	549.98	627.00	623.62	691.00	1326.38
03	52.0-52.5	555.95	634.00	631.01	694.05	1318.99
03	52.5-53	564.00	641.00	638.43	696.05	1311.57
03	53.0-53.5	573.98	650.00	646.31	703.08	1303.69
03	53.5-54	584.00	657.00	654.20	710.03	1295.81
03	54-54.5	594.98	665.00	662.17	716.03	1287.83
03	54.5-55	606.00	673.00	670.06	721.00	1279.94
03	55.0-55.5	617.00	679.00	677.46	724.00	1272.54
03	55.5-56	627.00	687.00	684.80	729.00	1265.21
03	56-56.5	639.00	695.00	692.28	732.00	1257.72
03	56.5-57	649.98	701.50	699.41	737.03	1250.59

Core	Depth (cm)	Minimum	Median	Mean	Max	Year
03	57.0-57.5	660.98	709.00	706.72	741.00	1243.28
03	57.5-58.0	673.98	716.00	714.55	744.00	1235.45
03	58.0-58.5	690.98	724.50	723.85	753.00	1226.15
03	58.5-59.0	709.98	736.00	736.16	765.03	1213.84
03	59.0-59.5	714.00	742.00	742.49	776.00	1207.51
03	59.5-60.0	718.00	747.00	747.97	785.00	1202.03
03	60.0-60.5	722.00	751.00	753.56	793.00	1196.44
03	60.5-61.0	725.00	757.00	758.64	801.00	1191.36
03	61.0-61.5	729.00	762.00	763.61	809.03	1186.40
03	61.5-62	732.00	767.00	768.58	816.00	1181.42
03	62.0-62.5	735.98	772.00	773.73	820.00	1176.27
03	62.5-63.0	739.00	778.00	778.99	826.00	1171.01
03	63.0-63.5	742.00	784.00	784.24	834.00	1165.77
03	63.5-64.0	747.00	789.00	789.43	838.00	1160.57
03	64.0-64.5	750.98	794.00	794.63	847.03	1155.37
03	64.5-65.0	754.98	799.00	799.69	853.00	1150.31
03	65.0-65.5	758.00	804.50	804.91	860.00	1145.10
03	65.5-66.0	761.00	809.50	810.18	865.03	1139.82
03	66.0-66.5	765.00	815.00	815.76	870.03	1134.24
03	66.5-67.0	768.00	820.50	821.10	878.00	1128.91
03	67.0-67.5	774.00	827.00	826.28	882.00	1123.73
03	67.5-68.0	779.98	833.00	831.69	888.00	1118.31
03	68.0-68.5	783.00	838.00	837.11	891.00	1112.89
03	68.5-69.0	785.00	843.00	842.28	895.03	1107.72
03	69.0-69.5	791.00	848.00	847.47	900.00	1102.53
03	69.5-70.0	797.00	854.00	853.04	904.00	1096.96
03	70.0-70.5	801.98	860.00	859.03	908.00	1090.97
03	70.5-71.0	808.98	869.00	869.57	920.00	1080.43
03	71.0-71.5	814.00	877.00	877.26	933.00	1072.74
03	71.5-72.0	822.00	886.00	885.47	941.03	1064.53
03	72.0-72.5	827.98	892.00	891.74	949.05	1058.26
03	72.5-73.0	830.00	899.00	898.04	958.00	1051.96
03	73.0-73.5	835.00	905.00	904.54	965.03	1045.46
03	73.5-74.0	837.98	910.00	910.86	977.00	1039.14
03	74.0-74.5	843.95	917.00	917.33	984.03	1032.67
03	74.5-75.0	847.98	923.00	923.72	993.03	1026.28
03	75.0-75.5	852.98	928.00	930.08	1001.00	1019.92
03	75.5-76.0	857.00	935.00	936.23	1011.00	1013.77

Core	Depth (cm)	Minimum	Median	Mean	Max	Year
03	76.0-76.5	859.98	941.00	942.16	1021.00	1007.84
03	76.5-77.0	862.98	948.00	948.40	1030.03	1001.60
03	77.0-77.5	866.95	954.00	954.60	1038.00	995.40
03	77.5-78.0	869.98	960.00	960.97	1048.03	989.04
03	78.0-78.5	876.98	965.00	967.14	1059.03	982.86
03	78.5-79.0	881.93	971.50	973.02	1063.00	976.98
03	79.0-79.5	883.98	976.00	979.02	1070.00	970.98
03	79.5-80.0	887.98	982.00	985.06	1075.03	964.94
03	80.0-80.5	891.98	990.00	991.20	1084.00	958.80
03	80.5-81.0	895.95	996.00	997.27	1091.08	952.73
03	81.0-81.5	901.93	1003.00	1003.27	1101.05	946.73
03	81.5-82.0	906.98	1008.50	1009.54	1108.00	940.46
03	82.0-82.5	910.98	1016.00	1015.91	1117.00	934.09
03	82.5-83.0	914.00	1022.00	1022.25	1125.00	927.76
03	83.0-83.5	921.95	1028.00	1028.44	1135.05	921.56
03	83.5-84.0	926.95	1033.00	1034.74	1141.03	915.26
03	84.0-84.5	933.88	1039.00	1040.91	1150.03	909.09
03	84.5-85.0	937.98	1047.00	1047.44	1157.15	902.56

Appendix E - $\delta^{15}N$

Core	Depth	Year (CE)	Margin of error	$d^{15}N_{air}$/‰ of Peak	%N of Sample Analysis
03	0.0-0.5	2022	1.5	4.946597583	1.133
03	4.0-4.5	2007	4.5	5.435747909	0.848
03	8.0-8.5	1977	10.5	4.51392647	0.962
03	12.0-12.5	1932	27.5	2.56337651	1.158
03	16.0-16.5	1870	49.0	-3.96299825	0.993
03	20.0-20.5	1809	70.0	-4.652851493	0.915
03	24.0-24.5	1749	80.0	-3.876262316	1.076
03	28.0-28.5	1688	90.5	-7.524214334	1.038
03	32.0-32.5	1627	96.5	-7.736011382	0.901
03	36.0-36.5	1566	97.0	-3.12992986	0.962
03	40.0-40.5	1505	96.0	3.41964172	0.982
03	44.0-44.5	1444	91.0	-2.169783241	1.086
03	48.0-48.5	1383	90.0	-8.670944067	0.916
03	52.0-52.5	1319	69.1	-7.312417286	1.09
03	54.0-54.5	1288	60.5	-1.747197702	0.995
03	56.0-56.5	1258	46.5	-10.55291212	0.972
03	58.0-58.5	1226	31.0	1.706102743	0.988
03	60.0-60.5	1196	35.5	-2.295852912	0.882
03	62.0-62.5	1176	42.0	-9.215565048	0.916
03	64.0-64.5	1155	48.0	-4.645791591	1.094
03	66.0-66.5	1134	52.5	-6.739556698	0.998
03	68.0-68.5	1113	54.0	6.139720955	0.977
03	70.0-70.5	1091	53.0	1.915882677	1.151
03	72.0-72.5	1058	60.5	0.292105307	1.018
03	74.0-74.5	1033	70.0	-2.84955091	0.924
03	76.0-76.5	1008	80.5	-7.529257121	1.045
03	78.0-78.5	983	91.0	-6.66593201	1.021
03	80.0-80.5	959	96.0	-6.097105651	0.991
03	82.0-82.5	934	103.0	4.061084209	1.034
03	84.5-85.0	903	109.6	-7.998236299	0.888