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Vegetation sensitivity during the mid-Holocene warming in western Ohio

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VEGETATION SENSITIVITY DURING THE MID-HOLOCENE WARMING IN WESTERN OHIO

A thesis submitted in partial fulfillment of the
requirements for the degree of
Master of Science

by

KRISTIN KOPERA

B.S., Juniata College, 2017

2019

Wright State University

WRIGHT STATE UNIVERSITY

GRADUATE SCHOOL

May 2, 2019

I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY SUPERVISION BY Kristin Kopera ENTITLED Vegetation Sensitivity During The Mid-Holocene Warming In Western Ohio BE ACCEPTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF Master of Science.

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ABSTRACT

Kopera, Kristin. M.S., Department of Earth and Environmental Sciences, Wright State University, 2019. Vegetation sensitivity during the mid-Holocene warming in western Ohio.

There has been a growing interest in prairie reconstruction in western Ohio, yet there are few recent academic sources supporting the claim that prairies appeared in western Ohio during the mid-Holocene. The hypsithermal was the warmest and driest part of the Holocene and occurred from 8,000-4,000 years ago in the Midwest. During the hypsithermal, the Prairie Peninsula appeared from Minnesota to eastern Ohio. If prairie did appear in Ohio, it occurred during the mid-Holocene hypsithermal. The goal of this study was to determine if western Ohio experienced a prairie period during the hypsithermal using pollen as a proxy for past regional vegetation. Outside of prairie reconstruction, vegetation studies are vital for climate modelling and understand an areas sensitivity to climate changes.

An 8.4m sediment core was collected from Crystal Lake, Clark County, OH. There are seven zones in the Crystal Lake record, covering the Pleistocene, the early, middle, and late Holocene, the mid-Holocene hypsithermal, and the movement of homesteaders into Ohio. There are no identifiable spikes in grass, sedge, or ragweed exceeding 10%, suggesting that prairie grassland was not present around Crystal Lake during the mid-Holocene hypsithermal. The only peak of ragweed, occurring at the top of the core, likely represents the beginning of homesteading activity in the area. Based on the lack of prairie taxa, the vegetation in the Crystal Lake area was likely insensitive to the warming and drying of the hypsithermal. Although the Crystal Lake area did experience a shift in vegetation in response to the hypsithermal, it was not a shift from deciduous forest to a prairie. The vegetation in the Crystal Lake area will likely remain insensitive and the vegetation is likely not to experience any large changes in response to ongoing climate change.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Table Page

Appendix

Table

ACKNOWLEDGEMENTS

Thanks are due to Dr. Rebecca Teed, my thesis advisor, of the Earth and Environmental Science department at Wright State University. She was a constant force of support. I thank my thesis committee, Dr. Chad Hammerschmidt and Dr. Silvia Newell of the Earth and Environmental Science department at Wright State University, for their guidance and their contributions to this research project. This project was funded by the Wright State University Women in Science Giving Circle. Many thanks to Sarah Graham, Jackie Manker, and Dante Villarreal, members of Dr. Teed's research lab, who collected the macrofossils that we dated for this project. Pollen samples were prepared by LacCore at the University of Minnesota and by Dr. Vaughn Bryan from Texas A & M University. AMSDirect and the AMS faculty at the Woods Hole Oceanographic Institution dated radiocarbon samples. I would like to thank David and Gabrielle for their photo-editing software knowledge. Finally, I would like to acknowledge my family and friends for their support through this process. This accomplishment would not have been possible without them.

I. INTRODUCTION

Climate Change and Climate Modeling

Human-induced climate change is causing negative environmental and ecological effects around the world. CO_2 emissions have increased by 40% since 1970 and concentrations of CO_2 in the atmosphere have increased from ~283 ppm to 408.8 ppm (IPCC, 2014; Keeling et al., 2018). The increased levels of CO_2 in the atmosphere have already begun to affect Earth's systems. The ocean has warmed 4° C above 1997 average, droughts and severe storms have increased, and sea level has risen 6.6 cm above the 1993 average (IPCC, 2014; Trenberth et al., 2013; Woth et al., 2006; Alexander and Tett, 2005; Rahmstorf, 2007; Easterling et al., 2000; Washington and Meehl, 1989; Manabe and Wetherald, 1975, 1980). At a local level, climate change threatens the property value of the areas surrounding lakes and ecology of lakes. Climate change leads to worsening water quality and algal blooms (Ye et al., 2013; Paerl and Huisman, 2009). At a regional level, agriculture and industry will suffer as droughts and flooding events become common (Adams et al., 1990).

Investigating past changes during the Holocene allows us to predict how vegetation will change in response to modern climate change using climate models.

Vegetation sensitivity, or a plant's ability to respond to climate changes, determines how much a flux in temperature or moisture will effect that taxon (Davis, 1983). Competition and variability in temperature and moisture lead to changes in biomass, species distribution, and species limits (Miller et al., 2008). Typically in the Northern Hemisphere, the range limits of vegetation will move north with warming climates or south with cooling climates. Vegetation that is sensitive to changing climate experiences observable changes in location and population numbers. Vegetation may also experience a decrease in diversity in response to climatic changes (Woodward and Rochefort, 1991). For vegetation to be insensitive to climate change, the plants must be able to survive without having to change range limits. Insensitive plants have the ability to locally adapt and develop a phenotype best suited to changing environmental pressures (Chapin, et al., 2004; Kremer, 2010). For example, drought-resistant plants persist in drier climates. Oak trees have the ability to keep areas moist when faced with drought conditions (Thompson and Hinckley, 1977; Samuelson, 1994; Kremer, 2010). The speed of change in climate limits the ability of a plant to respond quickly due the lag between climate change and the plant's dispersal or phenotype adaptation (Kremer, 2010; D'Odorico, 2013). Another consideration is the timing of the climate event; some regional vegetation may experience changes before others depending on the nature of the climate event.

Climate modelers rely on extensive data from the past to test the efficiency of the model by hindcasting previous climatic events. During hindcasting, the climate models create a reconstruction of a climatic event. If the model can accurately recreate the known observations, the model will be able to make future projections accurately. The hindcasting process requires detailed data of past climatic events, so studying climate changes during the early and mid-Holocene in Ohio provides the data needed to calibrate future climate models. Models can be used to predict how climate change will affect specific areas in North America, such as Ohio. However, the resolution of the model is typically not fine enough to discern exact responses in smaller regions. Determining the severity of climate change in Ohio is important to its industry and residents.

The COHMAP project was a collaboration between data scientists and modelers. In the project, climate modelers used climate models such as Community Climate Model, Version 0 and Version 1, to simulate changes from 21,000 calendar years ago to present. The scientists then compared globally collected paleontological data, such as pollen, lake level indicators, and foraminifera, to the outputs of the climate models (COHMAP members, 1988; Wright and Bartlein, 1993; Kutzbach et al., 1998). Between 21,000 to present, atmospheric CO_2 went from 180 to 280 ppm. The temperature and precipitation values reconstructed from the paleontological data and the models generally agreed, so the climate models should give accurate forecasts in response to changing CO_2 levels.

The Midwest is projected to have a 3°F increase in summer temperatures by 2035, and annual temperatures are projected to increase up to 10°F by the end of the century (Kunkel et al., 2013; GLISA and UMCC, 2016). Annual mean precipitation is projected to increase 2% to 6% by the end of the century (Kunkel et al., 2013; GLISA and UMCC, 2016). Specific consequences of climate change in the Midwest include increased regional flooding, severe thunderstorm and winter storm events, and heat waves (Andersen et al., 2012). Western Ohio will be specifically vulnerable to greater flood risks and extreme heat events (GLISA and UMCC, 2016).

The Midwest during the Holocene

The most recent period of rapid warming in Midwestern pollen records took place during the Holocene hypsithermal (Wright et al., 1993). A hypsithermal is defined as a period of maximum temperatures during an interglacial (Wright et al., 1993). The most recent hypsithermal occurred between 9,000 to 2,500 years ago in North America (Flint, 1971). The response to the hypsithermal was more profound in the Northern Hemisphere than in the Southern Hemisphere (Kutzbach and Webb III, 1993; Borzenkova et al., 2015). The increase in continental interior summer temperature varied throughout the Northern Hemisphere during the early and mid-Holocene. Some regions experienced temperatures 2 to 4° C above modern levels, and some areas were even as high as 5° C above modern levels (Kutzbach and Webb III, 1993; Borzenkova et al., 2015). The simulations done by Kutzbach and Webb III (1993) and Borzenkova et al. (2015) were global in scale. Responses to climate changes during the early and middle Holocene varied in timing of event, with site-specific landscape responses and precipitation changes (Umbanhower et al., 2006; Voelker et al., 2015). In the northern Midwest, the hypsithermal period is characterized by the transition to warm and dry climatic conditions (Webb III et al. 1993). The prairie-forest boundary moved northward and eastward in response to the rapid warming (Fig. 1). The largest advances of prairie occurred early in the Holocene, followed by a slow rate of retreat after the hypsithermal (Webb III et al. 1993; Williams, 2009).

The Prairie Peninsula was a portion of the western North American prairie that extended into the Midwest and was intermixed with forests. Gleason (1922) first introduced the geographical map of the Prairie Peninsula and Transeau (1935) described in more detail the pre-settlement prairie in Illinois and northwestern Indiana (Fig. 1).

During the mid-Holocene, prairies covered a greater proportion of the Midwest than it does today. For the majority of the scientific literature, the focus has been on

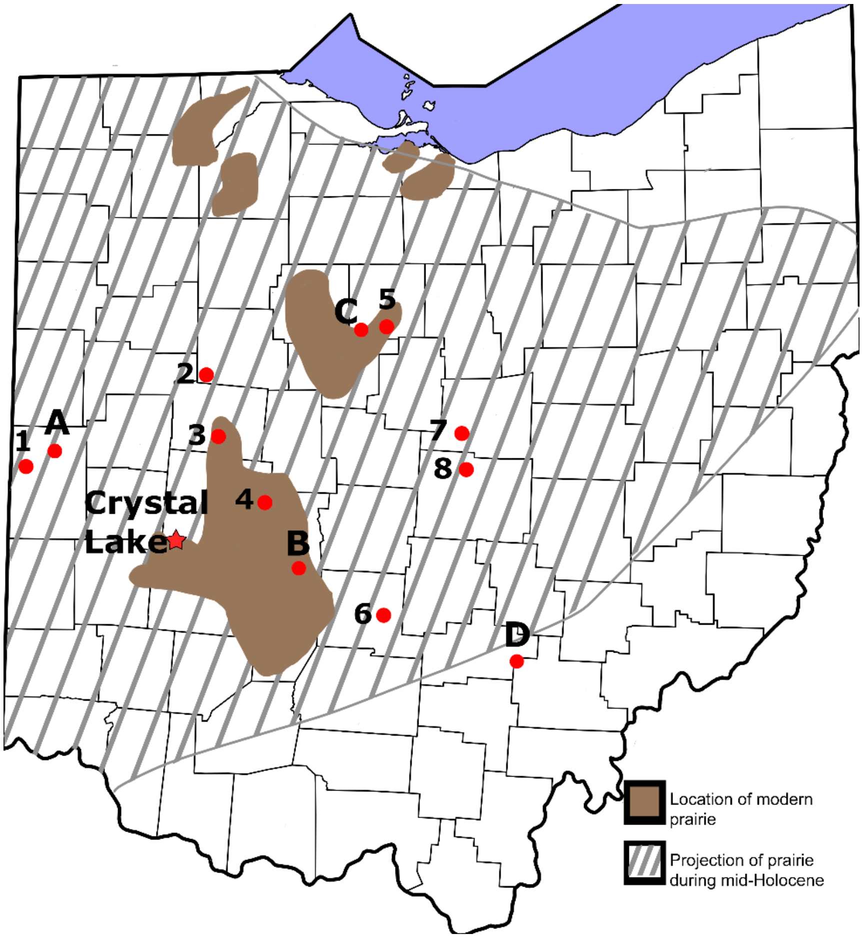

Figure 1: The modern prairie zones in Ohio are outlined in solid color. The star denotes the location of Crystal Lake in Medway, OH. The gray hatch pattern represents the extent of the Prairie Peninsula during the mid-Holocene hypsithermal. Nearby pollen records are numbered above: 1: Stotzel-Leis Site & Carter Site (Shane, 1987); 2: Neville Marsh (Shane and Anderson, 1993); 3: Silver Lake, Ohio (Ogden, 1966; Gill et al. 2012); 4: Fudger Lake (Shane, 1989); 5: Bucyrus Bog (Shane, 1989); 6: Stage's Pond (Shane, 2011); 7: Torren's Bog (Ogden, 1966); 8: Smoot Lake Bog (Shane and Anderson, 1993). Recent prairie studied labeled A-D: A: Sunbeam Prairie (Kapp and Gooding, 1964); B: Darby Plains (King, 1981); C: Daughmer Savannah (Mack and Boerner, 2004); D: Buffalo Beats (Wistendahl, 1975). (Modified from Stuckey, 1981; Ohio Prairie Association, 2018).

vegetation changes during the mid-Holocene hypsithermal in the Midwest (e.g. Webb III et al., 1984, Baker et al., 1992, Wright et al., 2004, Gonzales and Grimm, 2009, Williams et al., 2009, Grimm et al., 2011), specifically Michigan, Minnesota, Wisconsin, Illinois, Iowa, Indiana, and Ohio. There has been a focus on Midwestern sites because the mid-Holocene Prairie Peninsula was most pronounced in these states, the geographical extent of the appearance of prairie during the hypsithermal. In response to work on the Prairie Peninsula, Sears (1942a, 1942c) divided the Holocene and into five climatic phases. The first phase was moist and cool. The second phase was dry and slightly warmer than the first phase. Phase three was more humid and warm, while the fourth phase was warm and dry, the hypsithermal. The modern Midwestern climate, considered phase five, is cool and humid (Sears, 1942a). Following the description of the Holocene climatic phases, many studies have described the typical Holocene pollen record in the Midwest (e.g. Wright et al., 1963; Webb III and Bryson, 1971; Shane, 1975; Bernabo and Webb, 1977; Davis, 1977, Shane and Anderson, 1993). The typical pollen record begins with spruce and fir as the two most common taxa in the late glacial period assemblage. Pine began to replace spruce and fir in the early Holocene, until spruce and fir disappeared completely. Percentages of oak and other deciduous taxa, such as birch, maple, and beech, increased over time, and pine eventually moved into the north before disappearing from the record. At the time of the hypsithermal, herbaceous taxa, like grass, sedge, and ragweed, and oak were the most abundant. Following the hypsithermal, deciduous-type taxa were the most abundant in the Midwest (Sears, 1942a; Bernabo and Webb, 1997; Baker et al., 1992).

There are no recent studies with a complete pollen record of western Ohio during of the Holocene, and the literature is especially lacking in pollen records that include the hypsithermal. Most published data was collected in northeastern Ohio (e.g. Sears, 1930; Sears, 1931; Sears, 1941; Sears, 1942b, Shane, 1975, 1987, 1989; Shane and Anderson, 1993; Gill et al., 2009; Gill et al., 2012). The modern work done in Ohio has focused on the northeastern part of the state, primarily covering the late glacial period (e.g. Shane and Anderson, 1993; Shane, 1975, 1987, 1989; Gill et al., 2009; Gill et al., 2012). Gill et al. (2012) studied glacial pollen and fungal spores from Silver Lake, in Logan County, OH. At Silver Lake, the early transition of deciduous woodland from grassland occurred 13,900–12,700 BP (Gill et al., 2012). This date corresponds with the late Pleistocene in the Northern Hemisphere. Ogden (1966) also studied a pollen record from the same lake studied a record that extended across the entire Holocene. He noted a minor transition to prairie pollen types, between 5-10%, and a dip in beech pollen frequency during a warm and dry period approximately 3600 ± 212 years ago (Ogden, 1966). The literature lacks any more recent dates that are associated with the hypsithermal in the northeast.

Shane (1975, 1987) separated records from north and northeastern Ohio into pollen zones similar to those in the other Midwestern pollen records. They follow a similar pattern to other Midwest pollen zones throughout the Holocene, but lack a prairie period (Shane, 1975, Shane, 1987). Instead, northeastern Ohio typically experienced a maximum in deciduous taxa with negligible non-arboreal pollen during the hypsithermal, around 6000 BP (Shane, 1975, 1987). Even with the more recent data collected in the eastern part of the state, the Ohio Holocene record remains poorly studied.

Prairies in Ohio

There has been a growing interest in prairie reconstruction in western Ohio, in an attempt to rehabilitate prairie grasslands destroyed by human activity **(**State Nature Preserves, 2015; Five Rivers Metropark, n.d). Previous studies of western Ohio have suggested that prairie was probably present during the Holocene hypsithermal (Gleason, 1922; Transeau, 1935). However, few recent studies support the claim that western Ohio had prairies during the mid-Holocene. During the hypsithermal, prairies appeared throughout the Midwest, sometimes interfingered with forests (e.g. Wright, et al., 1963; Webb III and Bryson, 1971; Bernabo and Webb, 1977; Baker et al., 1992; Overpeck et al., 1992; Camill et al., 2003; Grimm et al., 2011; McLauchlan et al., 2013; Voelker et al., 2015). If prairie did appear in western Ohio, it would have occurred during the Holocene hypsithermal and would be present in a pollen record of the area.

It is not clear whether the prairie-forest boundary extended into western Ohio during the hypsithermal. The Prairie Peninsula covered an area from the Dakotas to Ohio, with the southern edge in Missouri and the northern boundary in southern Minnesota and Wisconsin. The location of the Midwestern prairie-forest boundary fluctuated during the hypsithermal (Wright et al., 1963; Wright et al., 2004). The timing and orientation of this boundary movement varied across North America (Wright et al., 2004; Camill et al., 2003). The hypsithermal was time-transgressive, occurring at different times across regions, or even varying between localized sites (Camill et al., 2003; Umbanhowar et al., 2006; Williams et al., 2009). Local moisture levels, vegetation, and the frequency and severity of fires played a role in the expression of the hypsithermal. This makes determining its exact boundary of the hypsithermal Prairie Peninsula challenging. There may not have been a single prairie expansion. Instead, prairie may have expanded at several different times in different parts of the Midwest during the mid-Holocene.

Recent studies lack evidence supporting the claim that Ohio prairies existed during the mid-Holocene. Mack and Boerner (2004) reported that the Daughmer Savannah, in Crawford County, Ohio was a remnant of the very eastern tip of the Prairie Peninsula. Mack and Boerner (2004) cited Transeau's 1935 study as the main resource on the Prairie Peninsula in Ohio. King (1981) compiled an overview of palynological studies in the Darby Plains area, near Columbus, OH. The record covered in King's study ends just after 11,000 years ago, but was compared to more complete pollen records from the Ohio and Great Lakes region. During the mid-Holocene hypsithermal, there is evidence in the pollen records that the climate became too warm and dry to support deciduous forests and prairie species dominated the plant communities (King, 1981). Kapp and Gooding (1964) analyzed the pollen record of a bog in Sunbeam Prairie, in Darke County, OH, in which the transition from coniferous to deciduous taxa occurred 11,700-10,600 BP, with undated core extending above this boundary. Sometime after 10,600 BP, there was an increase in larch, oak, and hickory pollen around the same time as an increase in nonarboreal pollen taxa, upwards of 30%, which has been attributed to the hypsithermal and an eastern extension of the Prairie Peninsula (Kapp and Gooding, 1964).

On the other hand, climate models indicate that mean temperatures did not vary greatly in western Ohio during the hypsithermal (Webb et al., 1993). During the hypsithermal, Ohio likely experienced between a 0.2° C and 0.35° C change in temperature (Schmidt et al., 2004; Bartlein et al., 2011). Due to the small change in temperature in the models, there was probably little change in vegetation in this region during the last 8,000 – 5,000 years. Without a large change in temperature and humidity, prairie may not have been able to move into western Ohio. Climate alone is not the only factor that can drive vegetation change. Other factors, such as human activity, may have allowed prairie to become established. Climate models rarely have a high resolution in small-scale areas, such as Ohio. Climate models cannot yet report exact climate conditions of Ohio during the mid-Holocene. Our understanding of the mid-Holocene is still reliant on pollen records and similar types of studies. The research into the possible prairies in Ohio is still limited and needs more studies to fill the holes in the literature.

Vegetation Reconstruction in Western Ohio

The focus of this study was the regional vegetation of western Ohio during the mid-Holocene warming. Specifically, the objective of this research was to determine whether western Ohio experienced a prairie period during the mid-Holocene. I reconstructed the Holocene vegetation history using the pollen record in Crystal Lake, in Clark County, OH. I chose Crystal Lake as an ideal location, as the lake appeared to have a continuous record throughout the Holocene, since its formation around 18,089 ± 320 cal BP. I used pollen as a proxy for past regional vegetation to describe regional climate at the time of deposition. The pollen analysis allowed me to determine what vegetation changes occurred in the western Ohio during the Holocene.

Based on previous scientific literature, my null hypothesis was that western Ohio did not experience a prairie period during the mid-Holocene. If so, there should be no change in pollen deposition during the mid-Holocene warming that indicates an increase in prairie pollen percentages. This suggests that western Ohio did not experience sufficient warming or drying during the hypsithermal to allow prairie to form. If there is a significant change in the pollen data, I offer two alternative hypotheses to explain it: 1) a large change in pollen taxa represents a scenario in which the vegetation changed rapidly during the mid-Holocene, or 2) a small change in pollen taxa or pollen deposition represents a slow response in vegetation to the hypsithermal warming.

II. METHODS

Study Site

Crystal Lake is located in Medway, Clark County, Ohio, and is 20.9 km from Wright State University's Dayton campus. Crystal Lake is a series of four interconnected kettle lakes; North Lake, South Lake, Hidden Lake, and Main Lake (Fig. 2). The four kettle lakes are manually connected via a draining system. Main Lake is seasonally fed by small streams to the north (Clemens, 2001). The entire Crystal Lake area is a total of 1.31 km^2 and the surface area of the lake is approximately 7.3 hectares (Woodruff, 1999).

Crystal Lake is one of the few naturally formed lakes in Ohio (Black, 1991; Bowell, 1980). Retreating glaciers carved out the kettle lakes during the Wisconsinan glaciation. Kettle lakes form when chunks of ice left behind by glaciers melt, without outwash, and are subsequently covered with glacial till (Fuller, 1914; Maizels, 1977). Crystal Lake is the one of the southernmost kettle lakes in Ohio (Woodruff, 1999). The lake formed naturally about 15,000 years ago, thus the sediment record potentially includes the entire Holocene and the late Pleistocene (T. Lowell, unpublished, 2008). The deepest drive of the sediment core revealed that the bottom of lake is made up of pebbles and cobbles, confirming the lake's glacial origin.

Crystal Lake, especially Main Lake, is shallow due to a carbonate shelf covering the bottom of the lake (Wisebaker, 2008) (Fig. 3). Due to the shallow water levels,

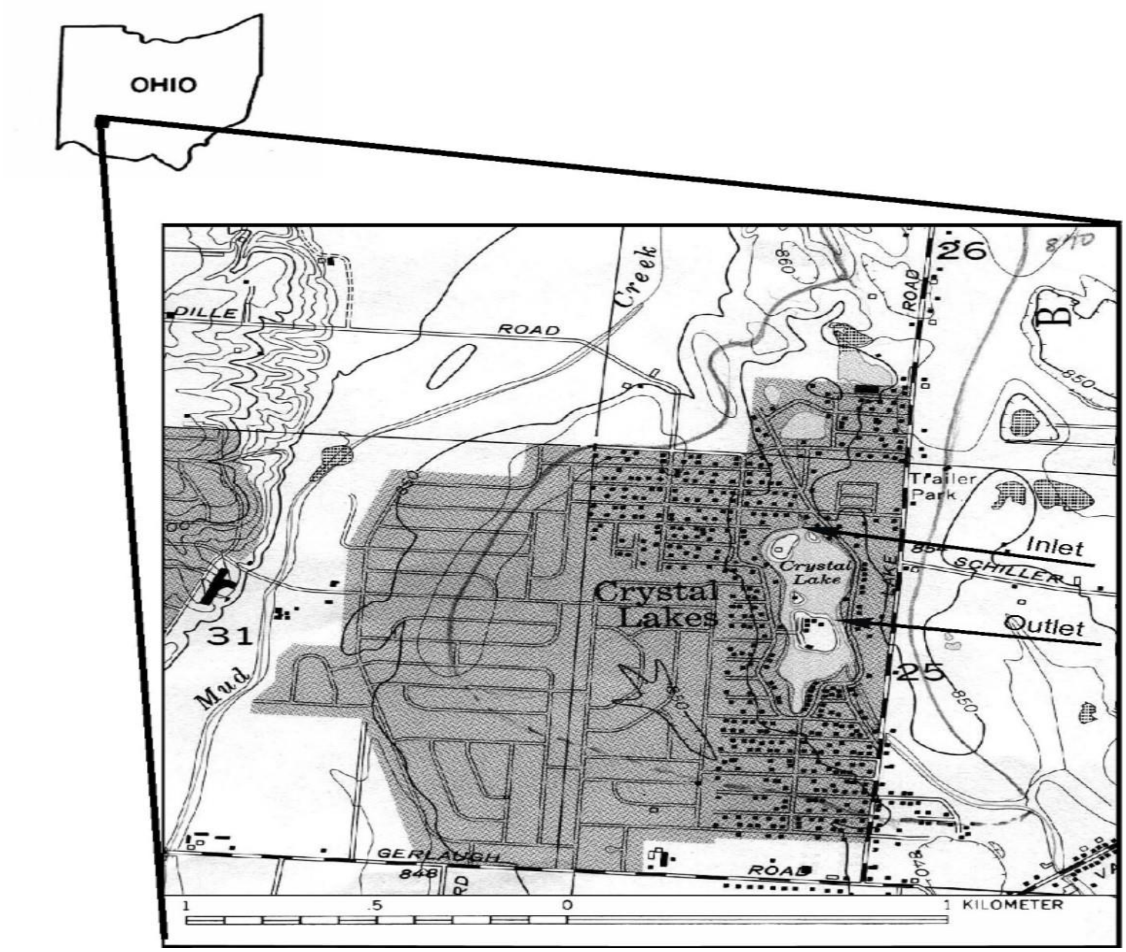

Figure 2: Crystal Lake is located in Medway, Clark County, Ohio (Figure from Teed et al., 2008). It is a series of four manually interconnected kettle lakes. Points of inlet and outlet for the lakes are pointed out above. The Crystal Lake CDP is 1.31 km^2 and of which 0.08 km^2 is water. The lake is surrounded residential structures and farmland.

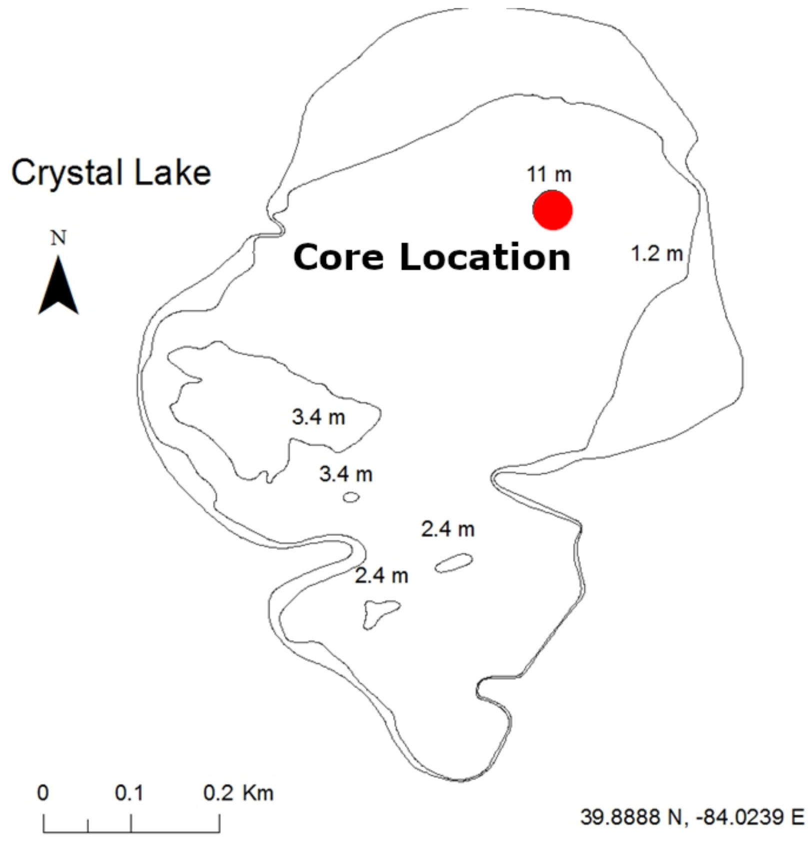

Figure 3: Bathymetric map of Crystal Lake. The lake is mostly shallow, except for the 11m deep point in the center of the lake. Main Lake (shown above) is the largest of the four kettle lakes and is used primarily for recreational purposes. The sediment core was collected in the deepest portion of the lake, marked above (39.88953 N 84.02336 W). (Modified from Agather, 2018).

aquatic plants like water lilies and cattails are common (Fig. 4). The lake is at its deepest (11.6 m) in the center of Main Lake (Wisebaker, 2008). Crystal Lake is a privately owned recreational area, used for swimming, fishing, and canoeing (Fig. 5). The Crystal Lake Property Owners Association maintains the lake area and granted permission to sample sediment from the lake. The watershed associated with Crystal Lake is used for both residential and agricultural practices, with residential buildings closely bordering the lake itself.

Sediment Collection

The collection of the core was a joint research project between the University of Cincinnati and Wright State University. Dr. Thomas Lowell and his students, from the University of Cincinnati worked with Dr. Songlin Cheng and Dr. Rebecca Teed from Wright State University. They collected the sediment core from Crystal Lake in 2007 with a Livingston-Wright piston corer, provided by the University of Cincinnati (Fig. 6–7); Wright et al., 1984). The sediment core is 8.4 m long, made up of 15 overlapping drives (Fig. 8–9). Dr. Rebecca Teed then split the core, wrapped each portion in aluminum foil and plastic film, and then placed the core in cold storage. Cold storage was kept at 42° F. Pollen results were collected 0.5 cm^3 subsamples taken 10-15 cm apart from the bottom of the sediment portion of the core at 1890 cm through to the sediment-water interface 1130 cm.

Sediment Preparation

Undergraduate student lab members sieved the sediment to isolate terrestrial plant materials, macrofossils, and large organic debris to use for radiocarbon dating. I chose to

Figure 4: During the spring and summer, shallow water plants and algae thrive in Crystal Lake.

Figure 5: The Crystal Lake Property Owners Association maintains the lake and the surrounding area. The majority of Main Lake is shallow and it used mainly for recreation activities such as swimming and fishing. The private beach is visible above.

Figure 6: Thomas Lowell from the University of Cincinnati, working with Songlin Chen and Rebecca Teed from Wright State University to prepare the piston corer. Students from the University of Cincinnati and Wright State University assist. Picture courtesy of Songlin Chen.

Figure 7: Each drive was wrapped in plastic wrap and aluminum foil in the field after collection. The drives are stored at Wright State University in cold storage at 42° C. Picture courtesy of Songlin Chen.

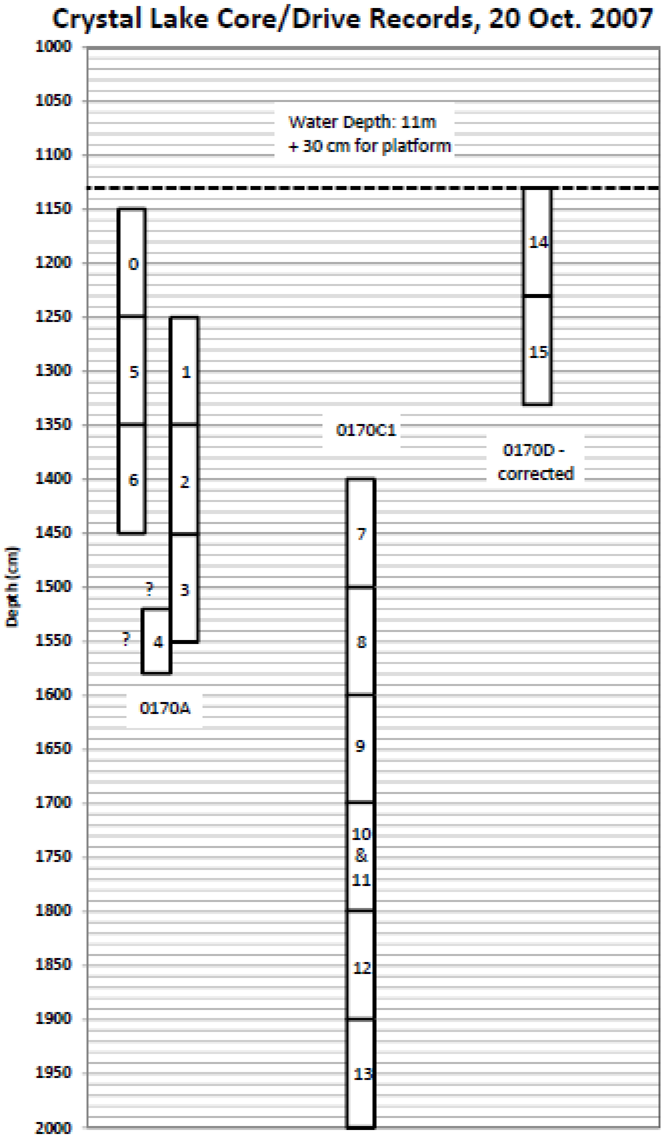

Figure 8: The core from Crystal Lake was collected on October 20, 2007. The water depth at the deepest point of the lake is 11 m. The coring platform was 30 cm above the water surface. The dotted line represents the sediment surface. Fifteen drives were taken from four separate locations, labeled by 0170A, 0170C1, and 0170D. Drives 3 and 4 of 0170A were not used.

Figure 9: The drive above is a portion of the sediment core collected from Crystal Lake. The entire core was 8.7 m long. None of the drives have any visual disconformities in the laminations.

date plant material rather than bulk sediment, as plant material provides a more accurate radiocarbon date (Faegri and Iversoen, 1989). I sent the samples to the DirectAMS Radiocarbon Dating Service. AMSDirect dated two macrofossil samples, from 1687-1688.5 cm and 1183-1185cm. Thomas Lowell also collected a radiocarbon sample from 1832.5 cm, which was dated by the radiocarbon dating AMS faculty at the Woods Hole Oceanographic Institution. Although it is ideal to have more samples, there is not sufficient time to sieve for more dateable samples in the time frame of this project.

LacCore at the University of Minnesota and Dr. Vaughn Bryan of Texas A&M University chemically prepared the sediment for pollen analysis. They followed standard pollen preparation procedures (Faegri and Iversoen, 1989). Chemical preparation of the pollen involves boiling the sediment in HCl, KOH, acetic acid, and HF to remove organic, humic, and mineral materials while leaving pollen grains behind. After chemical preparation, pollen grains are mixed into a mounting oil, either silicone oil or glycerol oil.

Slide Preparation and Analysis

I analyzed 62 pollen samples according to the standard pollen preparation, analysis, and pollen diagram protocol (Faegri and Iversoen, 1989). The pollen samples were spaced 10-15cm apart. I identified pollen at 400x magnification using standard light microscopy techniques. I made at least two evenly spaced traverses over the slide to reduce bias. Multiple traverses reduce human error from the analyst, but also correct for any clumping of pollen grains that could occur on the slides (Faegri and Iversoen, 1989). I counted and identified 500+ terrestrial grains per slide. To reduce the bias associated with pollen deposition, I counted a large number of pollen grains per sample (500+ grains); this is especially useful in woodland scenarios (Faegri and Iversoen, 1989;

Brown, 1999). Pollen can be distinguished to genus or family based on pollen grain morphology. Whenever possible, I identified each pollen grain to genus. I collected concentration data by counting spike particles. The concentrations of each taxa per slide were graphed against depth in a pollen diagram.

Pollen Diagrams

The pollen data are plotted as a pollen diagram, pollen percentages by taxon and depth in the core. I separated the diagram into different zones based on the zonation program psimpoll (Bennett, 1993-2009). Zones are a defined in terms of pollen assemblages of taxa and represents of a period of little change in pollen assemblage. 35 separate taxa were identified, and 15 of the terrestrial taxa are reported in the pollen diagram. The 15 taxa reported are fir, spruce, pine, birch, oak, ash, maple, beech, elm, walnut, alder, grass, sedge, and ragweed. These 15 taxa were chosen for the pollen diagram because these taxa exceeded 4% at one or more levels of the core. Pine species were not differentiated, and this is noted on the diagram. Sedge and grasses were only identified to family, while all other taxa were identified to genus. Both microspheres and *Lycopodium* were used as spikes in the pollen samples. Samples from CL-T7, CL-T8, CL-T9, and CL-T10 were spiked with 20,848 grains/mL of *Lycopodium*. Samples from CL-T11 and CL-T12 were spiked with 100,000 spheres/mL. Samples from CL-1, CL-T6, CL-T11, CL-T14, and CL-15 were spiked with 1.63×10^4 grains/mL of 22.6-micron spheres and 7.84×10^3 grain/mL of 45.5-micron spheres. Easily identifiable spikes are added to the pollen samples so that the concentration of the present pollen grains can be determined.

III. RESULTS

Vegetation History

The pollen diagram is separated into seven zones (Fig. 10). Each zone represents a section of the core with statistically or visually significant changes in the pollen taxa percentages as determined by psimpoll (Bennett, 1993-2009). The psimpoll program uses binary splitting by sum of squares to split the diagram into zones (Bennett, 1993-2009). Zone CL-1, CL-3, and CL-5 were added to the diagram in addition to the zones identified using the psimpoll program. Reported pollen percentages are percentages of the total pollen grains counted. The wind-pollinated taxa are represented more in this record than the insect-pollinated taxa. The coniferous and deciduous taxa in the pollen diagram are all wind-pollinated trees. Wind-pollinated taxa have higher percentages because wind-pollinating taxa produce more pollen than insect-pollinating taxa. Pollen from insect-pollinated trees, such as basswood or willows, did not occur above 5% at any time in the core. Due to the low percentages, insect-pollinated taxa do not appear in the diagram.

Zone CL-1: 1890 cm to 1875 cm

Zone CL-1 is characterized by spruce and pine. Pine pollen increased from 10% of terrestrial pollen at the base of the zone, peaked at 20% and returned to 10%. Spruce reached 60% and decreased to 30-40% when pine reached its maximum. Oak remained at a stable background level of 4% to 5%. Hickory appeared very briefly and reached 4% of the total. Fir, birch, and alder were below 5%. Ash, maple, beech, walnut, and elm were

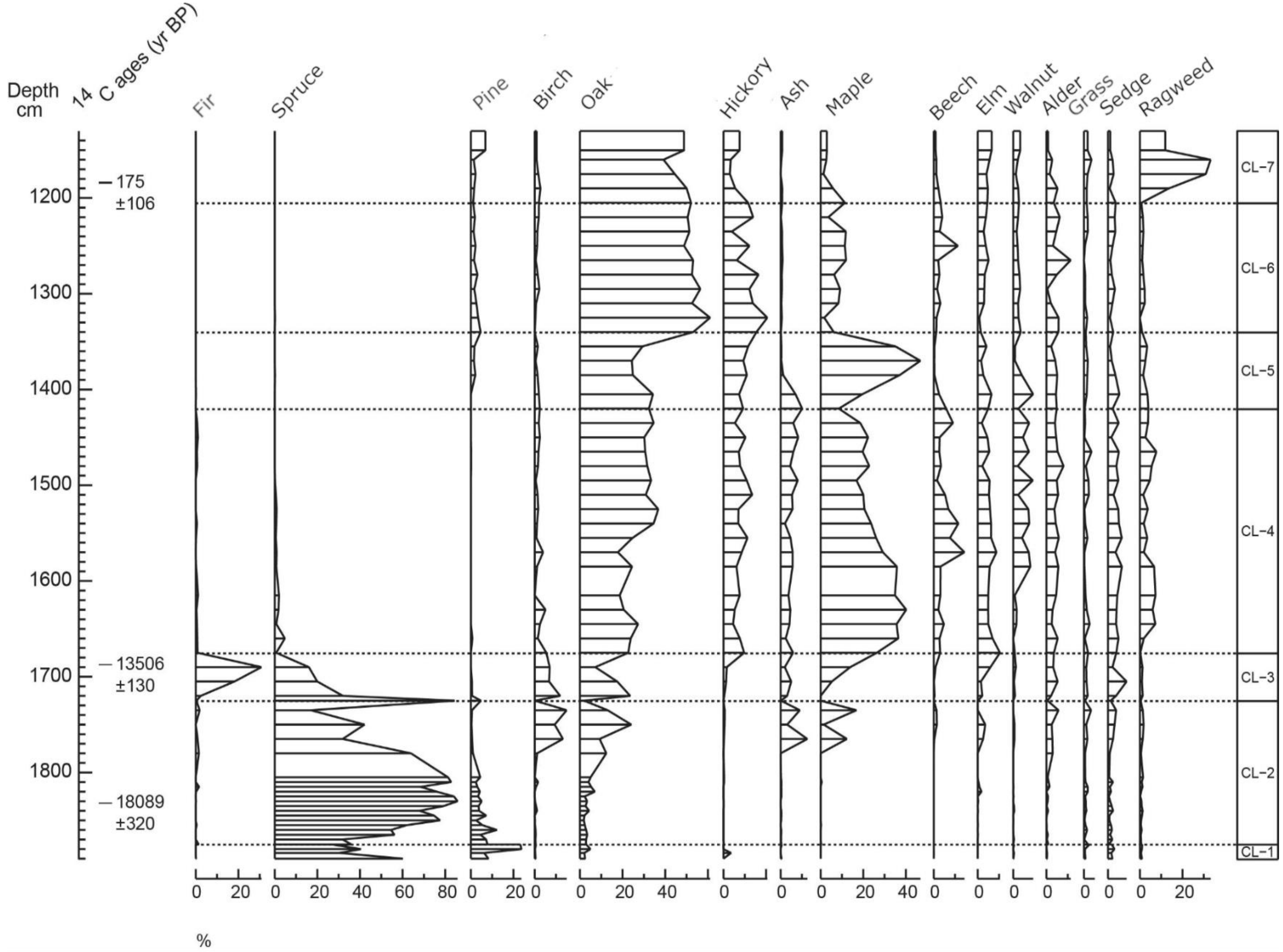

Figure 10: Pollen diagram from Crystal Lake, Medway, Ohio

not present in this zone. Grass and sedge had a low <5% background presence, and ragweed appeared in low levels (7%) throughout the zone.

Zone CL-2: 1870 cm to 1725 cm

In Zone CL-2, spruce remained the most common taxon. Spruce peaked around 85%. Following the peak, there was a rapid decrease in spruce until a sharp 84% peak. Pine slowly decreased from around 10% to below 5%. Fir was < 5%. Once pine disappeared, birch appeared and stayed around 10%. Oak slowly increased to 24%. Hickory remained around < 5%. Maple and ash appeared at the top of the zone at around 10% each. Alder appeared below 5%. Grass and sedge remained below 5%. No walnut grains were identified.

Zone CL-3: 1720 cm to 1675 cm

In Zone CL-3, fir reached a peak of 31%. Spruce and pine were < 5% at the level of the fir peak. Birch and oak fluctuated slightly, but remained at 7% and 17% respectively. Hickory increased to 10%. Ash fluctuated between 2% and 6%. Maple rapidly increased to 26% by the end of this zone. Beech and walnut appeared in background amounts of 1–3% and 1% respectively, along with grass (1–2%) and ragweed (1%). Alder remained below 5%. Sedge increased slightly, and reached 9%.

Zone CL-4: 1660 cm to 1420 cm

Oak replaced spruce and pine in Zone CL-4. Fir, spruce, and pine disappeared from the record. Oak was the most common pollen taxon (30–35%). Hickory remained around 10%. Ash slowly increased to 10%. Maple increased rapidly, peaked at 40% at 1630 cm, and steadily decreased to 10%. Beech peaked twice at 1570 cm (14%) and at

1540 cm (12%). Elm percentages (5–6%) remained constant. Walnut increased slowly, and then stayed at 8%. Alder was steady around 5%. Grass was still below 5%, but sedge hovered around 5%, and ragweed fluctuated between 2–7%.

Zone CL-5: 1405 cm to 1340 cm

Oak and maple were the most common taxa in Zone CL-5. Oak started around 30%, before it dipped slightly and then steadily rose to 53%. Maple reached a 47% peak at 1370 cm. Hickory increased slowly to 15%. Birch decreased to below 5%. Ash and beech disappeared. Elm decreased to 8%. Walnut peaked at 9% and then fell below 5%. Alder, grass, sedge, and ragweed were all around 5%.

Zone CL-6: 1325 cm to 1205 cm

In Zone CL-6, oak remained at 50%, except for the peak at 61% at 1325 cm. Hickory reached a peak of 21% and stabilized at 15% for the rest of the zone. Maple decreased sharply down to 2% before increasing to 10%. Pine, birch, ash, elm were all present at low background levels. Beech and alder spiked to 11% slightly before the oak and hickory peaks. Grass, sedge, and ragweed were all below 5%.

Zone CL-7: 1190 cm to 1130 cm

Ragweed increased to 33% in the middle of the zone and then leveled off to 12%. Oak remained common but decreased from 50% to 39%. Hickory rapidly declined to 5%. Maple continued to decline after the peak in Zone CL-6, and dipped below 5%. Pine returned and stayed at 5%. Birch (1–3%), ash (1%), walnut (1–3%), and alder (1–5%) remained at background levels. Beech steadily declined to levels below 5%. Grass and sedge were both below 5%.

Absolute Pollen Concentration

In Zone CL-2, pollen concentrations were higher and more variable than the other zones. The average absolute pollen concentration from 1805 cm to 1835 cm, was 3,252,000 grains/cm3. The concentration varied from the highest concentration of 3,252,000 grains/cm3 at 1830 cm to the lowest concentration of 179,000 grains/cm3 at 1870 cm. The increase in pollen concentration could have been due to a rapid increase in pollen deposition or an increase in the rate of sediment deposition.

Absolute pollen concentrations did not fluctuate considerably throughout the core above 1720 cm (Fig. 11). The average absolute pollen was 291,653 grains/cm3, with a standard deviation of 121,748 grains/cm3. The low variation in concentration indicates fairly constant sedimentation rates. Major differences in pollen percentages can be assumed to relate to changes in plant populations during the Holocene.

Radiocarbon Dates

Crystal Lake appeared to have an intact sediment record. I assumed the sediment record was intact because the sediment core recovered from the lake had no visible disconformities (Fig. 9).

We recovered macrofossils and charcoal remains from three levels in the core, 1183-1185 cm, 1687-1688.5 cm, and 1832.5 cm (Table 1). Dates are calibrated using CALPAL (Weninger et al., 2007). Radiocarbon dates are consistently too young because more ^{14}C was produced during the glacial period. ^{14}C dates are calibrated to correct for the variable amounts of ^{14}C produced in the past. Thomas Lowell and his team recovered charcoal from CL-T12 before this study began. The charcoal was dated to 14750 ± 80 ^{14}C

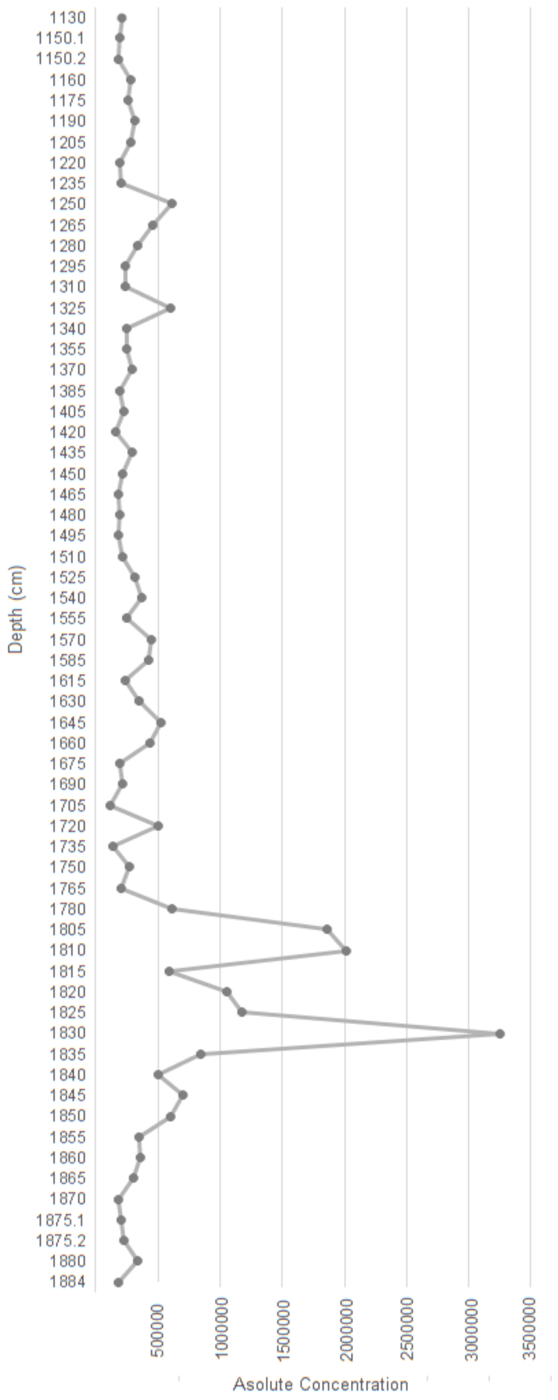

Figure 11: Absolute pollen concentration (grains/cm^3).

Table 1: The radiocarbon ages of the three macrofossils collected from the Crystal Lake core.

Zone	Core	Depth	Age (BP)	Cal. Age (cal BP)
CL-3	CL-T9	1687–1688.5	11619 ± 58	13506 ± 130
CL-2	CL-T12	1832.5	14750 ± 80	18089 ± 320
CL-7	CL-T14	1183–1185	192 ± 22	175 ± 106

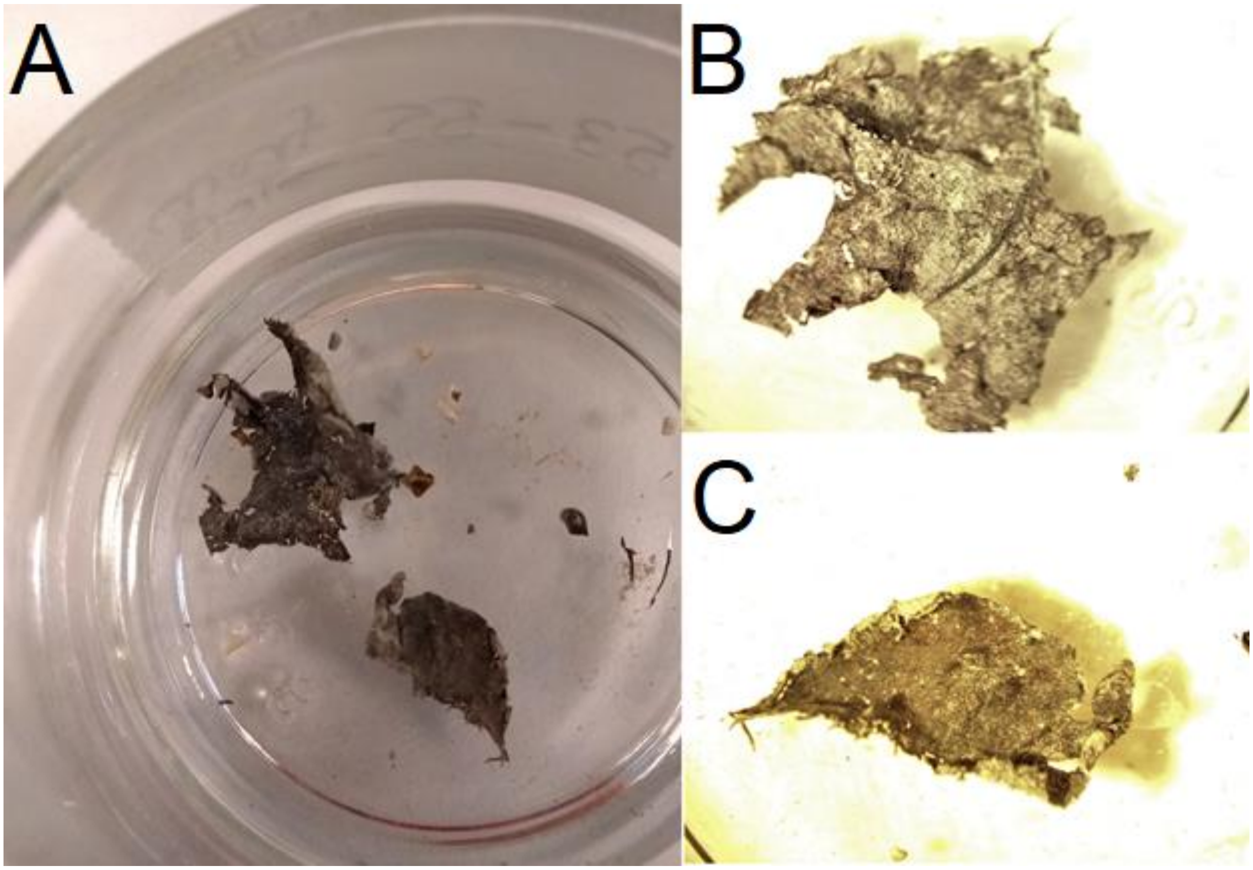

Figure 12: The maple leaf collected from 1183-1185 cm.

years BP with a calibrated age of 18089 ± 320 cal BP. From Drive T9, 1687–1688.5 cm, 0.10 g of charcoal was radiocarbon dated to 11619 ± 58 ^{14}C years BP. The calibrated age was 3506 ± 130 cal BP. A maple leaf was collected from 1183–1185 cm in Drive CL-T14. The age of the leaf was 192 ± 22 ^{14}C years BP and the calibrated age is 175 ± 106 cal BP (Fig. 12). Five to six radiocarbon dates across the core could be used to extrapolate the dates through the core-depth. If there is a disconformity in the record we need enough radiocarbon dates to detect it.

Detrended Correspondence Analysis

Due to the complex and multivariate nature of pollen data, detrended correspondence analysis (DCA) can be used to plot direction of variance and present trends in only two or three dimensions (Bennett and Hicks, 2005). DCA is appropriate because it corrects for the sequential nature of pollen data. Pollen data from a single record should be detrended because the data are not independent. I used the PSIMPOLL data analysis program to perform the DCA (Bennett, 1998-2009).

Using the species scores, I plotted Axis 1 against Axis 2 and then against Axis 3. I also plotted Axis 2 against Axis 3 (Fig. 13 A–C, Table 1). In Fig. 13A, there was a large contrast on the vertical axis between the very positive ash and the very negative ragweed eigenvalues. On the horizontal axis, most taxa loaded negatively except for pine and spruce. In Fig. 13B, most taxa were clumped near low negative values. Beech was very positive on both the horizontal and vertical axis and spruce was positive on the horizontal axis and negative on the vertical axis. In Fig. 13C, the taxa fall near the origin. On the horizontal axis, ash was very positive and ragweed was very negative. On the vertical axis, pine was very positive. The first three components accounted for 17%, 2%, and 0.5% of the total variance.

Based on the results, there was one main assemblage with only a few outliers. In Fig 13A and Fig. 13B, deciduous taxa were mostly slightly positive on Axis 1 and slightly negative on Axis 2. Spruce and pine, coniferous taxa, were the most positive on the horizontal axis on both Fig. 13A and Fig. 13B. The coniferous taxa remained separate from the deciduous taxa. Ragweed, a nonarboreal pollen type, was most the most negative on Axis 1 in Fig. 13A. Ragweed was positive on the vertical axis, but remained separate from the other taxa.

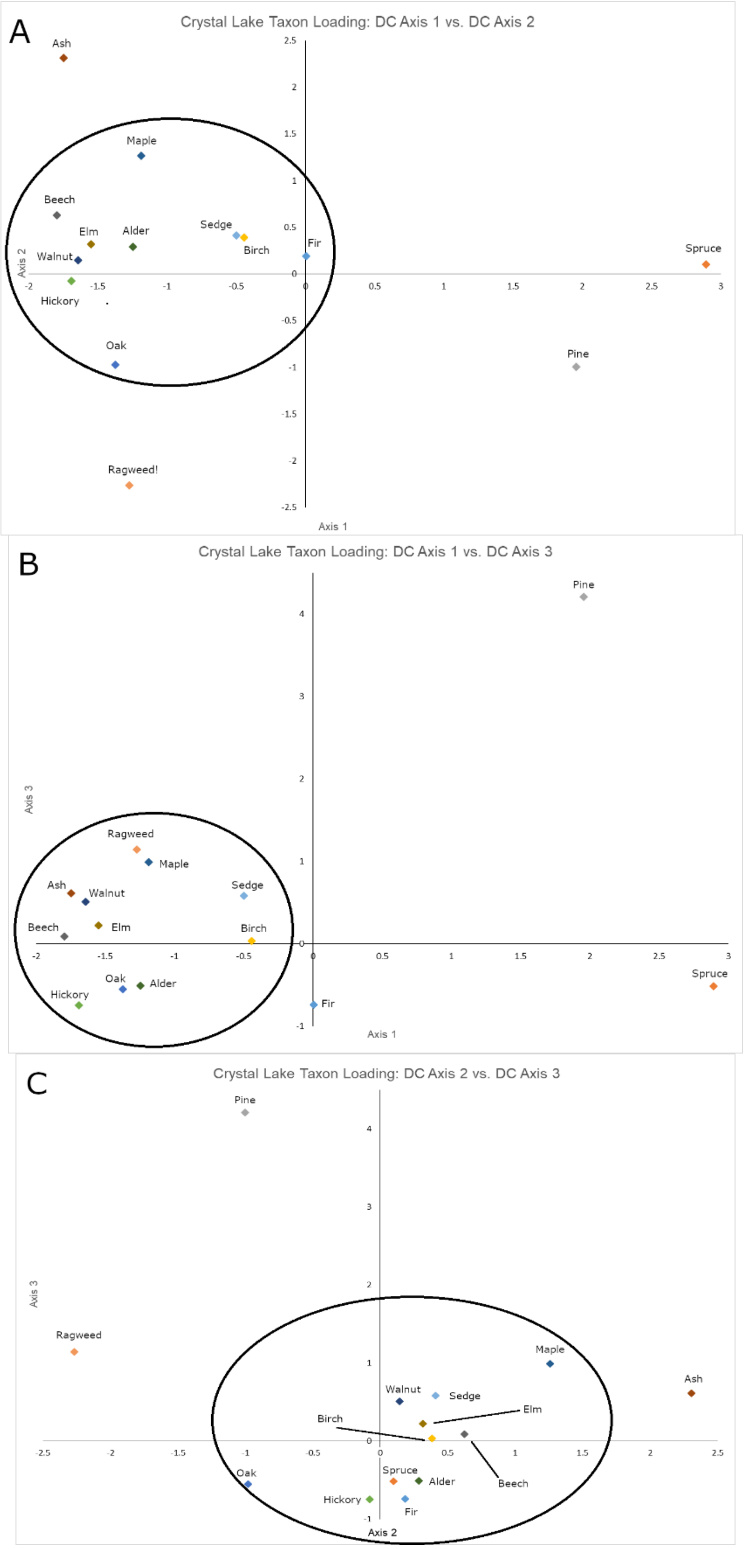

Figure 13: Crystal Lake taxon loading, showing trends in variance between taxa. The input data was the pollen deposition for each of the 14 taxa. Plotted values are Axis 1 vs. Axis 2 (A), Axis 1 vs. Axis 3 (B), and Axis 2 vs. Axis 3 (C).

Table 2: Results of the detrended correspondence analysis of 14 taxa from Crystal Lake, taken from the percentages of total pollen counted from each taxa.

Taxon	Axis 1	Axis 2	Axis 3	Axis 4
Fir	0.009002	0.187203	-0.74501	11.11702
Spruce	2.896306	0.100896	-0.517	-0.03121
Pine	1.959141	-0.99956	4.206145	0.494777
Birch	-0.44262	0.385999	0.029663	-1.56693
Oak	-1.37198	-0.97724	-0.55329	0.009933
Hickory	-1.68819	-0.07696	-0.74849	0.189272
Ash	-1.18251	1.261721	0.98515	-2.5237
Maple	-1.74374	2.307332	0.613012	0.799918
Beech	-1.79419	0.627693	0.086355	-2.90439
Elm	-1.54473	0.318133	0.218094	0.337045
Walnut	-1.63956	0.143554	0.507303	-0.72804
Alnus	-1.24511	0.288602	-0.51426	-0.04071
Sedge	-0.49664	0.412008	0.582271	-0.31693
Ragweed	-1.26925	-2.26563	1.140688	0.236185

IV. DISCUSSION

Crystal Lake appears to have recorded climate information since the late Pleistocene to the late Holocene (Fig. 10). Overall, coniferous taxa were present in high amounts at the base of the core and then decreased. As soon as coniferous taxa decreased, deciduous taxa became the most common taxa and remained a major part of the record. The resulting labeled zones in the pollen diagram represent the changing climate during the course of the Holocene in western Ohio. Zones Cl-1 – CL-3 are part of the cold late glacial period. The following four zones, CL-4 – CL-7 were all part of the Holocene. The mid-Holocene hypsithermal probably began at the base of Zone CL-6. At the top of the Zone CL-7, there was a peak in ragweed from land clearing in western Ohio when the first homesteaders moved into the region.

The Late Glacial Period: Zone CL-1, Zone CL-2, and Zone CL-3

Coniferous taxa, like spruce, pine, or fir, thrive in cool to cold environments, with the three having slightly different moisture thresholds. Coniferous taxa require low summer temperatures to remain prominent throughout the year. Coniferous taxa were present in Zone CL-1, Zone CL-2, and Zone CL-3. An environment suitable for spruce and pine is cold to cool and moist (Davis and Webb, 1975). Spruce was common during the late Pleistocene. This environment was similar to the modern boreal woodlands of Ontario or Newfoundland (Hare, 1950; Lamb, 1984). A modern forest tundra or open woodland scenario has a majority of spruce and 10–20% of the taxa present are nonarboreal (Davis and Webb, 1975). Based on the lack of nonarboreal pollen along with the spruce and pine peaks in this core, the area was likely not tundra in the late Pleistocene/early Holocene.

These three zones represent a cold to cool period with varying levels of moisture. The presence of pine means that the environment was slightly drier in Zone CL-1, because pine is more likely to survive in drier climates than spruce (Jacobson, 1979). Whereas, having fir present in Zone CL-3 indicates a very moist environment during this interval (Thompson et al., 2003). Not all fir species prefer especially moist environments, but balsam fir or noble fir are two examples of possible species present during this time. Zone CL-1 is characterized by the presence of spruce and pine, and very few other taxa. In Zone CL-1, pine peaked and declined before spruce began to decline. Other cores taken from Ohio do not share this trend. Typically, spruce will peak and decline, while pine persists before its decline at the transition of the Pleistocene and early Holocene. Although this zone was moist, it was not moist enough for fir to thrive. In Zone CL-2, the climate began to shift from a mainly spruce and pine environment to a mix of coniferous and deciduous taxa. Spruce remained high, but since pine and oak appeared concurrently, the environment was dryer and warmer (Berges et al., 2005). The middle of this zone was dated to 18,809 ± 320 cal BP, about 8,000 years before the Holocene began. At this time, the Crystal Lake area was still cool and moist. The pollen assemblage is similar to a modern boreal forest (Hare, 1950; Lamb, 1984). About halfway through the zone, coniferous taxa began to gradually transition to deciduous taxa. This shift in taxa was likely in response to the end of glaciation in the region and the warming that followed. In nearby Ohio pollen records, the glacial ice retreat typically caused a decrease in spruce and increase in ash (Shane, 1975). At Crystal Lake, as pine decreased, the remaining assemblage was mostly spruce with birch, oak, ash, and maple. This assemblage has no modern equivalent, as no modern climate can maintain this mix of coniferous and deciduous taxa (Shane, 1989, Gill et al., 2009). This implies that this no analog assemblage formed during a climatic period drastically different from any modern climate. Although pine percentages were low, a maximum in oak indicates that the environment is growing dry and warm as spruce declined at the top of Zone CL-2 (Davis and Webb, 1975).

Zone CL-3 recorded a reversal back to a cold and moist climate, as fir is the most common taxon. The deciduous taxa decreased when fir percentages increased. The fir assemblage likely represents an environment similar to the modern Maritime Provinces in Canada (Loucks, 1962). The fir peak, following the decline in other coniferous taxa, does not match the warming trend at the end of the Pleistocene. There was also a decline in deciduous taxa that thrive in a warmer and dryer environment. The rebound from warm-climate taxa back to cold-weather taxa may be in response to the Younger Dryas cooling. The Younger Dryas was a period of rapid cooling back to a glacial climate. The Younger Dryas occurred from 13,000 years ago to 11,700 years ago. Evidence for the Younger Dryas is most commonly found around the North Atlantic Ocean. Any indication of the oscillation in Ohio is unusual because records of the Younger Dryas are typically found in Europe and northeastern North America (Watts, 1980). The Younger Dryas was probably caused by meltwater runoff draining into the North Atlantic Ocean and reducing deep water formation in the ocean.

The timing is not exact, as the top of Zone CL-3 has been dated to 13,506 ± 130 cal BP. In Indiana, there is evidence for a resurgence in fir and spruce corresponding with the Younger Dryas 11,500 years ago (Shane, 1987). The Younger Dryas was cool, much like the glacial period and mainly affected the northern hemisphere. Time inconsistencies aside, the Younger Dryas oscillation was expressed as a decline in other coniferous taxa followed by a peak in fir in Silver Lake, OH (Gill et al., 2012). This was also observed in Illinois, where a peak in fir at 12,846–11,653 cal yr BP was attributed to the Younger Dryas (Gonzales and Grimm, 2009). There are spots in northeastern Ohio that have evidence for a cooling event from 11,000-10,000 years ago and 11,000-9,000 years ago (Shane, 1989). In north-central Ohio, a cooling event may have caused a peak in spruce and fir (Shane, 1987, 1989). Crystal Lake records a very similar pattern, although it is earlier than other sites in the Midwest. After the fir peak at the top of the zone, the climate continues its warming trend into the early Holocene.

The Early Holocene: Zone CL-4 and Zone CL-5

The transition to the early Holocene in the core occurred after 13,506 ± 130 cal BP. In Zone CL-4, deciduous taxa increased to over 88% of the main sum. Deciduous taxa, such as oak, maple, hickory, and beech prefer environments with moderate moisture availability and are found in warmer environments (Braun, 1950). This deciduous-trees assemblage indicates a modern warm and humid climate (Braun, 1950). Deciduous taxa can also exist under different precipitation regimes, but they all require warmer temperatures.

Zone CL-4 was likely warm and moist, supported by the presence of beech. Modern beech forests are found in south to eastern Texas and Northern Florida. Beech is specialized for warm growing seasons and abundant precipitation (Fang and Lechowicz, 2006). A peak in beech, followed by peaks in oak and hickory, indicates a decrease in moisture (Fang and Lechowicz, 2006). Beech peaked during Zone CL-4, and all but disappeared in Zone CL-5. The disappearance of beech means that the Crystal Lake area was moving towards a dry and warm climate. In Zone CL-5, maple is the most common taxon, but hickory and oak are also prevalent. When hickory and oak appeared together, this means the climate was warm and dry (Sander et al., 1983). The disappearance of beech and ash in Zone CL-5 indicates that the region was no longer moist (Fang and Lechowicz, 2006). Oak pollen percentages rose, pointing towards an increase in aridity and temperature (Abrams, 1990). The addition of background levels of pine indicates that this period was relatively dry. However, maple peaked in Zone CL-5, and maple typically grows in moist environments (Jarvi and Burton, 2013). The region was likely warm in Zone CL-4 and Zone CL-5.

The Mid-Holocene: Zone CL-6

The maximum percentages of oak and hickory, and the minimum of beech, represent the warmest and driest part of the Holocene, especially in northern Ohio (Sears, 1942b; Shane, 1975). Following the maple peak in Zone CL-5, there was a short-term peak in oak and hickory pollen at the base of Zone CL-6, concurrent with low percentages of beech and maple. The oak and hickory maximum probably represents the warmest and driest point of the mid-Holocene at Crystal Lake.

In northern Ohio, the hypsithermal occurred from 8,000-4,000 years ago (Shane, 1987). Sources in Minnesota have recorded maximum aridity occurring from 7,000-4,500 years ago (Camill et al., 2003). These dates fall within the range of the hypsithermal in the rest of the Midwest, which experienced prairie conditions as early as 11,000 years ago and until 7,000 years ago (Bernabo and Webb, 1977). The maximum geographic extent of the prairie occurred around 6,000 years ago (Williams, 2009). During the hypsithermal in northern Ohio, the majority of the pollen taxa were deciduous with moderately high levels of nonarboreal pollen (NAP), like sedge, grasses, or ragweed, in the Alleghany Plateau (Shane, 1987). Other Ohio locations have a similar transition from a deciduous assemblage with a beech maximum to an oak and hickory maximum with a beech minimum (Sears, 1942a; Shane 1987). The decrease in beech likely represents a transition from a moist and warm environment to a warm and dry environment (Fang and Lechowicz, 2006). Sears (1935, 1941) found that the hickory maximum is representative of the maximum dryness of the hypsithermal.

Zone CL-6 was probably deposited during the hypsithermal in western Ohio because of the peak in oak and hickory at the base of the zone. Prairie taxa are conspicuously absent from the record. In open oak savannah conditions, lower elevations and wetter conditions aid herbaceous undergrowth (Broderick et al., 2018). Therefore, in oak savannah systems, lowland regions have a high percentage of NAP. Many prairies can also grow in dry environments. However, prairie types do exist on a wet-dry continuum (Mack and Baerner, 2004). Certain prairie taxa can survive in open woods, woodland margins, and floodplain openings (Baker et al., 2002). The lack of high levels of NAP in the Crystal Lake area indicates that it was not entirely dry enough to support a prairie. It was also not moist enough for any prairie formation. In addition, there was no decrease in deciduous taxa. Instead, there was an increase in oak and hickory. Types of oak, especially bur oak, are specifically drought tolerant (Abrams, 1990). Rather than an increase in NAP, there is only an increase in oak and hickory pollen. The increase in NAP occurs at the very top of the core (175 ± 106 cal BP), which is probably associated with homesteaders and not prairie. I conclude that there was little or no prairie present in the Crystal Lake area. The small percentages of NAP in the record could have come from the long-distance transport of pollen from river banks or along the lake shore.

Although prairie was not evident in the Crystal Lake watershed, this does not mean the Prairie Peninsula did not extend into Ohio during the mid-Holocene hypsithermal. Rather, it is possible that prairies were localized. It is already well known that the prairie-forest boundary was regionally variable and not a stark line between forest and prairie (Transeau, 1935; Sears, 1935, 1941; Camill et al., 2003; Williams, 2009; Broderick et al., 2018). Prairies were typically found on flat uplands, shallow valleys, and upland knolls in Ohio throughout the Holocene because of local fire events (Transeau, 1935). Not all areas of Ohio were suitable for prairie growth without local fire events, or more recently, human agriculture. Climate changes, specifically affecting precipitation or seasonality, tend to have a bigger effect on local conditions than on national conditions (Umbanhower et al., 2006; Teed et al., 2008). Local areas already dry and barren would have become more suitable for prairie plant growth as the climate warmed during the mid-Holocene hypsithermal. This suggests that prairies were localized to dry and barren areas with frequent fires that were exacerbated by the warm and dry climate of the hypsithermal. The Prairie Peninsula could have still extended into Ohio, but it was likely not as widespread as previously suspected.

The Late Holocene and European Influences: Zone CL-7

Ragweed pollen percentages were highest at the top of the core (12-39%). Oak percentages remained high (39-52%), while NAP remained very low. Ragweed, paired with the upland grasses, typically indicates a previously barren environment (Weaver, 1968). Without other NAP, finding ragweed alone in such high quantities does not create a clear image of the past clime. However, ragweed is prevalent in regions where agriculture and land clearing are common. The rise of ragweed at the top of the core is likely indicative of a rise in plowing and grazing in the area (Wright et al., 2004; Cox and Moore, 2010; Grimm et al., 2011).

The top of the core culminated in an assemblage with oak as the most common taxon, with other minor deciduous taxa. This assemblage represents the return to a cool and moist environment (Davis and Webb, 1975). Increased ragweed, paired with a mixture of deciduous type taxa, is a common assemblage for all of Ohio during this part of the Holocene (Sears, 1942a, 1942b; Ogden III, 1966; Shane, 1975). Ogden III (1966) found that the Silver Lake record had an increase in ragweed, chenopod, and amaranth pollen around 1684 ± 191 cal AD. In western Ohio, there was a decrease in oak in after homesteaders removed almost all of this taxon in 1780 (Ogden III, 1966). Oak in the Crystal Lake area does not decline at the top of the core.

Rare Taxa

Pollen from aquatic taxa, like water lilies, cattails, or watermilfoil, was not abundant at any level in the core. Aquatic-plant pollen was rare, but not absent, from the Crystal Lake record. Low percentages of aquatic-plant pollen indicate deep water levels (Wright et al., 1963). However, this is unlikely to be true to Crystal Lake. In the modern lake, water lilies and other aquatic-plants are common near the shore (Fig. 4). Based on the shallow nature of the edges of lake, the aquatic taxa pollen was probably deposited onto the marl shelf and is not carried to the center of the lake.

Larch was not present in the core. Larch is a common taxon during the early and middle Holocene in assemblages from northeastern parts of Ohio (Sears, 1931; Wright et al., 1963; Baker et al., 2002; Gonzales and Grimm, 2009; Gill et al., 2009, 2012). Larch was found in the pollen records from both Silver Lake (Ogden, 1966; Gill et al. 2012) and Fudger Lake (Shane, 1989) and both lakes are located in western Ohio. Despite the presence of larch in both eastern and western Ohio pollen records, it was absent in the Crystal Lake core. Larch does not produce a lot of pollen, making it rare in lake deposits even if it is growing nearby the lake (Peñalba and Payette, 1997). Larch may have been present, but was not close enough to Crystal Lake to appear in the record.

Ohio Climate in the Future

The amount of climate change during the mid-Holocene is a possible analog to current climate change, although it is not a perfect analog (Clark et al., 2001). However, the mid-Holocene hypsithermal is the most recent warming period in Earth history. Since it is easier to study past climates that are closer in time to the present, we can gain important information from the mid-Holocene warming. While the impetus for modern climate change is the influx of anthropogenic greenhouse gas emissions (IPCC, 2014), the mid-Holocene hypsithermal was driven by the glacial-interglacial orbital cycles. Despite the different mechanisms, the changes to climate during the mid-Holocene could still have caused similar vegetation changes to what we can expect to see in the future.

During the mid-Holocene hypsithermal, average temperatures increased, summers lengthened, and precipitation decreased over the Midwest (Webb III and Bryson, 1971). The combination of changes in insolation, seasonal temperature, and precipitation was the driving cause of the warming (Overpeck et al., 1992). Estimates of temperature increases vary by location. The Midwest experienced a 0.5-2° C increase in temperature during the summer months and a 10-25% decrease in precipitation (Bartlein et al., 1984, Camill et al., 2003). The movement of the air mass controlled the timing of the appearance of prairies (Baker et al., 1992). Pacific air moved in during the summer months at the beginning of the warming and the times of maximum aridity occurred when tropical air moved over the Midwest (Webb III and Bryson, 1971; Yue al., 1997). These times of maximum aridity led to an increase in fire frequency, allowing for prairie growth to occur throughout the Midwest.

Modern climate change in the Midwest is likely to cause longer growing seasons, an increase in extreme weather events, and a change in forest compositions (Wuebbles and Hayhoe, 2004; Pryor et al., 2014). Of the 31 common tree species in southern Ohio, 15 are expected to decline (Iverson and Prasad, 1998). Temperatures are predicted to vary across the Midwest, as they did during the mid-Holocene (Bartlein et al., 1984; Hayhoe, 2010). Based on general circulation models (GCMs), specifically scenarios from the HadCM3 model, daily maximum temperatures are expected to increase from 2-9° C under current projections (Wuebbles and Hayhoe, 2004). The relatively coarse-scale atmosphere-ocean general circulation models (AOGCMs) have projected the near-term increase in temperature to be 1.4 ± 0.6° C and the mid-century increase to be between 2.0 ± 0.7° C and 3±1° C (Hayhoe, 2010).

There is evidence that the warming of the hypsithermal was too rapid for vegetation to migrate in response (Overpeck et al., 1992). Based on the Crystal Lake record, the climate change around Crystal Lake was likely too rapid for vegetation changes to occur. Climate-vegetation disequilibrium occurs in response to the rapid change (Prentice et al., 1991; Overpeck et al., 1992). Many studies have found evidence supporting the lag of vegetation behind climate change (Overpeck et al., 1992; Baker et al., 1992). Soil development, plant species migration, and the average lifespan of a species control climate-vegetation disequilibrium (Campbell and McAndrews, 1993). Not all studies support the disequilibrium model, instead some favor the dynamic equilibrium model that implies that vegetation changes and climatic changes occurred at the same pace (Prentice et al., 1991). Vulnerability of prairie-forest transitions to changes in aridity complicates the models of mid-Holocene change. The prairie-forest boundary was prone to rapid changes in response to increases in temperature and aridit, because prairies and woodlands have different sensitivities to changes in temperature and moisture (Clark et al., 2001).

The vegetation response to warming during the mid-Holocene is complicated, and that is reflected in studies of modern vegetation change. Campbell and McAndrews (1993), using the FORET-derived model, determined that modern forests in northern Michigan have still not reached equilibrium following the changes in the Holocene. They suggest that most forests are still intermediate mixed forests and could take centuries to reach equilibrium (Campbell and McAndrews, 1993). Another challenge for predicting forest changes is anthropogenic interference. Modern forest composition patterns have been controlled by human land use, which obscures the extent of climate change influences (Fuller et al., 1998). Rates of vegetation change have increased in forests around human activity, but have not returned to previous compositions before human interference (Fuller et al., 1998).

V. CONCLUSION

Based on the data collected in this study, western Ohio may not experience a large shift in regional forest composition. During the supposed height of the mid-Holocene hypsithermal, there was only a minor peak in both oak and hickory pollen. The abundance of oak and hickory decreased slightly after the hypsithermal, but both have remained the two most common taxa in the Crystal Lake record. In the Crystal Lake pollen record, there is no abrupt transition from forest to prairie taxa during the mid-Holocene. Nonarboreal taxa, like ragweed, sedge, and grasses never exceed 10%. Based on the lack of prairie in the area, Crystal Lake was not as sensitive to climate change as areas that did experience a prairie period, like Indiana and eastern Minnesota. Given the stability of the deciduous assemblages, western Ohio may not experience massive shift in forest composition changes in the future. Under the current climate model projections that predict, at most, a 3° C increase, there is not likely to be a massive decrease of forest in response. Current residents should not expect a drastic change in regional forest composition in the Crystal Lake area as the average temperatures increase. Beyond the 3° C threshold of the mid-Holocene hypsithermal, along with the fast rate of present climate change, it is hard to say if the region will experience a more severe change.

APPENDIX

Table A1: The absolute concentration of pollen grains of each layer.

Zone	Depth (cm)	Abs. Conc.	Zone	Depth (cm)	Abs. Conc. (grains/cm^3)
CL-T14	1130-1145	216294.4	CL-T9	1615	242670.7
CL-T14	1150.1	196499.6	CL-T9	1630	347536.2
CL-T14	1150.2	185636.6	CL-T9	1645	520157.6
CL-T14	1160	283162.2	CL-T9	1660	437808
CL-T14	1175	261194.8	CL-T9	1675	193052.5
CL-T14	1190	311888.8	CL-T9	1690	219321
CL-T14	1205	277127.2	CL-T10	1705	119250.6
CL-T14	1220	197948	CL-T11	1720	505000
CL-T15	1235	200844.8	CL-T11	1735	141943.2
CL-T15	1250	613397.4	CL-T11	1750	273989
CL-T15	1265	454314.8	CL-T11	1765	207604
CL-T15	1280	341581	CL-T11	1780	613000
CL-T15	1295	238020.4	CL-T11	1805	1866000
CL-T15	1310	233916.6	CL-T12	1810	2019000
CL-T15	1325	602293	CL-T12	1815	592000
CL-T1	1340	253952.8	CL-T12	1820	1055000
CL-T6	1355	248159.2	CL-T12	1825	1176000
CL-T6	1370	292094	CL-T12	1830	3252000
CL-T6	1385	197223.8	CL-T12	1835	841000
CL-T7	1405	232246.7	CL-T12	1840	501000
CL-T7	1420	158027.8	CL-T12	1845	702000
CL-T7	1435	294999.2	CL-T12	1850	598000
CL-T7	1450	212232.6	CL-T12	1855	352000
CL-T7	1465	182211.5	CL-T12	1860	357000
CL-T7	1480	197847.5	CL-T12	1865	304000
CL-T7	1495	178875.8	CL-T12	1870	179000
CL-T8	1510	221405.8	CL-T12	1875.1	204000
CL-T8	1525	310426.7	CL-T12	1875.2	225000
CL-T8	1540	365882.4	CL-T12	1880	341000
CL-T8	1555	246423.4	CL-T12	1884	178000

Table A2: Total pollen counts for each taxa, separated by zone, depth, and core-drive.

Zone	CL-7	CL-7	CL-7	CL-7	CL-7	CL-7
Depth (cm)	1130-1145	1150.1	1150.2	1160	1175	1190
Core-Drive	CL-T14	CL-T14	CL-T14	CL-T14	CL-T14	CL-T14
Larix	0	0	0	0	0	0
Abies	0	0	0	0	0	0
Picea	0	0	0	0	0	0
Pinus undiff.	44	28	41	12	18	10
Betula	6	5	8	8	14	17
Populus	0	0	1	0	0	0
Quercus	315	270	241	345	366	317
Carya	49	88	94	30	25	35
Fraxinus	5	4	2	3	0	5
Acer	19	35	35	24	11	37
Fagus	6	13	10	11	10	14
Tilia	0	0	0	0	0	0
Ostrya/Carpinus	0	0	0	0	0	0
Ulmus	42	32	44	49	34	30
Juglans	21	32	34	19	10	15
Corylus	0	0	0	0	0	0
Platanus	0	0	0	0	0	0
Juniperus	0	0	0	0	0	0
Alnus	5	12	10	24	13	33
Cephalanthus	0	0	0	0	0	0
Salix	0	0	0	1	0	0
Tsuga	0	0	0	0	0	0
Poaceae	0	25	15	31	14	8
Cyperaceae	11	11	10	19	22	5
Ambrosia	7	8	9	292	254	86
Artemisia	77	1	0	0	1	0
Chenopodiineae	1	0	0	0	0	0
Ast. Tub.	0	0	0	0	0	0
Pteridium	0	0	0	0	0	0
Filicales	0	0	0	0	0	0
Lycopodium	4	4	3	3	0	0
Indeterminate	0	0	4	4	0	0
Nuphar	0	0	0	0	0	0
Typha lat./ang.	0	0	0	0	9	0
Myriophyllum	0	0	0	0	0	0
Spike	72	70	75	75	76	49
Main Sum	645	570	577	880	822	633
Grain/sphere	8.96	8.14	7.69	11.73	10.82	12.92
Abs. Conc.	216294	196500	185637	283162	261195	311889

Zone	CL-6	CL-6	CL-6	CL-6	CL-6	CL-6
Depth (cm)	1205	1220	1235	1250	1265	1280
Core-Drive	CL-T14	CL-T14	CL-T15	CL-T15	CL-T15	CL-T15
Larix	0	0	0	0	0	0
Abies	0	0	0	0	0	0
Picea	0	0	0	0	0	0
Pinus undiff.	6	11	8	15	8	17
Betula	11	11	8	8	3	8
Populus	0	0	2	0	0	0
Quercus	287	290	312	335	280	290
Carya	64	80	24	84	33	91
Fraxinus	4	1	4	5	5	3
Acer	63	21	72	78	63	35
Fagus	18	23	17	78	11	15
Tilia	1	1	2	0	2	0
Ostrya/Carpinus	1	0	0	0	0	0
Ulmus	25	22	17	26	27	18
Juglans	15	13	10	14	12	16
Corylus	0	0	0	0	0	0
Platanus	0	0	0	0	0	0
Juniperus	0	0	0	0	0	0
Alnus	19	36	28	21	60	27
Cephalanthus	0	0	0	0	0	0
Salix	0	0	1	0	0	0
Tsuga	0	0	0	0	0	0
Poaceae	7	10	11	3	0	3
Cyperaceae	20	18	21	15	6	10
Ambrosia	4	8	10	9	6	9
Artemisia	0	0	0	0	1	0
Chenopodiineae	0	0	0	0	0	0
Ast. Tub.	0	0	0	0	0	0
Pteridium	0	0	0	0	0	0
Filicales	0	0	0	0	0	0
Lycopodium	0	0	0	0	0	0
Indeterminate	0	0	30	0	0	0
Nuphar	0	0	0	0	0	0
Typha lat./ang.	5	0	0	0	0	0
Myriophyllum	0	0	0	0	0	0
Spike	48	70	73	27	28	39
Main Sum	551	574	607	686	527	552
Grain/sphere	11.48	8.2	8.32	25.41	18.82	14.15
Abs. Conc.	277127	197948	200845	613397	454315	341581

Zone	CL-6	CL-6	CL-6	CL-5	CL-5	CL-5
Depth (cm)	1295	1310	1325	1340	1355	1370
Core-Drive	CL-T15	CL-T15	CL-T15	CL-T1	CL-T6	CL-T6
Larix	0	0	0	0	0	0
Abies	0	0	0	0	0	0
Picea	0	0	1	0	0	0
Pinus undiff.	11	15	18	26	10	9
Betula	15	4	2	0	9	3
Populus	1	0	0	0	0	0
Quercus	384	301	320	302	172	150
Carya	83	79	108	88	68	58
Fraxinus	4	2	3	1	2	2
Acer	62	48	9	35	206	289
Fagus	11	18	7	7	2	2
Tilia	1	0	1	0	2	0
Ostrya/Carpinus	0	2	0	0	0	0
Ulmus	21	17	4	8	24	10
Juglans	22	13	13	20	5	5
Corylus	0	0	0	0	0	0
Platanus	0	0	0	0	0	0
Juniperus	0	0	0	0	0	0
Alnus	3	12	30	32	13	26
Cephalanthus	0	0	0	0	0	0
Salix	0	0	0	0	0	0
Tsuga	0	0	0	0	0	0
Poaceae	4	3	8	5	6	11
Cyperaceae	22	12	5	14	6	11
Ambrosia	15	13	0	6	20	16
Artemisia	0	1	0	0	1	1
Chenopodiineae	0	0	0	0	0	0
Ast. Tub.	0	0	0	0	0	0
Pteridium	0	0	0	0	0	0
Filicales	0	0	0	0	0	0
Lycopodium	0	1	0	0	0	0
Indeterminate	0	0	0	1	0	0
Nuphar	0	0	0	0	0	0
Typha lat./ang.	0	0	0	0	0	0
Myriophyllum	0	0	0	0	0	0
Spike	69	59	21	54	57	51
Main Sum	680	572	524	568	586	617
Grain/sphere	9.86	9.69	24.95	10.52	10.28	12.1
Abs. Conc.	238020	233917	602293	253953	248159	292094

Zone	CL-5	CL-5	CL-4	CL-4	CL-4	CL-4
Depth (cm)	1385	1405	1420	1435	1450	1465
Core-Drive	CL-T6	CL-T7	CL-T7	CL-T7	CL-T7	CL-T7
Larix	0	1	0	0	0	0
Abies	0	0	0	0	6	3
Picea	1	0	0	0	0	0
Pinus undiff.	12	11	0	17	0	1
Betula	8	0	14	8	14	10
Populus	0	191	2	0	1	2
Quercus	142	41	189	290	172	174
Carya	63	39	54	91	59	41
Fraxinus	7	109	59	3	47	34
Acer	212	14	50	35	127	112
Fagus	2	6	34	15	16	15
Tilia	0	13	5	0	3	1
Ostrya/Carpinus	0	36	20	0	2	4
Ulmus	15	52	29	18	26	31
Juglans	23	0	14	16	26	42
Corylus	0	0	0	0	0	0
Platanus	0	0	0	0	0	0
Juniperus	0	25	0	0	0	0
Alnus	29	0	28	27	26	30
Cephalanthus	0	1	0	0	0	0
Salix	0	1	6	0	0	0
Tsuga	0	0	0	0	0	0
Poaceae	9	7	2	3	1	20
Cyperaceae	20	30	13	10	9	29
Ambrosia	9	20	23	9	15	44
Artemisia	1	1	0	0	0	1
Chenopodiineae	0	0	0	0	0	0
Ast. Tub.	0	0	0	0	0	0
Pteridium	0	0	0	0	0	0
Filicales	0	0	0	0	0	0
Lycopodium	1	0	0	0	0	0
Indeterminate	0	0	0	0	0	0
Nuphar	0	0	0	0	0	0
Typha lat./ang.	0	1	0	0	0	0
Myriophyllum	0	0	0	0	0	0
Spike	70	50	77	39	56	65
Main Sum	572	557	584	552	570	568
Grain/sphere	8.17	11.14	7.58	14.15	10.18	8.74
Abs. Conc.	197224	232247	158028	294999	212233	182212

Zone	CL-4	CL-4	CL-4	CL-4	CL-4	CL-4
Depth (cm)	1480	1495	1510	1525	1540	1555
Core-Drive	CL-T7	CL-T7	CL-T8	CL-T8	CL-T8	CL-T8
Larix	0	0	0	0	0	0
Abies	4	0	0	0	3	1
Picea	0	1	3	5	4	3
Pinus undiff.	1	0	0	0	0	0
Betula	9	3	8	9	6	5
Populus	1	1	0	0	0	0
Quercus	177	192	174	197	188	149
Carya	44	63	76	38	38	68
Fraxinus	25	46	30	30	11	28
Acer	128	97	113	110	129	157
Fagus	19	9	30	37	63	46
Tilia	0	1	1	1	1	1
Ostrya/Carpinus	5	8	4	2	2	0
Ulmus	12	32	30	31	34	38
Juglans	12	53	13	38	41	25
Corylus	0	0	0	0	0	0
Platanus	0	0	0	0	0	0
Juniperus	0	0	0	0	0	0
Alnus	45	28	31	20	24	35
Cephalanthus	0	0	0	0	0	0
Salix	3	0	0	0	0	0
Tsuga	0	0	0	0	0	0
Poaceae	5	12	13	1	3	10
Cyperaceae	22	28	15	26	28	39
Ambrosia	31	27	9	20	10	21
Artemisia	0	0	1	0	0	0
Chenopodiineae	0	0	0	0	0	0
Ast. Tub.	0	0	0	0	0	0
Pteridium	0	0	0	0	0	0
Filicales	0	0	0	0	0	0
Lycopodium	0	0	0	0	0	0
Indeterminate	0	0	0	0	0	0
Nuphar	0	0	0	0	0	0
Typha lat./ang.	0	0	0	0	0	0
Myriophyllum	0	0	0	0	0	0
Spike	59	67	53	36	31	51
Main Sum	560	575	563	536	544	603
Grain/sphere	9.49	8.58	10.62	14.89	17.55	11.82
Abs. Conc.	197848	178876	221406	310427	365882	246423

Zone	CL-4	CL-4	CL-4	CL-4	CL-4	CL-4
Depth (cm)	1570	1585	1615	1630	1645	1660
Core-Drive	CL-T8	CL-T8	CL-T9	CL-T9	CL-T9	CL-T9
Larix	0	0	0	0	0	0
Abies	0	1	6	2	3	4
Picea	5	4	11	10	4	26
Pinus undiff.	0	0	0	0	0	4
Betula	21	6	0	28	13	8
Populus	0	0	16	0	0	0
Quercus	95	131	102	113	143	130
Carya	46	33	42	29	24	42
Fraxinus	30	30	20	25	22	13
Acer	156	192	191	221	187	199
Fagus	77	17	17	12	25	15
Tilia	0	0	0	0	0	0
Ostrya/Carpinus	0	0	3	1	5	0
Ulmus	47	30	27	27	26	38
Juglans	39	43	4	9	8	0
Corylus	0	0	0	0	0	0
Platanus	0	0	0	0	0	0
Juniperus	0	0	0	0	0	0
Alnus	22	30	25	16	13	29
Cephalanthus	0	0	0	0	0	0
Salix	0	0	2	0	0	0
Tsuga	0	0	0	0	0	0
Poaceae	1	1	4	7	14	2
Cyperaceae	19	35	24	22	20	27
Ambrosia	10	36	40	33	38	10
Artemisia	0	0	0	0	0	2
Chenopodiineae	0	0	0	0	0	0
Ast. Tub.	0	0	0	0	0	0
Pteridium	0	0	0	0	0	0
Filicales	0	0	0	0	0	0
Lycopodium	0	0	0	0	0	0
Indeterminate	0	0	0	0	0	0
Nuphar	0	0	0	0	0	0
Typha lat./ang.	0	0	0	0	0	0
Myriophyllum	0	0	0	0	0	0
Spike	25	26	47	33	21	26
Main Sum	534	536	547	550	524	546
Grain/sphere	21.36	20.62	11.64	16.67	24.95	21
Abs. Conc.	445313	429886	242671	347536	520158	437808

Zone	CL-3	CL-3	CL-3	CL-3	CL-2	CL-2
Depth (cm)	1675	1690	1705	1720	1725	1735
Core-Drive	CL-T9	CL-T9	CL-T10	CL-T11	CL-T11	CL-T11
Larix	0	0	0	0	1	0
Abies	5	175	110	16	2	11
Picea	4	91	121	220	465	102
Pinus undiff.	0	0	3	4	26	3
Betula	31	40	41	82	1	90
Populus	0	3	0	0	0	0
Quercus	128	41	106	162	11	78
Carya	55	9	8	3	0	4
Fraxinus	33	11	30	21	1	54
Acer	149	79	32	0	0	101
Fagus	17	5	1	3	0	8
Tilia	0	0	0	0	0	3
Ostrya/Carpinus	2	1	1	0	0	0
Ulmus	59	34	9	15	0	0
Juglans	4	7	2	6	0	0
Corylus	0	0	0	0	0	0
Platanus	0	0	0	0	0	0
Juniperus	0	0	0	0	0	0
Alnus	20	18	32	15	3	34
Cephalanthus	0	0	0	0	0	0
Salix	0	0	2	0	2	3
Tsuga	0	0	0	0	0	0
Poaceae	11	6	7	12	3	20
Cyperaceae	22	12	53	26	7	23
Ambrosia	1	7	6	9	2	8
Artemisia	0	0	0	1	5	2
Chenopodiineae	0	0	0	0	0	0
Ast. Tub.	0	0	0	0	0	0
Pteridium	0	0	0	0	0	0
Filicales	0	0	0	0	0	0
Lycopodium	0	0	0	0	0	0
Indeterminate	0	0	0	0	0	0
Nuphar	0	0	0	0	0	0
Typha lat./ang.	0	0	0	0	0	0
Myriophyllum	0	0	0	0	0	0
Spike	61	54	106	136	34	102
Main Sum	565	568	606	687	551	600
Grain/sphere	9.26	10.52	5.72	5.05	16.21	5.88
Abs. Conc.	193052	219321	119251	505000	n/a	141943

Zone	CL-2	CL-2	CL-2	CL-2	CL-2	CL-2
Depth (cm)	1750	1765	1810	1815	1780	1805
Core-Drive	CL-T11	CL-T11	CL-T12	CL-T12	CL-T11	CL-T12
Larix	0	0	0	0	0	2
Abies	0	6	0	10	9	0
Picea	287	214	451	430	388	440
Pinus undiff.	2	4	13	19	6	24
Betula	64	89	9	4	7	0
Populus	3	0	0	0	0	1
Quercus	164	62	22	33	75	27
Carya	4	2	2	0	0	2
Fraxinus	21	84	2	2	0	1
Acer	10	83	3	0	0	0
Fagus	10	2	0	0	0	0
Tilia	0	1	0	0	0	0
Ostrya/Carpinus	1	0	0	0	1	1
Ulmus	24	17	2	5	0	0
Juglans	4	4	0	1	0	0
Corylus	0	0	0	0	0	0
Platanus	0	0	0	0	0	0
Juniperus	0	19	0	0	0	0
Alnus	17	0	6	9	18	3
Cephalanthus	0	0	0	0	0	0
Salix	0	0	0	0	1	0
Tsuga	0	0	0	0	0	0
Poaceae	7	11	4	11	3	3
Cyperaceae	21	16	13	6	5	3
Ambrosia	12	9	5	8	3	8
Artemisia	2	1	2	2	0	3
Chenopodiineae	0	0	0	0	0	0
Ast. Tub.	0	0	0	0	0	0
Pteridium	0	0	0	0	0	0
Filicales	0	0	0	0	0	0
Lycopodium	0	0	1	0	0	0
Indeterminate	0	0	0	0	1	0
Nuphar	0	0	0	0	0	0
Typha lat./ang.	0	0	0	0	1	0
Myriophyllum	0	0	0	0	0	0
Spike	60	78	27	106	99	29
Main Sum	681	671	545	628	607	541
Grain/sphere	11.35	8.6	20.19	5.92	6.13	18.66
Abs. Conc.	273989	207604	2019000	592000	613000	1866000

Zone	CL-2	CL-2	CL-2	CL-2	CL-2	CL-2
Depth (cm)	1820	1825	1830	1835	1840	1845
Core-Drive	CL-T12	CL-T12	CL-T12	CL-T12	CL-T12	CL-T12
Larix	0	0	1	0	0	0
Abies	1	0	1	0	0	0
Picea	425	455	586	460	425	436
Pinus undiff.	24	18	35	21	24	42
Betula	0	0	1	4	7	0
Populus	0	0	0	3	0	0
Quercus	39	12	23	15	27	12
Carya	0	0	1	1	0	0
Fraxinus	2	2	0	0	2	2
Acer	0	0	0	0	0	0
Fagus	0	0	0	0	0	0
Tilia	0	0	1	0	1	1
Ostrya/Carpinus	0	0	0	0	0	0
Ulmus	10	0	2	0	1	0
Juglans	0	1	0	2	3	0
Corylus	0	0	0	0	0	0
Platanus	0	0	0	0	0	0
Juniperus	1	0	1	0	0	0
Alnus	0	4	4	1	5	1
Cephalanthus	0	0	0	0	0	0
Salix	0	0	0	2	0	0
Tsuga	0	0	0	0	0	0
Poaceae	10	3	6	5	7	3
Cyperaceae	8	2	7	10	15	4
Ambrosia	3	1	5	5	8	6
Artemisia	1	2	1	1	1	0
Chenopodiineae	0	0	0	0	0	0
Ast. Tub.	0	0	0	0	0	0
Pteridium	0	0	0	0	0	0
Filicales	0	0	0	0	0	0
Lycopodium	0	0	0	0	0	0
Indeterminate	0	1	0	0	0	0
Nuphar	0	0	0	0	0	0
Typha lat./ang.	0	0	0	0	0	0
Myriophyllum	0	0	0	0	0	0
Spike	53	46	21	69	125	83
Main Sum	559	541	683	580	626	583
Grain/sphere	10.55	11.76	32.52	8.41	5.01	7.02
Abs. Conc.	1055000	1176000	3252000	841000	501000	702000

Zone	CL-2	CL-2	CL-2	CL-2	CL-2	CL-1
Depth (cm)	1850	1855	1860	1865	1870	1875.1
Core-Drive	CL-T12	CL-T12	CL-T12	CL-T12	CL-T12	CL-T12
Larix	0	0	0	6	1	1
Abies	0	3	0	0	0	14
Picea	557	436	380	424	369	364
Pinus undiff.	18	38	85	34	83	79
Betula	1	1	3	4	4	5
Populus	1	1	0	0	0	0
Quercus	13	16	20	26	33	28
Carya	0	0	0	0	0	2
Fraxinus	2	0	2	2	3	3
Acer	0	2	0	0	0	3
Fagus	0	0	0	0	0	0
Tilia	0	0	0	1	0	0
Ostrya/Carpinus	0	0	0	0	0	0
Ulmus	0	1	0	1	0	0
Juglans	1	0	0	1	4	1
Corylus	0	0	0	0	0	0
Platanus	0	0	0	0	0	0
Juniperus	0	0	0	0	0	0
Alnus	0	1	1	5	3	9
Cephalanthus	0	0	0	0	0	0
Salix	0	1	0	0	0	0
Tsuga	0	0	0	0	0	0
Poaceae	2	5	10	6	1	19
Cyperaceae	5	10	13	8	24	4
Ambrosia	4	3	6	3	6	6
Artemisia	1	2	3	1	5	1
Chenopodiineae	0	0	0	0	0	0
Ast. Tub.	0	0	0	0	0	0
Pteridium	0	0	0	0	0	0
Filicales	0	0	0	0	0	0
Lycopodium	1	0	1	0	0	1
Indeterminate	0	0	0	0	0	0
Nuphar	0	0	0	0	0	0
Typha lat./ang.	0	0	0	0	0	0
Myriophyllum	0	0	0	0	0	0
Spike	120	200	195	248	648	496
Main Sum	718	704	696	755	1157	1012
Grain/sphere	5.98	3.52	3.57	3.04	1.79	2.04
Abs. Conc.	598000	352000	357000	304000	179000	204000

Zone	CL-1	CL-1	CL-1	CL-1
Depth (cm)	1875.2	1880	1884	1890
Core-Drive	CL-T12	CL-T12	CL-T12	CL-T12
Larix	1	0	0	0
Abies	0	0	0	1
Picea	243	290	355	423
Pinus undiff.	210	170	73	58
Betula	6	1	3	3
Populus	0	0	2	0
Quercus	27	35	24	17
Carya	0	0	42	0
Fraxinus	5	0	0	3
Acer	0	0	0	0
Fagus	0	0	1	0
Tilia	0	0	0	0
Ostrya/Carpinus	0	0	0	0
Ulmus	0	0	0	0
Juglans	4	0	4	1
Corylus	0	0	0	0
Platanus	0	0	0	0
Juniperus	0	0	0	0
Alnus	0	1	4	2
Cephalanthus	0	0	0	0
Salix	0	0	2	0
Tsuga	0	0	0	0
Poaceae	23	3	5	5
Cyperaceae	16	22	18	15
Ambrosia	10	7	6	7
Artemisia	1	2	3	0
Chenopodiineae	4	0	0	0
Ast. Tub.	0	0	0	0
Pteridium	3	0	0	0
Filicales	0	0	0	0
Lycopodium	0	1	0	0
Indeterminate	0	0	0	0
Nuphar	0	0	0	0
Typha lat./ang.	0	0	0	0
Myriophyllum	0	0	0	0
Spike	402	210	657	189
Main Sum	905	717	1170	703
Grain/sphere	2.25	3.41	1.78	3.72
Abs. Conc.	225000	341000	178000	n/a

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