# Archaeological Landscapes during the 10–8 ka Lake Stanley Lowstand on the Alpena-Amberley Ridge, Lake Huron

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## ABSTRACT

Archaeologists have long been interested in the Lake Stanley lowstand event (~10–8 ka) in the Lake Huron basin, as archaeological sites from the Late Paleoindian/Early Archaic cultural periods were inundated by subsequent high water levels. Recent archaeological and paleoenvironmental investigations of this submerged landscape have documented stone structures that were likely utilized for caribou hunting by these cultural groups during the late Lake Stanley lowstand phase of Lake Huron. In 2011 and 2012, a total of 67 core, sediment, and rock samples were collected in a 50 km$^2$ area by divers and a sonar sampler deployed from a survey vessel. These samples were analyzed for sediment size, sorting, morphology and source, organic and carbonate content, testate amoebae, and organic materials. A series of indicators, including distinct microfossil assemblages (such as species only found in sphagnum moss and boggy arctic ponds), rooted trees (tamarack and spruce) and charcoal (ca. 8–9000 years old) reveal a series of microenvironments that are consistent with a sub-arctic climate. The analysis of the Alpena-Amberley Ridge provides a detailed picture of the environment exploited by ancient peoples during the Lake Stanley lowstand period. The methodologies employed in this study can in turn help identify other unique micro regions that may yield more archaeological sites with less obvious archaeological footprints.

## INTRODUCTION

Most archaeological research on Early Holocene settlement patterns in the Great Lakes focuses on the record available from terrestrial archaeological sites (Ellis et al., 1998; Ellis, Timmins & Martelle, 2009). However terrestrial archaeological sites alone cannot provide a complete record of human adaptation as large tracts of prehistoric coastlines and adjacent terrestrial landscapes have been inundated by fluctuating water-levels (Bailey, 2004). These now submerged landscapes are of tremendous archaeological importance, as they contain well-preserved evidence of early human migration, settlement patterns and subsistence strategies (Faught, 2004; Bailey & Flemming, 2008; Rick et al., 2013; Westley, Plets & Quinn, 2014; Ward, Larcombe & Veth, 2015).

The Great Lakes basins (Figure 1A) have high potential for submerged archaeological sites due to water level changes during deglaciation, and as a result of Holocene climate change (Quimby, 1963). The Holocene period in the modern Lake Huron basin (*ca*. last 12,000 years) was marked by several phases of drier climate and low lake levels (lowstands) including the Lake Stanley lowstand which dates to 11,300–8400 cal. yr B.P. (Hough, 1962; Dryzyga, 2007; Lewis et al., 2007). During the Lake Stanley low water phase, levels in the modern Lake Huron basin were 70–100 m below modern lake levels and large areas of the contemporary lake bed were exposed terrestrial landscapes (Hough, 1962) (Figure 1A). This time of lowered water-levels coincides with the occupation of Late Paleoindian/Early Archaic peoples in this region and the lack of terrestrial archaeological sites from this period is likely due to the subsequent submergence of this landscape (Jackson et al., 2000).

Late Paleoindian and Early Archaic sites in the Great Lakes region are often difficult to find on terrestrial surveys due to their small and diffuse artifact densities (Ellis, 2013). For the sites that are discovered, they rely heavily on paleoenvironmental reconstruction as a means of supplementing sparse cultural materials (e.g., Julig, 1992; Johnston, 1984). Submerged archaeological site investigation also relies heavily on paleoenvironmental data, but as a means of narrowing down potential site locations (e.g., Sonnenburg et al., 2012). Due to the often vast landscapes that need to be investigated for submerged sites, the data is often collected at a very coarse resolution (Ward, Larcombe & Veth, 2015). It is rare to first find a submerged archaeological site, and only afterwards collect high-resolution, focused and localized paleoenvironmental data to provide context to that site. One of these rare cases is the Alpena-Amberley Ridge, where a series of caribou hunting drives lanes and hunting blinds were discovered in 2007.

Subsequent investigations have found additional sites, and it became clear that there was a need for fine-grained paleoenvironmental data, in order to provide a more robust understanding of how these prehistoric peoples interacted with their changing landscape.

The initial focus for the paleoenvironmental reconstruction was the investigation area known as Area 1 (Figure 1C), where the first structures were located and documented. The aim of this study was to provide high resolution paleoenvironmental information of an exposed Lake Stanley-era terrain that also would have been inhabited (at least seasonally) by humans. The collected paleoenvironmental data will be used to evaluate the potential uses of microdebitage; for locating additional archaeological sites; improving and enhancing computer simulations of caribou movement (Vitale et al., 2011); and predicting the locations of additional cultural features, such as campsites, meat caches and stone-tool production areas.

## STUDY AREA

The Alpena-Amberley Ridge is a 200-km long ridge capped with Middle Devonian limestone that resisted erosion and bisects Lake Huron, running from Alpena, Michigan to Point Clark, Ontario (Thomas, Kemp & Lewis, 1973) (Figure 1B). The maximum width of the ridge is approximately 15 km, and lies in water that ranges between 15 and 50 m depth. The Ridge was exposed during the Lake Stanley low water phase (Thomas, Kemp & Lewis, 1973; O'Shea & Meadows, 2009). The topography of the area is complex, with distinct topographic depressions and rocky outcrops creating areas of higher elevation. The elevation on the edge of the ridge drops rapidly, creating sharp cliff faces on either side of the ridge, and marking the boundary of the Ridge (Thomas, Kemp & Lewis, 1973).

## PREVIOUS RESEARCH

There have been numerous studies that have investigated various aspects of Lake Huron, such as post-glacial sedimentary deposits and processes (e.g., Hough, 1962; Thomas, Kemp & Lewis, 1973), lowstand events and climate changes (e.g. Rea et al., 1994; Lewis et al., 2007; McCarthy et al., 2012), isostatic rebound (e.g. Clark, Zylstra & Befus, 2007; Dryzyga, Shortridge & Schaetzl, 2012) and archaeological potential (Janusas at al., 2004). Most of these studies are focused on the northern and western basins of Lake Huron, where sediment deposition allows for better recovery of sediment cores for the investigation of sediments for paleoenvironmental proxies such as pollen and other microfossils, isotopic analysis, magnetic susceptibility and particle size analysis. While most of these studies do not deal directly with the Alpena-Amberley Ridge, they provide an excellent overview of basin-wide climatic conditions immediately before, during and after the Lake Stanley lowstand.

### Lake Stanley Lowstand

The hypothesis of a lowstand event occurring within the Lake Huron basin was first proposed by George Stanley in 1936, and was confirmed through the work of J.L. Hough in the 1960s. While the mechanism and timing of the event was still not well understood, it did provide the initial idea that archaeological sites might have been submerged during the recovery of water levels after the lowstand event (Quimby,1963). In the past decade, more advanced geotechnical and geophysical techniques allowed for a more precise timeline of the Lake Stanley lowstand, with the last low-water phase dating between 9000 and 8350 cal. yr B.P. (Lewis et al., 2012). Pollen and testate amoebae analysis from sediment cores in Georgian Bay identified the probable cause of the lowstand event as a combination of isostatic rebound and climatic change, allowing for complete hydrologic closure and separation of Lake Michigan, Lake Huron and Georgian Bay (McCarthy et al., 2007; 2012; Lewis et al., 2007; McCarthy & McAndrews, 2012). McCarthy et al. (2007) also noted a lack of post-Lake Stanley sedimentation that occurred in some parts of Lake Huron and Georgian Bay.

## Sediments

The most comprehensive study of sediments of the Alpena-Amberley Ridge (AAR) was part of a larger, basin-wide study of the surficial sediments of Lake Huron (Thomas, Kemp & Lewis 1973). This study led to additional analysis of these sediments using seismic stratigraphy and geotechnical properties such as particle size analysis and magnetic susceptibility in the 1990s (Rea et al. 1994). These studies characterized the AAR sediments as being either till or bedrock, with small pockets of glaciolacustrine clays and post-glacial muds in small depressions. Covering the till or bedrock was a thin drape of quartz-dominated coarse sands that were coated with ferromanganese oxides. Sediment deposition varies greatly within the Lake Huron basin due the role of the Alpena-Amberley Ridge had in affecting lake- bottom topography. The lake bottom on the south side of the Ridge is smooth and gently undulating, while on the north side, it is complex and provides deep basins where much of the sediment in Lake Huron is deposited (Thomas, Kemp & Lewis 1973).

Paleoenvironmental Reconstruction

The use of benthic organisms and other microfossils have provided a record of the regional paleoenvironment during the Lake Stanley lowstand phase of Lake Huron. Isotopic studies using ostracods and other bivalves in Lake Huron (Macdonald & Longstaffe 2008; Rea et al., 1994) note variation in both the carbon and oxygen isotope record from the northern and southern basins, likely related to the mid-lake position of the Ridge. Especially during lowstand events, the Ridge would have acted as a barrier to water movement between the different basins within Lake Huron, allowing for different trophic conditions within the isolated basins to develop.

The most common means of reconstructing paleoenvironments in and around the Lake Huron basin is the utilization of pollen and testate amoebae analysis. The pollen phases in Lake Huron that are relevant to the Lake Stanley lowstand include Phase 1 (prior to 10,000 cal. yr B.P.) which records the post-glacial landscape of spruce and tundra, Phase 2 (10,000 to 8000 cal. yr B.P.) showing the shift to a pine-dominated boreal forest environment, and Phase 3 (after 8000 cal. yr B.P.) where the establishment of more modern mixed-forest environments begins (McCarthy et al., 2007). Phase 2 pollen assemblages are synchronous with the Lake Stanley lowstand and also recorded along with Phase 2 pollen assemblages are low-diversity testate amoebae assemblages dominated by *Centropyxis* species, which are tolerant of brackish conditions. These brackish conditions during the Phase 2 pollen assemblages provided additional evidence of closed basin conditions during the Lake Stanley lowstand (McCarthy and McAndrews, 2012).

Archaeological Potential

Quimby (1963) noted the possibility of submerged archaeological sites in the Lake Huron basin, and Lovis et al. (1994) modeled submerged archaeological site potential along the west coast of Lake Michigan. It wasn't until the late 1990s that improved and commercially available technology allowed for detailed investigation of pre-contact submerged archaeological sites. Janusas et al., (2004) investigated submerged paleochannels in Georgian Bay, and recovered a single piece of fire-cracked rock. They also were able to map the area using high-resolution multi-beam bathymetry, which provided a clearer picture of a Lake-Stanley-era landscape. However, it was not until the discovery of caribou hunting structures in 2007 (O'Shea & Meadows, 2009) and the subsequent recovery of stone tool flakes (O'Shea et al., 2014) that definitive proof of a submerged archaeological site in Lake Huron was obtained.

## METHODS

The location of the hunting structures in Area 1 was initially discovered through a side-scan sonar search of the area in 2007. In 2008, subsequent investigation of the area using a hand-deployed Remotely Operated Vehicle (ROV) confirmed the existence and layout of the structures. Multi-beam sonar was used to map the entire area to gain a more comprehensive understanding of the surrounding topography and map paleolandscape features such as shorelines and river channels. Following extensive geophysical survey and ROV investigations, diver survey was initiated in 2011 to get a closer look at the structures, investigate lake bottom conditions and visibility, and map the structures at close range.

Further ROV and diver surveys were conducted in 2011 and 2012 to collect sediment samples for paleoenvironmental analysis. These surveys were conducted on a 8.5 m-long Parker 2530 survey vessel Blue Traveler which was large enough to accommodate divers and equipment, but allowed for reduced gas costs and travel time to the site location approximately 80 km offshore from Alpena, Michigan.

The 2007-2008 surveys of the Ridge also noted there were many areas encrusted with invasive quagga mussels (O'Shea & Meadows, 2009) (Figure 2A), which was then confirmed by both ROV and diver survey. Quagga mussels colonize on top of each other on both hard and soft surfaces, creating layers of mussels several inches thick (Wilson, Howell & Jackson, 2006). This obscures subtle landscape features, such as shallow depressions, and makes identifying small cultural material (such as flakes or stone tools) nearly impossible. The solution to the problem of limited sediment thickness and the quagga mussels was to collect surface sediment (grab) samples in 100 ml plastic vials and short hand-pushed cores in PVC piping and clear plastic tubes by divers. These samples were collected in areas near caribou hunting structures, and nearby landscape features such as paleo-shorelines and river channels. Landscape features in areas without hunting structures were also sampled. A total of five short push cores (10–25 cm in length), 33 sediment grab samples and four pieces of wood (50 cm-4 m in length) were collected in Area 1 (Figure 1). All elevations of sediment samples were calculated using the International Great Lakes Datum, 1985 (IGLR85), which is the reference system by which Great Lakes water levels are measured.

### Particle Size Analysis and Loss on Ignition

Twenty grams of each of the sediment grab samples were analyzed for microdebitage, microfossils, grain size, and organic and carbonate content (Figures 3 and 4). The three short cores were sub-sampled at 2 cm intervals for analysis, lithofacies logged in detail and photographed. Sediment color was determined using a Munsell soil color chart (Figure 3). All samples were sieved and divided into three categories: <1 mm (microdebitage and mineral analysis), 1mm-250 µm (microdebitage), and 250-10 µm (microfossils). Microfossil, organic and carbonate content analysis were completed at the Archaeoscience Laboratory at the University of Michigan, Museum of Anthropological Archaeology. Particle size distribution (PSD) was measured on a Coulter LS230 laser diffraction particle size analyzer at McMaster University. Wood samples were identified by Lee Newsom at Pennsylvania State University. AMS radiocarbon dates were obtained at the University of Arizona Accelerator Mass Spectrometry Laboratory and the National Ocean Sciences Accelerator Mass Spectrometry Facility (NOSAMS) (Table 1). AMS radiocarbon dates were obtained on a total of eight samples (Figure 1C; 2; Table 1) using the acid-alkali treatment method. Samples were calibrated to two sigma, and the median date calculated using Calib 7.01 program and the IntCal13 calibration curves (Reimer et al., 2013).

High-resolution particle size analysis was completed on 27 grab samples and all core samples (Figures 3, 4). Particle size was not performed on six samples that were sieved before bulk samples could be obtained. For the short cores, the mean particle sizes (µm) were plotted versus core depth (Blott & Pye, 2006) to determine down-core changes in sediment texture (Figure 3). The samples were not pre-treated to remove organics, carbonates and diatoms as microscopic analysis of the particles did not reveal an abundance of any of these materials. Particle size from grab samples were plotted using the Gradistat software program to determine sorting and sediment type (Blott & Pye, 2012) (Figure 4). Sediment type is the dominant percentage of silt, clay, and sand, while sorting is the amount of sediment of the same size in each sample (Plummer et al., 2007). The organic matter content, carbonate content, and silicate (the remaining non-organic and non-carbonate sediments) content were determined using the loss on ignition (LOI) method (Heiri, Lotter & Lemcke, 2001) (Figure 3).

## Sediment Particle Morphology

A minimum of 1g each of 14 sediment samples chosen to represent different sampling areas from the <1 mm fractions were analyzed under light microscope at 40X magnification to identify rock types (Figure 5) (Pellant, 2002; Lynch & Lynch, 2010), organics, and any potential archaeological materials (e.g., stone tool fragments, fire-cracked rock). Rocks and minerals found in all samples included quartz, quartzite, chert, limestone, basalt, granite, gneiss, olivine and feldspars. Organic materials included wood fragments, charcoal, ash, seeds and shell. 1000 grains from a 1/16 randomly split fraction from the 250 μm sediment portion were analyzed to determine sphericity and angularity (Powers, 1953), and lithic type to determine source, transport, and processes (Figure 5).

## Microfossils

Testate amoebae (thecamoebians) have been used to complement pollen analysis for more robust paleoclimatic reconstructions in lake basins (e.g., Lamentowicz & Obremska, 2010; McCarthy et al., 2007; McCarthy & McAndrews, 2012). Testate amoebae are ubiquitous and abundant in freshwater environments. Their tests are commonly preserved even in low pH environments, and can be used as indicators of lake trophic status, bottom and surface water conditions, paleohydrology and salinity changes through time (Booth, 2008; Reinhardt et al., 2005; Swindles et al., 2009; Van Hengstum et al., 2008). Testate amoebae have been shown to be very sensitive to subtle environmental changes and may react to climate shifts more quickly than pollen (McCarthy et al., 1995). They have been used successfully in other parts of Lake Huron to determine paleoenvironmental conditions (McCarthy et al., 2007; 2012).

2.5 ml of sediment samples of 250–43 μm size were split into random 1/8 fractions and counted until >150 specimens were reached (Patterson & Fishbein, 1989; Scott & Hermelin, 1993). Samples were analyzed under light microscope at 80x magnification. Identification of species was based on Kumar & Dalby (1998) and Scott, Medioli & Schafer (2001). Fractional abundance was calculated on each sample to ensure similarity between samples for statistical analysis. Standard error was calculated on the fractional abundance to determine which samples had statistically significant counts (Patterson & Fishbein, 1989). If the standard error was higher than the fractional abundance, the sample was removed from the cluster analysis (Fishbein & Patterson, 1993). Eleven samples had enough testate amoebae to be considered statistically significant (Table 2; Figure 6). Diversity was calculated using the Shannon-Weaver Diversity Index (Hammer, Harper & Ryan, 2001) in order to determine which samples had high or low diversity of species which can indicate how stressed an environment is (Reinhardt et al., 2005). Cluster analysis using Euclidean distance in both Q and R-mode analyses (Davis, 2002) was completed in the PAST program (Hammer, Harper & Ryan, 2001). Euclidean distance is the shortest distance between the fractional abundances, and is most commonly used when the statistically significant samples have low standard errors (Fishbein & Patterson, 1993). Q-mode analysis determined similarities between samples, and R-mode analysis determined the similarities in species (Fig. 5) (Davis, 2002).

## RESULTS

### Sediments

Sediment coring was only able to extract between 10 and 25 cm of sediment, as this was the maximum amount of sediment available on top of the bedrock of the Ridge. Core 1 was taken from the Overlook area (Figure 1C), so named because it a topographic high overlooking a paleo-river channel and potentially could have been used as a lookout for migrating caribou. The upper 4 cm consists of reddish brown moderately sorted medium sand, changing to a 2 cm lens of grayish brown moderately well sorted medium sand (Figure 3). The next 5 cm is a dark grey moderately sorted medium sand which contains small amounts of charcoal in this lens. The bottom 4 cm is the same color, sediment type and sorting as the lens at 4–6 cm (Figure 3). Mean particle size is about 400 um, with a very small percentage of organic and carbonate content (less than 0.4%) (Figure 3).  AAR-5 was the longest core extracted (25 cm), and the upper 7 cm is gray, poorly sorted mud (Figure 3). The sediment changes from mud to a coarser, light brownish gray, very poorly sorted fine silty medium sand. There is a decrease in carbonate content, from 6.4 % at the top of the core to 4.7 % at the mud/fine silty sand contact (Figure 3). The bottom 10 cm of the core is poorly sorted mud, and changes color at 20 cm to a light yellowish brown.  Core 92912E has the most complex sedimentation of all the cores. The sediment is medium to coarse moderately sorted sand throughout the core (Figure 3).  At 3 cm below surface, the color of the sediment changes from dark grayish brown to a light olive brown which contains wood fragments, and has a gradual increase in sediment size (500 to 700 µm), carbonate and organic content (0.2 to 0.5%) before it peaks at 7 cm to a 2 cm-thick lens of dark brown oxidized sand. The sediment color, particle size, carbonate and organic content return to the same values as seen in the upper 3 cm.  At 9 cm, there is another distinct color change to a 2 cm lens of black sediment containing charcoal.   From 11 cm to the bottom of the core, the sediment is relatively consistent with small variations in color from very dark grayish brown to dark grey and a gradual increase carbonate and organic content (Figure 3).

In the grab samples, sediment size ranges from very coarse sand to mud. Fifty percent of the samples are medium sand, but samples from Spruce 1, 2 and 3, as well as River-1 all contain mud and finer grained silty sediments (Figure 4A). The finer sediments are usually poorly sorted, with the medium and coarse sands being better sorted. Most areas have a mix of both well-sorted and poorly sorted sediments (Figure 4B).

The majority of particles are quartz, composing an average of 67% of the total grain type (Figure 5). Other sources include chert, quartzite, sandstone, limestone, basalt, granite, olivine and a small percentage of undetermined source material. Chert was the next most abundant lithic type, ranging from 6 to 20% of the total grain type, with the exception of EI-1, which had almost no chert (Figure 5). The shape of the particles was collapsed into three categories: high sphericity angular and low sphericity angular (including very angular, angular and sub-angular particles) and rounded. This was done with the hope of identifying potential differences between transportation processes such as wind and water action (Krinsley & Doornkamp, 1973). On average, particle shapes are distributed evenly between the three classes. Exceptions are in the Dragon Run area (AM-1 and AF-1), with a very high percentage (60–70%) of high sphericity angular fragments, and samples from the High Ground (EI-1, EK-1), Top_HT2 (AAR10) and Spruce (BY-1) almost completely split between low sphericity angular and rounded fragments (Figure 5).

Testate Amoebae

Four distinct assemblages were determined based on Q-mode cluster analysis: Boggy Pond (BP), Forested Swamp (FS), Sphagnum Bog (SB) and Kettle Hole (KH) (Figure 6; Table 2). Average testate amoebae abundances for all samples with statistically significant counts were between 200 and 450 specimens per cc (Table 2). Sample 52312 (Pond Assemblage) had the highest abundances with over 6000 specimens per cc. Diversities of all samples were relatively low, and average 1.54–1.87 (Table 2). The predominant species in all samples were *Centropyxid* species, primarily *C. constricta* ‘aerophila’, which reached over 50% of the total species in some samples. In the R-mode cluster analysis, *C. constricta* ‘aerophila’ is the most dissimilar of all of the species. Almost all species with higher dissimilarity are more abundant (over 10% of any given sample) and are associated with marginal conditions such as boggy arctic ponds and marshes (McCarthy et al., 1995; Burbidge & Schroëder-Adams, 1998; Reinhardt et al., 1998; Dallimore, Schroëder-Adams & Dallimore, 2000; Neville et al., 2010; Kihlman & Kauppila, 2012) (Fig. 7; Table 3). Several less abundant species cluster closely together and are associated with higher sediment and nutrient input (Burbidge & Schroëder-Adams, 1998; Torigai, Schroëder-Adams & Burbidge, 2000; Kihlman & Kauppila, 2009).

The Boggy Pond Assemblage is heavily dominated by *Centropyxis constricta* ‘aerophila’ and *C. aculeata* ‘discoides’ , which comprises over 70% of the total assemblage (Table 2). These are species which are early colonizers of nutrient poor environments and are found in boggy Arctic ponds (Dallimore, Schroëder-Adams & Dallimore, 2000). Other species which occur in smaller amounts are *Difflugids, Curcurbitella tricuspis* and *Arcella vulgaris*. These species are associated with nutrient loading and high Phosphorous values (Roe et al, 2010; Patterson, Roe & Swindles, 2012), and *D. bidens and D. urceolata* do not occur in any other assemblage. However, other species more closely associated with wetlands also appear in this assemblage (*Bullinaria, Phyraganella* species) (Booth, 2008; Swindles et al., 2009; Asada & Warner, 2009). The Boggy Pond Assemblage is located at the edge of the major structures in Area 1 (Funnel and Dragon Run) and represents a shallow water-filled depression just below the high ground where the structures are located (Figures 1C; 2). Adjacent to the pond would have been the shoreline of Lake Stanley, and periodic flooding would have washed nutrients in from the larger lake, which would explain the higher number of nutrient-rich species found in the samples.

The Kettle Hole Assemblage only consists of one sample and is heavily dominated by *C. constricta* and *C. aculeata* strains (>80%) (Table 2). It has the highest numbers of specimens per cc (6592), but low diversity (1.57). The assemblage is similar to the Pond assemblage except it lacks high nutrient species such as *Difflugids*, *C. tricuspis* and *A. vulgaris* (Roe et al., 2010; Patterson, Roe & Swindles, 2012). It is described as a kettle hole based on the multi beam backscatter data which shows a slight depression at Spruce 2 next to the river channel (River-1) (Figure 1C), although it is not deep enough to have been a ‘true’ kettle hole, which usually trap sediments. As a result of its shallowness, the nutrient loading which is characteristic of kettle holes (Roe et al., 2010) does not occur here. In addition, the nearby paleo-river channel (River-1) would have flushed some sediments and nutrients out of the shallow depression. Sediment samples collected from the River-1 area do not contain any testate amoebae or pollen material.

The Sphagnum Bog and Spruce/Tamarack Swamp Assemblages are classified primarily by the presence of *Hyalosphenia papilio*, *Bullinularia indica* and *Difflugia globulus* specimens which are found in Sphagnum mosses and swamps (Scott, Medioli & Schafer, 2001; Booth, 2008), along with other wetland species such as *Nebela collaris (*Table 2) (Charman, Hendon & Woodland, 2000). In addition, the Sphagnum Bog assemblage contains *Cyphoderia ampulla*, *Euglypha*, and *Corythion* which are associated with mosses and drier conditions (Turner & Swindles, 2012). The Spruce/Tamarack assemblage has more *Centropyxid* species which are associated with wetter conditions (Table 2) (Booth, 2008; Turner & Swindles, 2012; Oris et al., 2013). These bogs are no longer extant, but the assemblages have remained entrained within the existing sediment. The Sphagnum Bog samples are located near the River-1 area, while the Spruce/Tamarack Swamp assemblage samples are located next to tamarack and spruce wood recovered in the same area (Figure 1C).

## Radiocarbon Dates

Of the eight radiocarbon dates obtained, four date between 9124 and 8543 cal. yr B.P., which is consistent with the Lake Stanley lowstand (McCarthy et al., 2012, Lewis & Anderson, 2012). Three of these samples were from large wood pieces (two spruce and one tamarack), one of which was still rooted to the lake bottom. The remaining sample was from sediment containing charcoal and ash from a stone ring (92912F). One sediment sample (AT1) had a very early date of 18291-18813 cal. yr B.P. Three anomalous young dates (*ca*.1800 CE) were obtained from two pine samples and one from a sediment core (92912E) (Table 1).

The anomalous date in 92912E is likely the result of modern material entering the core during extraction. In other samples from Area 1, small pieces of anthracite, a type of coal commonly shipped across the lakes during the 19$^{th}$ century, were recovered from the sediment. Ship debris also likely accounts for the young dates of the two pine specimens. Subsequent dating of these anomalous specimens with different treatment processes (the direct dating of cellulose) returned similar dates, indicating that contamination from other sources such as quagga or zebra mussel filaments (Janusas et al., 2004) is not a likely scenario. Despite the problematic charcoal and pine tree dates, the consistency of the dates from the larger wood samples (one of which was from a rooted tree) indicate the area was at least stable enough to support tree growth, and the trees have remained in place since inundation. Other areas in Lake Huron also have well-preserved in-situ tree stumps that were drowned as water levels recovered after 8000 years ago (e.g. Hunter et al., 2006).

## DISCUSSION

### Conditions for Sediment, Microfossil and Archaeological Preservation on the Alpena-Amberley Ridge

Particle size data collected by Thomas et al. (1973) characterized the sediment of the AAR as having similar characteristics to the nearshore environments around Lake Huron. The assumption was that since the area is shallower than the deep basins adjacent to the Ridge, they would be under similar influences as the nearshore environments, with poorly sorted coarse sands, pebbles and cobbles. Similar sediments can be found in Georgian Bay, which also had land bridge that once connected Manitoulin Island to the mainland of Ontario at Tobermory during the same time as the Lake Stanley lowstand (Janusas, pers.comm). The sediments collected by Thomas, Kemp & Lewis (1973) on the Ridge were classified as till and clays, although their data also shows considerable variation in the sediment types of the Ridge compared to nearshore environments.

The collection of sediments in 2011 and 2012 from Area 1 also shows a considerable amount of variation in particle size. Unlike the samples collected by Thomas, Kemp & Lewis (1973), approximately half of the sediment collected in Area 1 are classified as fine to medium sand. The other 50% of the sediment is equally divided amongst more typical nearshore, till-like sediments, and fine muds and silts which more consistent with sediments from deeper basins (Thomas, Kemp & Lewis 1973).This variation of sediment types on the Ridge compared to the samples collected by Thomas, Kemp & Lewis (1973) provides one of the most important reasons for microregional environmental studies. The surface sample collection of Thomas, Kemp& Lewis (1973) was meant to gain an overall, large scale understanding of the sediments of Lake Huron; samples were collected on a 10 km by 10 km grid. By focusing sediment collection on specific, small areas of the Ridge (less than 10 $km^2$), we now understand the sediment regime on the AAR is much more variable than previously thought, and these sediments can provide more detailed information regarding preservation potential of both archaeological and paleoenvironmental material in this submerged landscape.

The preservation of deposits of fine-grained sediments, along with wetland-dwelling testate amoebae microfossils supports a hypothesis of the submergence of this area as occurring rapidly, but gently. Supporting this hypothesis is publically available multibeam bathymetric data, plus high-resolution side scan collected over Area 1 (O'Shea, 2015). This geophysical data allows for a more detailed reconstruction of lake-basin geography, which shows the Ridge not as a monolithic structure, but as an area of varied topography. These variations in topography are partially responsible as a driver of the preservation of archaeological and paleoenvironmental data. These topographic changes, while only a few meters in the modern environment, would have been greatly exaggerated during the Early Holocene, when isostatic rebound was an important influence in water-level fluctuations (along with climate) (Lewis et al.,2007). It is not uncommon for there to be different rates of isostatic rebound on different parts of the Great Lakes shorelines, and Lake Huron is no exception. Lake Huron experiences differential rebound in north-south and east-west directions, caused a 'twisting' of the basin. As the AAR runs in a northwest to southeast direction, not only would the northern and southern extents of the Ridge have experienced isostatic rebound, but there also would have been differences between the eastern and western sides of the AAR (Lewis, Blasco & Gareau, 2005; Dryzyga, Shortridge &Schaetzl, 2012).

In other research in the Great Lakes watershed, differential isostatic rebound can have a dramatic effect on changes in water-levels even in small lake basins. In Rice Lake, north of Lake Ontario, differential isostatic rebound has resulted in an elevation change of 8 meters from west to east over a 10 km section of the lake (Sonnenburg, Boyce & Suttak, 2012). It is not inconceivable that in the 6 km extent of Area 1, isostatic rebound played a large role in how quickly sections of the Ridge flooded. This would have affected the preservation potential of different sections of Area 1, allowing for good preservation with minimal sediment movement in some sections, with other areas experiencing scour and erosion from more pronounced shoreline processes in areas that flooded more gradually (Sonnenburg 2015).

However, it is still unclear as to the nature and timing of the inundation of the AAR after the recovery of water-levels in Lake Huron sometime after 8000 years BP. Based on large-scale reconstructions of elevation of the Ridge during the early Holocene (Lewis, Blasco & Gareau, 2005; Dryzyga, Shortridge &Schaetzl, 2012), some sections would have remained sub-aerially exposed for longer periods of time as water levels rose after 8000 years ago, while others may have been partially inundated prior to this date. In the case of Area 1, it appears that this section was rapidly inundated in a short period of time. Despite having what was likely only a thin drape of sandy sediments, at least some of the sediments (as indicated by testate amoebae microfossil and fine-grained sediment recoveries) have been preserved *in-situ*, strongly indicating a rapid inundation which kept sediments from becoming transported over long distances. Rooted trees, still clinging to shallow sediments along gentle shorelines, are clearly visible on the lake bottom, and radiocarbon dates acquired from one of these trees date to prior to 8000 years ago (O'Shea et al., 2014; Table 1). No visible features of geomorphic or sedimentary structures such as erosional contacts, large beach ridges and blowouts indicates the area was not subject to major erosional processes such as shoreline wind and wave action.

There are few well-defined shorelines in the area, and the shorelines that do exists are gentle, without the cobbles and larger materials that would be associated with a high energy, nearshore environments (Thomas et al., 1973). The sediments from these shoreline areas are more consistent with a gentle, sloping beach (Figure 4) than a high energy shoreline. It seems likely that most of the shorelines in Area 1 are established during the lowstand phase, in small depressions, creating small inland lakes and ponds (Figure 7). Testate amoebae recovered from samples in these depressions bear out these assertions, showing an abundance of shallow water species, instead of oligotrophic, deep water species such as *Difflugia oblonga.* In other areas of the Ridge, outside of Area 1 where the more pronounced shorelines and ripples were located, *Difflugia oblonga* is the dominant testate amoebae recovered (Sonnenburg, 2015).

Archaeological and Paleoenvironmental Implications

The ability to determine the potential for recovery of paleoenvironmental data also informs a more detailed understanding of the environmental conditions on the AAR. The testate amoebae data from the AAR support an interpretation of a microenvironment more similar to modern sub-arctic environments, where indigenous peoples still hunt caribou (O'Shea et al., 2013). Small water-courses and ponds would have been a source of fresh water for both human and caribou (Figure 7). Shorelines of inland lakes and ponds would have been fringed by wetlands as demonstrated by the recovery of wetland dwelling testate amoebae such as *Hyalosphenia papilio* and *Bullinularia indica* (Figures 6 & 7). These wetland environments would have supported additional resources such as waterfowl, fish, and aquatic plants, supplementing larger game (Sonnenburg, Boyce & Reinhardt, 2013).

Pollen records from elsewhere in the modern Lake Huron basin indicate the area would have been a mix of coniferous trees and hardy grasses, mosses and ferns and is more closely associated with a prairie parkland or boreal forest environment (McCarthy & McAndrews, 2012; Lewis & Anderson, 2012). It is unclear why the Ridge is more consistent with a sub-arctic environment compared to other areas of the Great Lakes. Since the Ridge separated Lake Stanley into two distinct, hydrologically closed basins (Croley & Lewis, 2006), this would cause differentiation in trophic conditions in each basin. The northern basin was influenced by sudden inputs of glacial meltwater (Lewis et al., 2007), while the southern basin was influenced predominately by precipitation as well as being much shallower (Macdonald & Longstaffe, 2008). It is also possible that the Ridge created a corridor for windier conditions that created a cooling effect, allowing for a more sub-arctic like environment to thrive (Holtmeier & Broll, 2010). This would also explain the smaller trees that have been documented (O'Shea et al., 2014), compared to larger tree stumps found in coastal areas of Lake Huron (Hunter et al., 2006). Reconstructions of paleo-wind directions ca 11,000 yr BP based on sand spits in northern Michigan show an intense, cold and gusty climatic conditions (Krist & Schaetzl, 2001). However, the lack of wave cut terraces and extensive sand spits on the Ridge clearly show that by the time of the lowest level of the Lake Stanley phase, these winds had either died down or changed direction as the Laurentide ice sheet moved further northwards.

The combination of topography and environment was also very influential in the placement of hunting structures, which in turn was based on the behavior of caribou, observed over the course of millennia. Caribou have certain predictable behavioral attributes that can be easily manipulated by simple changes to the environment. One of the quirks in Caribou behavior is the propensity for following straight lines. This is the one of the reasons caribou will follow along shorelines, and also have wreaked havoc on modern caribou populations when their migratory routes are interrupted by modern linear structures such as pipelines (O'Shea et al., 2013).

The documented hunting structures on the Ridge are clustered in higher elevation areas where the topography had natural linear features, such as shorelines and rocky outcrops that created natural pinch points, such as in the Funnel and Dragon Run locales (Figures 1C, 7). The other areas where structures are clustered are around the Overlook/High Ground and River areas (Figure 7). This small area of higher elevation would have created a natural lookout point for hunters tracking caribou herds. This area has an inland lake connected to a river channel, which would have created both a liner feature and a source of freshwater for migrating caribou. Additional archaeological evidence from this area includes potential microdebitage from within a 'V' shaped structure in the High Ground location (Sonnenburg, 2015) and charcoal and ash from a circular structure adjacent to the River location (Figure 7). A flake recovered from the other side of the Inland Lake (Lakeshore NW) may have been transported from the higher elevations of the Funnel and Dragon Run, as it exhibits features of water transport (Lemke, 2015). There may also be additional archaeological material nearby, as this area only consists of two samples to date.

## CONCLUSIONS

The reconstruction of the microenvironment of a submerged archaeological site provides insights into the types of microenvironments that ancient caribou hunters were exploiting on the AAR. Using a combination of ethnographic analogy, computer simulation, high-resolution remote sensing, paleoenvironmental and sedimentological data, we have been able to provide insight into the kind of environment that would have been optimal for caribou hunting, as well as gaining a better understanding of how ancient caribou hunters were utilizing existing landscape features and built structures to hunt caribou.

The reconstruction of the landscape and environment of the AAR can offer some solutions to the difficulty in locating submerged archaeological sites. By focusing on microenvironments and looking at archaeological sites on a small scale, we are now able to better plan for new surveys in this vast landscape. We now know we are looking for very specific landscape and environmental conditions where we will be able to find additional hunting structures, as well as helping us to differentiate natural occurring rock formations or glacial erratics from human-modified structures. Knowing the specific environmental and landscape characteristics of hunting areas may also help us identify other area of interest, such as storage caches or campsites.

This type of small scale environmental reconstruction will also be of use to other researchers of submerged landscapes, where coarse resolution geophysical survey and paleoenvironmental reconstructions do not allow for efficient exploration of vast areas of submerged land which may have small, scattered archaeological sites. In addition, by focusing on hunting structures, which are common worldwide, and much more visible on the landscape, we may be able to start fading the more ephemeral sites that have long eluded archaeologists.

We are starting to gain a better understanding of the complex environment of the AAR. Sediment samples taken from Area 1 on the Ridge have yielded valuable information on the paleogeography and microenvironments that were used by prehistoric peoples. Our results show several areas on the Ridge have *in situ* sediments which would indicate a reasonably well preserved landscape with minimal disturbance from post-depositional processes such as wave and wind action. Our reconstructions of the Ridge paleoenvironment during the Lake Stanley lowstand show that this environment was different than other areas of the modern Lake Huron basin during this time period, indicating that the Ridge itself may have affected local climatic conditions.

The concept of looking at smaller micro-regions for understanding environmental conditions, water level fluctuations, shoreline development (or lack thereof) for determining the probable locations of submerged prehistoric archaeological sites has been a more defined emphasis over the past five years (Ward, Larcombe & Veth, 2015; O'Shea et al., 2014; Sonnenburg, Boyce & Suttak, 2012). This is the result of large scale studies, while valuable as a baseline, cannot provide the kind of information needed to narrow down study areas that are difficult to access, and do not usually have an obvious footprint. Prehistoric sites in North America can be notoriously difficult to locate in terrestrial settings, much less in 40 m of water. Since hunting structures have a more visible archaeological footprint than most prehistoric sites, as well as good preservation, the AAR provides a unique laboratory in which to refine methodologies for identifying microenvironments. These methodologies can in turn help identify other unique micro regions that may yield more archaeological sites with less obvious archaeological footprints.

Some of the most important questions in human prehistory require the investigations of submerged landscapes. The understanding of submerged landscapes, such as the AAR, and determining the paleoenvironmental conditions specific to these areas allows for the investigation of archaeological sites which are not disturbed by human activity. These findings provide a more detailed picture of paleoenvironments utilized by prehistoric peoples in this region during a period of rapidly-changing climate.

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## FIGURE CAPTIONS

Figure 1: Study area map. A- Central and Eastern Great Lakes basins with modern and lowstand shorelines (redrawn from Anderson and Lewis, 2012). B-Lake Huron showing three areas of interest on the Alpena Amberley Ridge. C- Area 1 close-up with bathymetric contours (5m intervals) with locations of sample collection, radiocarbon dates and cores.

Figure 2: Rock structures from the Alpena-Amberley Ridge. A) Circular 'blind'. B) Sector scan sonar image of the 'Funnel' drive lane hunting structure (O'Shea 2015).

Figure 3: Lithology, mean particle size (µm) and loss-on-ignition data from three short cores taken on the Ridge. Note the distinct horizon on core 92912E.

Figure 4: Sample locations for particle size analysis in Area 1. A) Sediment size (µm). B) Sediment sorting. Size and sorting classifications were determined using Blott & Pye, 2006.

Figure 5: Sediment particle type and shape from Area 1. Shown are the most common particle materials of Quartz, Quartzite and Chert. Particle shape was combined into three categories to highlight areas that may have been subject to long distance transport (rounding).Samples are listed in order from north to south.

Figure 6: Q and R mode cluster analysis and species abundances of sediment samples from Area 1. Similarity was calculated using Euclidean distance.

Figure 7: Paleogeographic reconstruction of the Alpena-Amberley Ridge between 8 and 9,000 years ago based on topography, testate amoebae assemblages and sediment analyses.

Table 1: Radiocarbon dates from the Alpena-Amberley Ridge. Sample locations can be seen in Figure 1C. All dates were run at the National Ocean Sciences AMS facility at Woods Hole except X20851, which was run at University of Arizona AMS laboratory. All dates are calibrated to 2 sigma standard deviation using the IntCal 13 calibration curve (Reimer et al., 2013). IGLD is the International Great Lakes Datum.

| Laboratory Number | Sample Unit # | UTM (WGS 84) | Elevation (m) (IGLD85) | Material | 14C yr B.P. | SDV | 1 sigma | 2 sigma | Median date | d13C (‰) |
|---|---|---|---|---|---|---|---|---|---|---|
| X20851 | AA95226/Wood1 | 383889 E 4959985 N | 142.12 | Spruce | 8038 | 46 | 8783-9016 | 8722-9071 | 8905 | -25.5 |
| OS-99473 | Wood 4 | 383428 E 4960849 N | 140.97 | Rooted Spruce | 7960 | 55 | 8725-8978 | 8642-8994 | 8828 | -25.12 |
| OS-96127 | ATI Lake Huron | 381739 E 4964404 N | 151.52 | Charcoal | 15,300 | 120 | 18,440-18,70 | 18,291-18,81 | 18,565 | -24.7 |

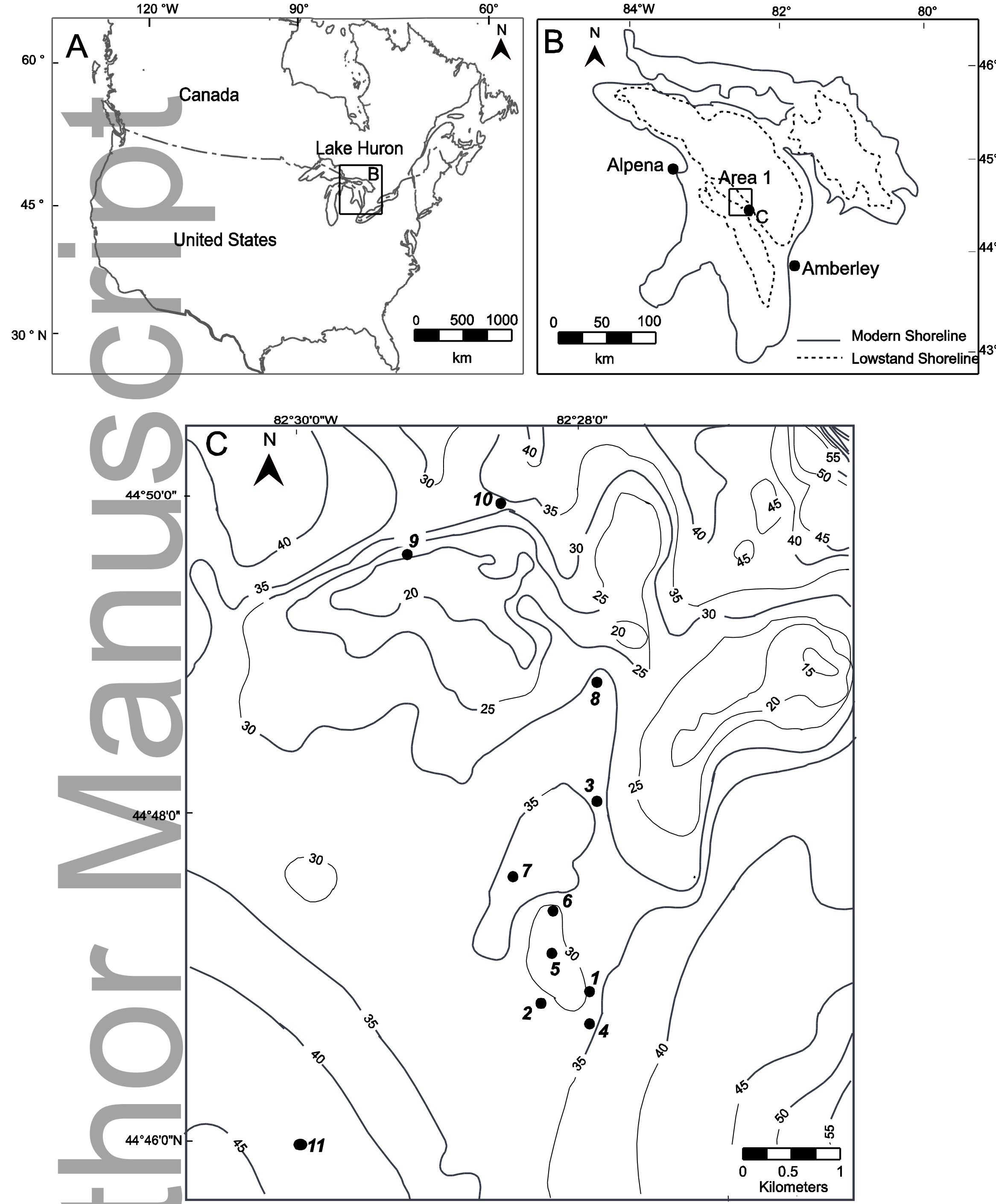
| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | 6 | 3 | | |
| OS-99472 | Wood 3 | 381747 E 4958045 N | 134.29 | Pine | 115 | 25 | 27-269 | 13-259 | 114 | -25.55 |

| Assemblage | Boggy Pond | Sphagnum Bog | Spruce/Tamarack Swamp | Kettle Hole |
|---|---|---|---|---|

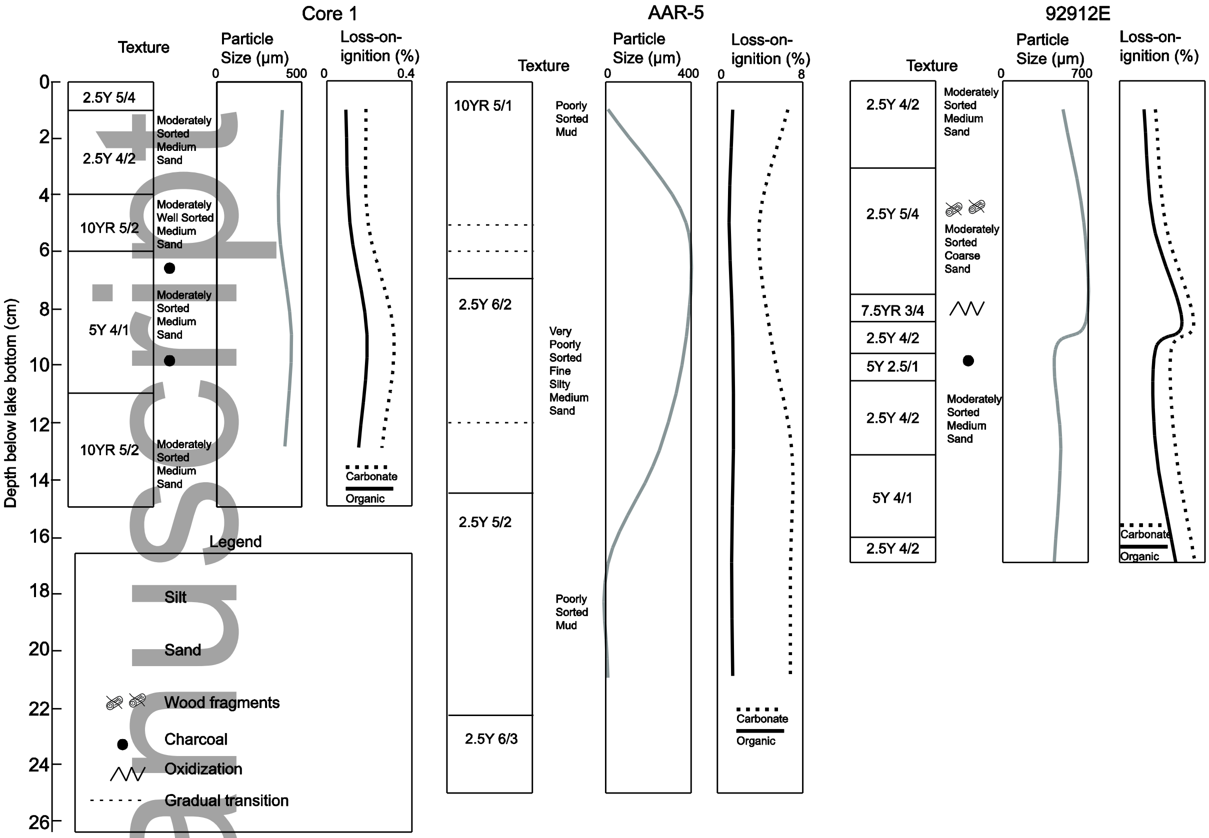
| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| OS-99471 | Wood 2 | 383914 E 4959974 N | 141.02 | Pine | 140 | 25 | 12-270 | 7-280 | 143 | not measured |
| OS-100524 | Wood 5 | 383267 E 4960826 N | 143.86 | Tamarack | 7840 | 40 | 8556-8648 | 8543-8762 | 8620 | -26.12 |
| OS-100525 | 92912E | 383267 E 4960826 N | 142.03 | Charcoal from sediment core | 105 | 20 | 32-255 | 24-262 | 111 | -26.44 |
| OS-100526 | 92912F | 383267 E 4960826 N | 142.03 | Charcoal from stone ring | 8080 | 35 | 8987-9074 | 8790-9124 | 9012 | -26.54 |

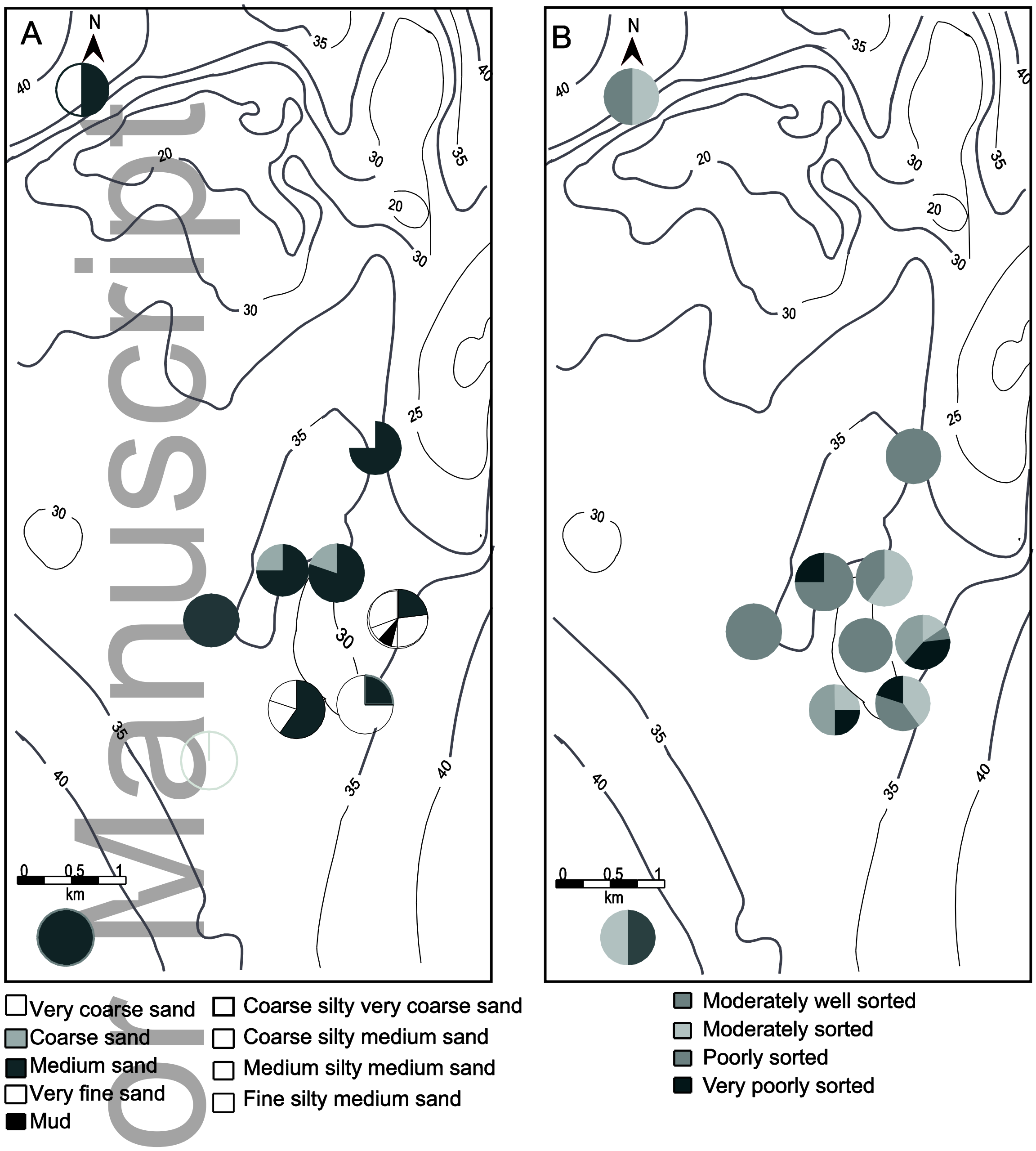
Table 2: Summary statistics for testate amoebae assemblages. Species abundances are in percent. The Kettle Hole assemblage is only represented by one sample, 52312.

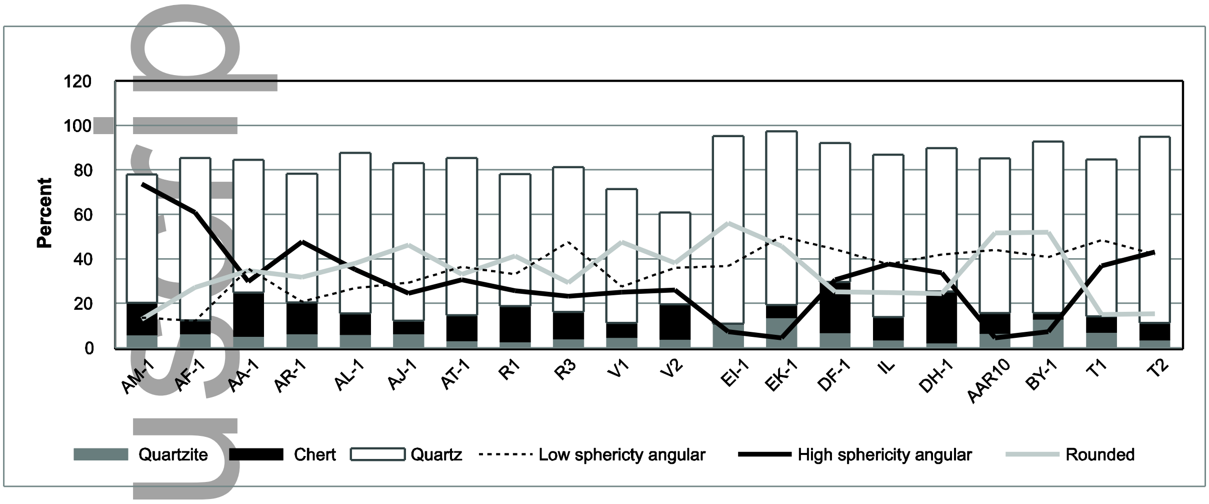
| | Mean | SD | Mean | SD | Mean | SD | 52312 |
|---|---|---|---|---|---|---|---|
| Total counted | 214.67 | 14.43 | 162.50 | 27.58 | 227.20 | 16.30 | 412.00 |
| Counts per cc | 449.07 | 159.81 | 255.67 | 24.51 | 420.58 | 162.48 | 6592.00 |
| Diversity | 1.54 | 0.11 | 1.87 | 0.23 | 1.80 | 0.16 | 1.57 |
| Centropyxis constricta 'aerophila' | 50.41 | 3.35 | 27.12 | 4.17 | 35.98 | 1.95 | 27.43 |
| Difflugia oblonga | 1.94 | 3.37 | 0.90 | 0.28 | 4.38 | 3.51 | 0.97 |
| D. globulus | 3.68 | 1.50 | 10.31 | 1.73 | 20.67 | 7.16 | 4.37 |
| D. protaeiformis | 0.92 | 0.42 | 0.00 | 0.00 | 0.85 | 1.17 | 0.00 |
| Bullinaria indica | 0.30 | 0.52 | 1.92 | 2.72 | 3.32 | 1.20 | 1.21 |
| Nebela collaris | 0.15 | 0.26 | 0.55 | 0.78 | 0.25 | 0.37 | 0.00 |
| C. constricta 'constricta' | 7.46 | 1.13 | 6.84 | 2.75 | 5.28 | 3.62 | 34.71 |
| C. aculeata 'discoides' | 21.76 | 1.40 | 17.38 | 9.04 | 12.88 | 4.50 | 8.74 |
| C. aculeata 'spinosa' | 2.00 | 0.61 | 16.13 | 2.05 | 4.73 | 3.67 | 20.63 |
| D. glans | 1.48 | 1.84 | 0.82 | 1.17 | 2.08 | 1.62 | 0.00 |
| D. bidens | 0.75 | 0.68 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| D. urceolata | 0.65 | 0.78 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Curcurbitella tricuspis | 4.82 | 5.93 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Arcella vulgaris | 3.18 | 1.62 | 2.27 | 2.23 | 0.17 | 0.38 | 0.00 |
| Phyrganella | 0.34 | 0.58 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Pontigulasia compressa | 0.17 | 0.29 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Lagenodifflugia vas | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Cyphoderia ampulla | 0.00 | 0.00 | 0.00 | 0.00 | 0.08 | 0.18 | 0.00 |
| Heliopera sphagni | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Hyalosphena | 0.00 | 0.00 | 15.73 | 0.49 | 8.60 | 2.99 | 1.94 |
| Corythion | 0.00 | 0.00 | 0.00 | 0.00 | 0.63 | 1.42 | 0.00 |
| Euglypha | 0.00 | 0.00 | 0.00 | 0.00 | 0.09 | 0.20 | 0.00 |



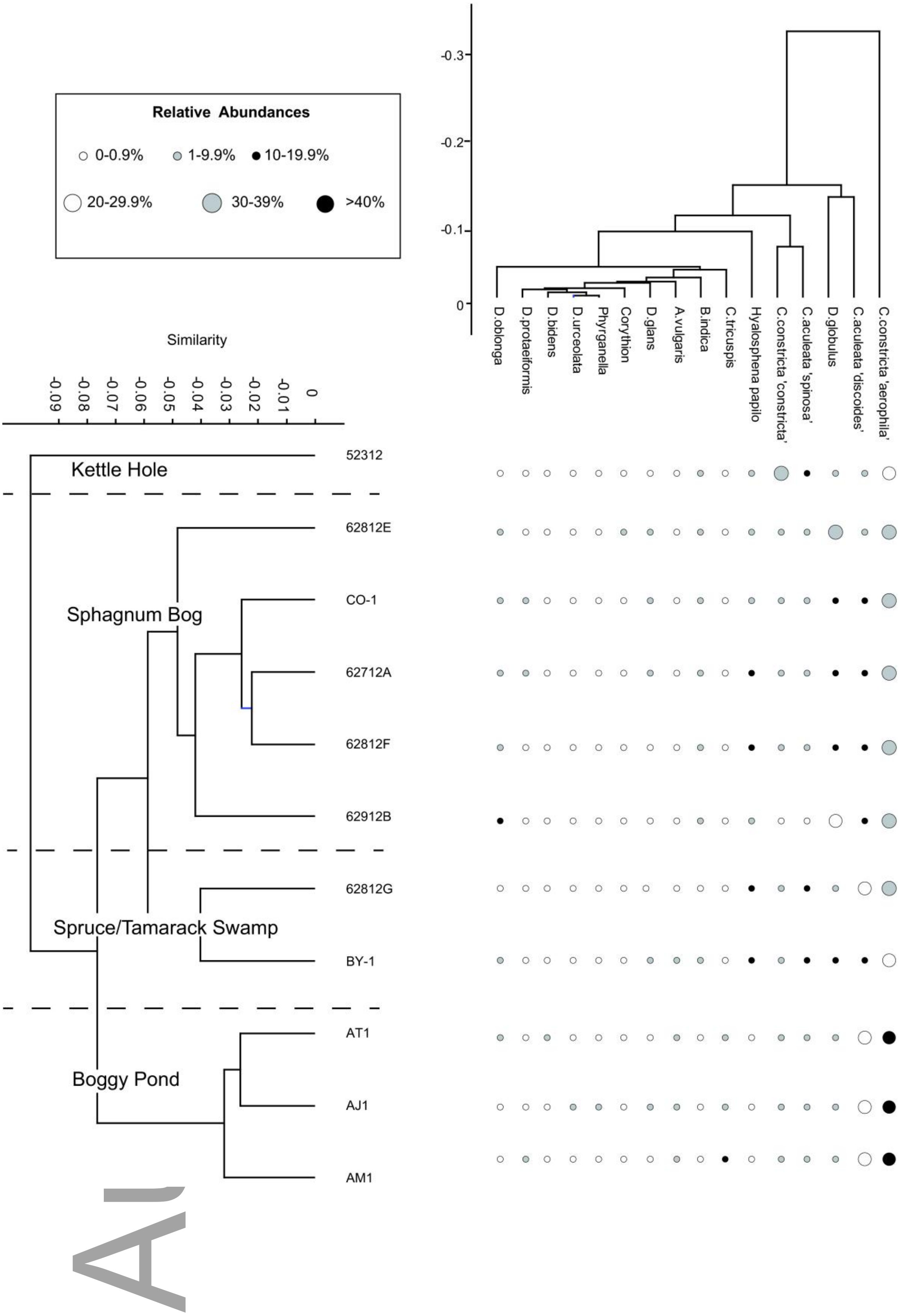

1. Spruce 2. Spruce -1 3. Spruce -2 4. River-1 5. High Ground 6. Overlook 7. Inland Lake 8. Lakeshore Northwest 9. Funnel 10. Dragon Run 11. Till Area

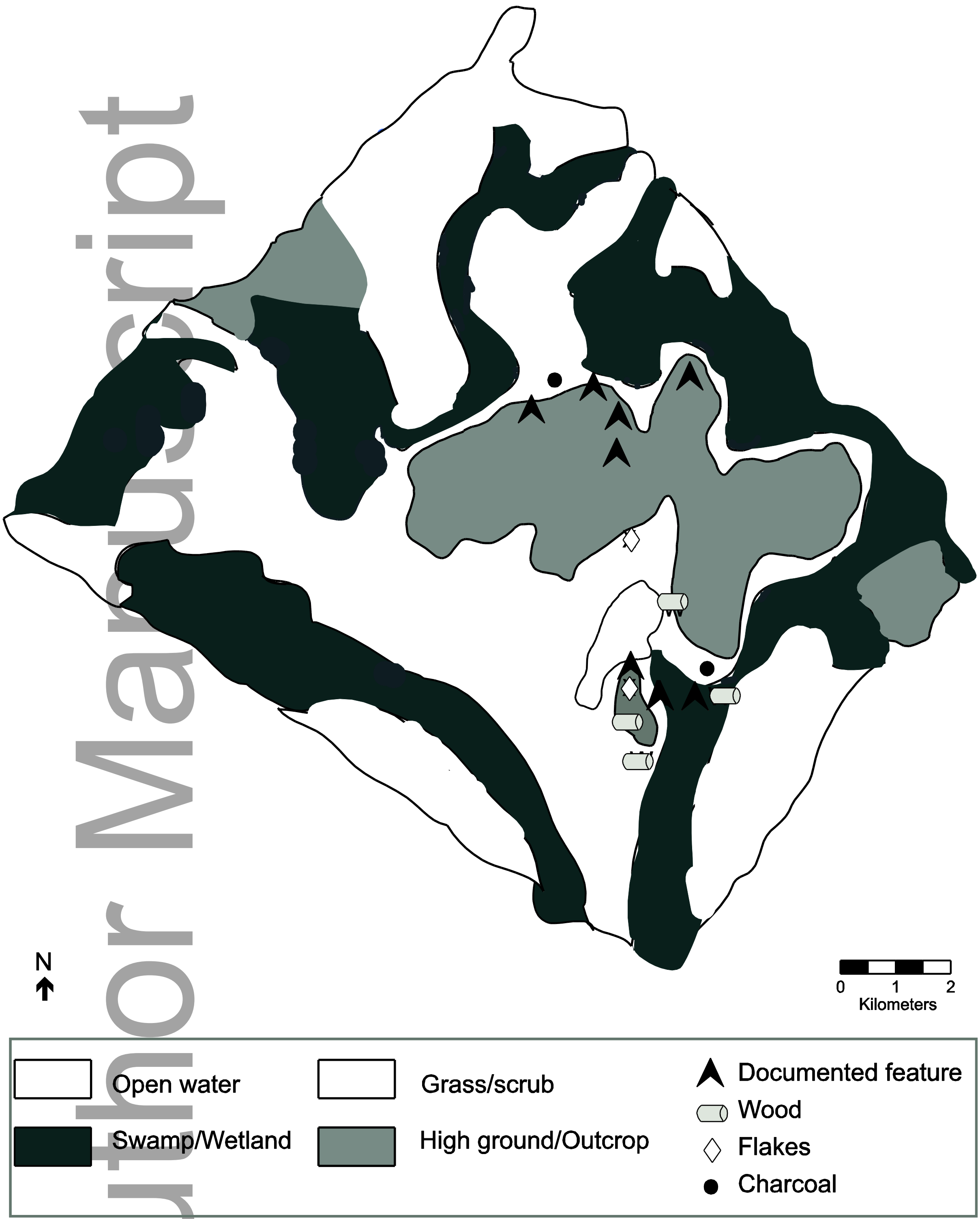

Core 1
AAR-5
92912E
Texture
Particle Size (µm)
Loss-on-ignition (%)
Depth below lake bottom (cm)
2.5Y 5/4
2.5Y 4/2
10YR 5/2
5Y 4/1
10YR 5/2
Moderately Sorted Medium Sand
Moderately Well Sorted Medium Sand
Moderately Sorted Medium Sand
Moderately Sorted Medium Sand
Carbonate
Organic
Legend
Silt
Sand
Wood fragments
Charcoal
Oxidization
Gradual transition
10YR 5/1
2.5Y 6/2
2.5Y 5/2
2.5Y 6/3
Poorly Sorted Mud
Very Poorly Sorted Fine Silty Medium Sand
Poorly Sorted Mud
2.5Y 4/2
2.5Y 5/4
7.5YR 3/4
2.5Y 4/2
5Y 2.5/1
2.5Y 4/2
5Y 4/1
2.5Y 4/2
Moderately Sorted Medium Sand
Moderately Sorted Coarse Sand
Moderately Sorted Medium Sand

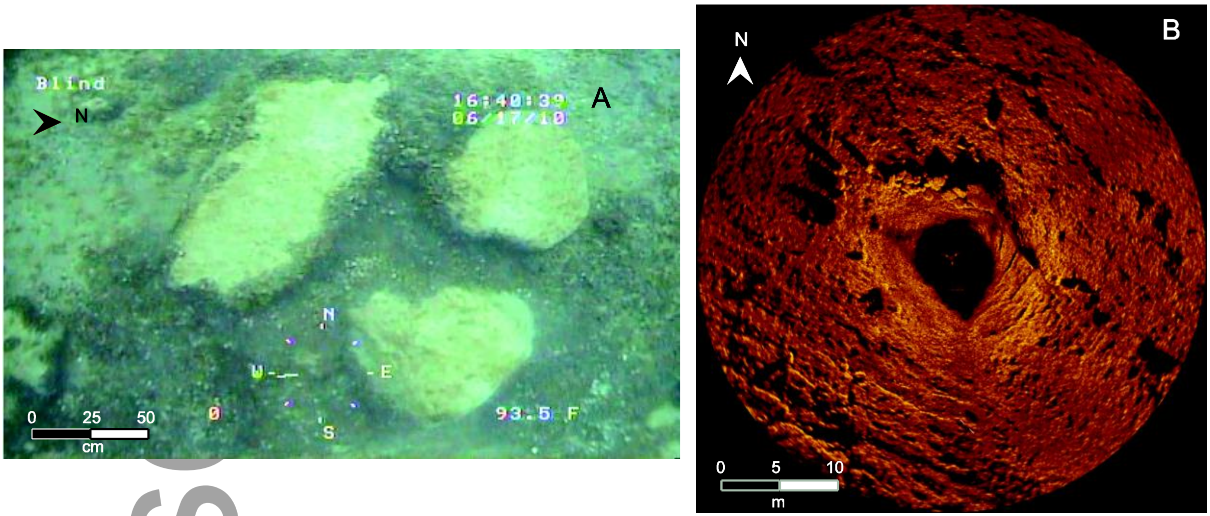

A
B
N
0 0.5 1
km
Very coarse sand
Coarse sand
Medium sand
Very fine sand
Mud
Coarse silty very coarse sand
Coarse silty medium sand
Medium silty medium sand
Fine silty medium sand
Moderately well sorted
Moderately sorted
Poorly sorted
Very poorly sorted



120
100
80
60
40
20
0
Percent
AM-1
AF-1
AA-1
AR-1
AL-1
AJ-1
AT-1
R1
R3
V1
V2
EI-1
EK-1
DF-1
IL
DH-1
AAR10
BY-1
T1
T2
Quartzite
Chert
Quartz
Low sphericty angular
High sphericity angular
Rounded


Relative Abundances
0-0.9%
1-9.9%
10-19.9%
20-29.9%
30-39%
>40%
Similarity
Kettle Hole
Sphagnum Bog
Spruce/Tamarack Swamp
Boggy Pond
52312
62812E
CO-1
62712A
62812F
62912B
62812G
BY-1
AT1
AJ1
AM1
D.oblonga
D.protaeiformis
D.bidens
D.urceolata
Phyrganella
Corythion
D.glans
A.vulgaris
B.indica
C.tricuspis
Hyalosphena papilo
C.constricta 'constricta'
C.aculeata 'spinosa'
D.globulus
C.aculeata 'discoides'
C.constricta 'aerophila'


N
0 1 2
Kilometers
Open water
Grass/scrub
Documented feature
Wood
Swamp/Wetland
High ground/Outcrop
Flakes
Charcoal


Blind
N
16:40:39
06/17/10
A
N
W
E
S
0
93.5 F
0 25 50
cm
N
B
0 5 10
m