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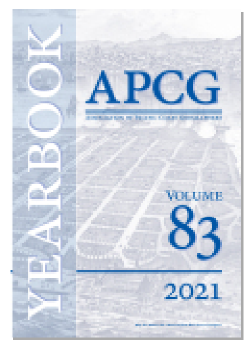

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Evaluating Best Practices for Macroscopic Charcoal-Based Fire History Reconstructions through a Research Experience for Undergraduates

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ABSTRACT

Macroscopic charcoal analysis has emerged as the leading method for reconstructing local fire histories. However, after more than thirty years of research, numerous methodological questions remain unaddressed. Through the efforts of ten student researchers, most of whom participated in a NSF-funded Research Experience for Undergraduates, important variables including site selection, coring strategy, and data reproducibility were evaluated using sediment cores extracted from two lakes located in the eastern Cascades of Washington. The design of this study made it possible to evaluate charcoal data produced by the same student researcher analyzing multiple cores from the same site, multiple student researchers analyzing the same cores from the same site, and multiple student researchers analyzing different cores from the same site. The charcoal curves illustrate that data reproducibility is possible, even when using "less-than-ideal" study sites. This is particularly true for sediment cores analyzed by the same student researcher. Our results show that data produced by different student researchers from both the same sediment core and study site indicate a good level of agreement, especially when overall trends instead of absolute values are considered. We encourage other researchers to address similar methodological questions to improve best practices for fire history studies.

Keywords: *Fire history, lake sediment cores, macroscopic charcoal analysis, site selection, charcoal data reproducibility*

Introduction

Over the past several decades, macroscopic charcoal analysis (MCA) has emerged as the most widely used method for reconstructing long-term, local (i.e., approximately watershed-scale) fire histories (Clark and Patterson 1997; Clark et al. 1998; Whitlock and Anderson 2003; Gavin et al. 2007; Lafon et al. 2017). Charcoal particles, which are the by-product of the incomplete combustion of biomass during a wildfire, accumulate horizontally in lake, wetland, and other perennially wet sediments (Patterson, Edwards, and Maguire 1987; Scott 2010). Macroscopic charcoal particles >100 microns (μm) are separated from vertically extracted sediment cores using the wet-sieve technique, and are easily identifiable under low-power stereomicroscopes (Whitlock and Bartlein 2003; Conedera et al. 2009). A simple quantification of how the number of charcoal particles varies throughout the length of a core provides a record, often times many hundreds to thousands of years long, of past fire activity near a study site (Long et al. 1998; Walsh, Whitlock, and Bartlein 2008).

Some of the benefits of using MCA to reconstruct fire history are that it is relatively simple to learn and teach, as well as low-cost; the primary expense is associated with radiometrically dating the sediment core to establish a chronology (Conedera et al. 2009). Additionally, because sediment records can be analyzed in a relatively short amount of time, depending on core length, MCA is a quick and easy method in which to train student researchers (Walsh 2014). Using MCA, undergraduate researchers, such as those participating in a Research Experience for Undergraduates (REU), can complete a hands-on project in a matter of weeks or months and produce results that are applicable to current ecosystem health and fire management issues. While it is ideal if the sediment core analyzed ends up providing a useful fire history record in terms of the length of the record and/or the characteristics of the observed charcoal trends, important methodological questions related to MCA can be addressed even if it does not.

One issue that remains understudied in MCA is that of data reproducibility, either within the same sediment core or multiple sediment cores from the same study site. While it is typical for a study design to include the analysis of multiple sediment cores from a study area or geographic region (Millspaugh and Whitlock 1995; Gavin et al. 2001; Foster et al. 2002;

Brunelle et al. 2005; Higuera et al. 2009; Walsh, Whitlock, and Bartlein 2010; Caffrey and Horn 2015), very few studies utilize multiple sediment cores from the same lake or wetland (Whitlock and Millspaugh 1996; Edwards and Whittington 2000; Walsh et al. 2018). This is likely because the goal of most paleoecological studies is to attain a full-length record of a site's environmental history. Even when multiple cores are extracted from a site, typically only one is selected for charcoal, pollen, and other analyses (Whitlock and Anderson 2003). However, taking and analyzing a greater number of sediment cores from a study site can yield important information regarding charcoal taphonomic (i.e., depositional) processes and can inform best practices for MCA (Edwards and Whittington 2000; Whitlock and Anderson 2003). Additionally, analyzing more than one sediment core allows for the evaluation of "less-than-ideal" study sites, as defined by lake size, bathymetry, and watershed topography, among other variables, with the idea that fire history reconstructions from a "good" study site will yield similar charcoal data from multiple sediment cores.

The purpose of this research is to use MCA to test data reproducibility from multiple lake sediment cores derived from two "less-than-ideal" study sites in the eastern Cascades of Washington State (USA). This research was conducted during three consecutive summers by myself and ten undergraduate researchers involved in a Central Washington University (CWU) REU: *Hazards and Risks of Climate Change in the Pacific Northwest*, as well as two additional undergraduate students from CWU. The goal of the study is to inform best practices regarding MCA of lake sediment cores, and to contribute to our collective understanding of what makes a "good" study site in fire history research. Additionally, this research highlights undergraduate student researcher participation in the field, laboratory, and data analysis components of this study.

The specific objectives of this study are as follows:

- To test whether the analysis of multiple sediment records from the same study site, conducted by the same student researcher, produces similar trends in the charcoal data.
- To test whether multiple analyses of the same sediment record, conducted by different student researchers, produce similar trends in the charcoal data.
- To test whether multiple analyses of multiple sediment records from the same study site, conducted by different student researchers, produce similar trends in the charcoal data.

Note that because of the nature of MCA, during which the charcoal particles are broken when counted, it is impossible for multiple researchers to count the exact same charcoal samples. Therefore, this variable was not tested.

The results of this study allow us to address the following research questions:

Q1: What do the charcoal data trends as shown by multiple records from a study site, analyzed both by the same and different student researchers, suggest about MCA data reproducibility?

Q2: What do the charcoal data trends suggest about the use of "less-than-ideal" study sites in MCA (i.e., fire history) research?

Q3: What do the study results suggest about the inclusion of undergraduate researchers in fire history research using MCA?

Study Area and Methods

Setting and Study Sites

The general study area for this research is the eastern Cascades of central Washington (USA). The lower-elevation, dry forests of this province are an ideal location in which to study fire history because fires occurred frequently prior to Euro-American settlement (Everett et al. 2000; Wright and Agee 2004; Walsh, Duke, and Haydon 2018). Additionally, many of these forests experienced a dramatic decline in fire activity during the twentieth century due to logging, grazing, and active fire suppression, and more recently a rise in fire size and severity in association with modern climate warming and the legacy effects of fuel build-up (Arno et al. 1997; Hessburg and Agee 2003; Rushton and Walsh 2021). These fire regime shifts, when observed in the charcoal record, make it easy to relate the data at hand to important environmental and cultural issues, including Indigenous use of fire, forest health, and climate change impacts.

The specific sites used in this study are shown in Figure 1, and their characteristics are detailed in Table 1. Lightning Lake exists within the boundaries of the Okanogan-Wenatchee National Forest, approximately fifty km west of Yakima, WA. Camp Lake sits approximately forty-five km NW of Ellensburg, WA, within the newly formed Teanaway Community Forest (TCF), which is state-owned but managed with significant community input (Washington Department of Natural Resources [WaDNR], 2015). It is important to note that these sites were not selected because they are "ideal"

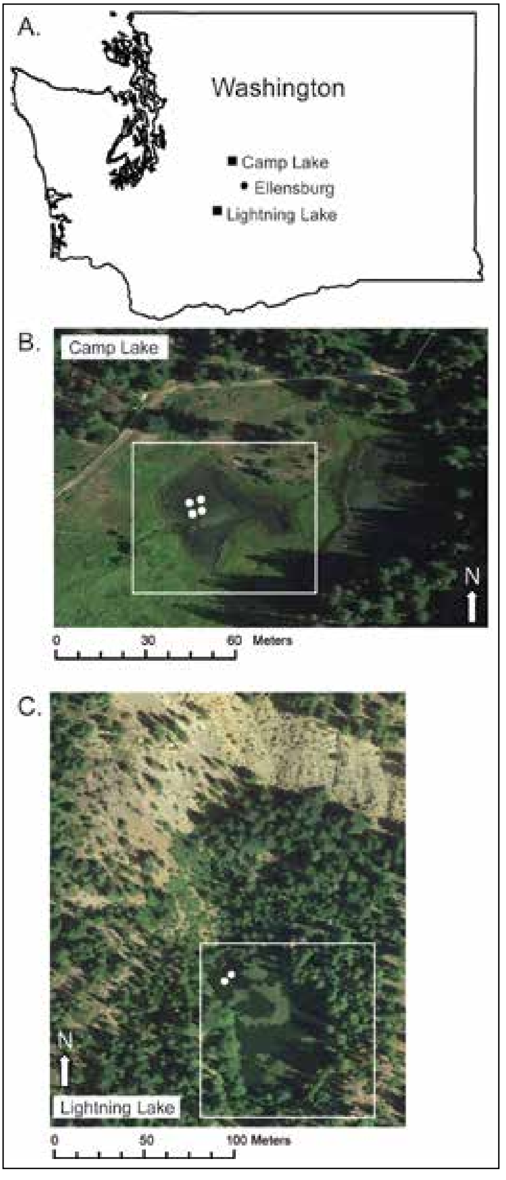

Figure 1.—(a) Map showing the location of the study sites within the state of Washington. (b) Aerial image of Camp Lake (white dots indicate the sediment core locations). (c) Aerial image of Lightning Lake (white dots indicate the sediment core locations).

in terms of traditional site requirements (i.e., lake depth, watershed/lake area ratio, surrounding topography) (Tolonen 1986; Larsen and MacDonald 1993; Whitlock and Anderson 2001). Instead, these sites were chosen because of their proximity to Ellensburg, ease of access, and because they exist in a specific area of interest. For example, Camp Lake is the only water body within the TCF and is located within the perimeter of the 2017 Jolly Mountain Fire, which burned nearly 15,000 hectares in the TCF and neighboring national forest (United States Forest Service [USFS], 2017). Lightning Lake also exists in an overstocked, low-elevation forest where fire has been suppressed for the better part of a century.

Field and Laboratory Techniques

Sediment cores were recovered from Lightning and Camp Lakes by the lead author and the REU students during the summers of 2018 and 2019, respectively. Multiple cores were retrieved from both sites, each within a few meters of the other and

Table 1. Physical and climatic data for Lightning Lake and Camp Lake.

	Lightning Lake, WA	**Camp Lake, WA**
Latitude	46.6765° N	47.3135° N
Longitude	121.1434° W	120.8807° W
Elevation (m)	1038	834
Area (ha)	0.45	0.1
Maximum water depth (m)	2.06	0.77
Period of meteorological record[a]	1981-2010	1981-2010
Mean January temp (˚C)	-2	-1.8
Mean August temp (˚C)	15.4	16.6
Mean annual precipitation (mm)	950	1057
% Precipitation November-April	78	78

[a]Climate data retrieved from the PRISM Climate Explorer (https://prism.oregonstate.edu/explorer/).

from the deepest parts of the lakes (Figure 1; Table 2). All cores were extracted using either a modified Livingstone piston corer or a Bolivia short corer lowered from a floating platform or raft. Long cores were extruded in the field and packaged in plastic wrap, aluminum foil, and split PVC shells for transport to the CWU Paleoecology Lab. Short cores were subsampled in the field into plastic bags at 1-cm intervals. All cores were kept under refrigeration.

The student researchers carried out all laboratory methods. Macroscopic charcoal analysis followed protocol outlined in Whitlock and Larsen (2001) as modified by Walsh, Whitlock, and Bartlein (2008). Students extracted 2-cm^3 samples of mud at 1-cm contiguous intervals from the sediment cores using a modified syringe (Figure 2). Samples were placed in 20 ml vials with ~10 ml of a solution of 5% sodium hexametaphosphate, shaken gently, and left for a minimum of 24 hours to deflocculate the sediment. Approximately 5 ml of sodium hypochlorite (commercial bleach) was then added to the samples, and they were shaken gently and allowed to sit for ~1-2 hours or until the samples were visibly light colored. The samples were then wet sieved through 125-µm and 250-µm screens, and the remaining residue was transferred into scored petri dishes for counting using a stereoscope at 10–40X magnification. Counting entailed completing transects up and down the petri dishes so that no particles, or potential particles, were

Table 2. Lake sediment core characteristics.

Core (ID)	Core type	Captured sediment-water interface?	Core length (cm)	Coring water depth (cm)
Lightning Lake				
LNL19A	Bolivia	No	76	204
LNL19B	Bolivia	Yes	71	203
Camp Lake				
CALA18A	Bolivia	Yes	92	75
CALA18B	Bolivia	Yes	84	77
CALA18C	Livingstone	No	85	77
CALA18D	Livingstone	No	92	77

missed. Each particle was tallied as either a woody or herbaceous charcoal morphotype, and identifications were made based on reference samples, published images, and written descriptions (Walsh, Whitlock, and Bartlein 2008, 2010; Walsh, Duke, and Haydon 2018).

In order to train each student to both correctly identify charcoal particles and differentiate between the charcoal morphotypes (i.e., woody and herbaceous), the lead author first counted the top 10–15 samples from each sediment core without breaking any of the charcoal, as doing so would

Figure 2.—Images showing (a) Lightning Lake LNL12B sediment core, (b) modified syringe used to sample sediment for MCA, (c) scored petri dishes used in MCA, (d) sediment residue in petri dish after processing and sieving, (e) Camp Lake CALA18A sediment core split longitudinally.

lead to erroneous counts by the students. The students then counted the samples while asking questions of the lead author and referring to printed images and reference samples. The students were instructed to look for the charcoal "sheen" or "shimmer" to distinguish charcoal particles from other dark colored objects in the dishes, such as minerals and unburned vegetation. They used a metal-tipped dissection needle to break apart any potential charcoal particle in order to listen for the charcoal "crunch." The lead author continued to count the charcoal samples ahead of the students until our counts were within one or two particles of each other, and also remained available for consultation throughout the analysis process. After completing the analysis, charcoal counts were by dividing by the sample size (2 cm^3) to convert to concentrations, and plotted against mud depth (cm).

Additionally, magnetic susceptibility (MS) and loss-on-ignition (LOI) were measured for each of the sediment cores. MS primarily identifies the presence of ferromagnetic material in the core and typically indicates the presence of tephra or other erosional deposits (Thompson and Oldfield 1986). This was measured at contiguous 1-cm intervals using a Sapphire Instruments magnetic cup or ring sensor. LOI, which is used to determine the organic content of the sediment cores, followed protocol outlined in Heiri, Lotter, and Lemke (2001). Samples of 1 cm^3 were taken at contiguous 1-cm intervals, dried at 90°C for >24 hours, and weighed. Samples were then heated in a muffle furnace at 550 °C for 2 hours and weighed again. The following calculation was used to determine the organic content of the samples: $LOI_{550} = ((Weight_{90}-Weight_{550})/Weight_{90})*100$.

Results

Objective 1*: To test whether the analysis of multiple sediment records from the same study site, conducted by the same student researcher, produces similar trends in the charcoal data.*

MCA of the two sediment cores recovered from Lightning Lake was used to address objective 1. Based on the tephra layer present in both cores and the MS curves, it was determined that the sediment recovered in the cores was offset by 13 cm because LNL19A did not capture the sediment-water interface (Figure 3). As a result, the starting depth of core LNL19A was adjusted downward by the same amount so that the sample depths matched those of LNL19B. The charcoal concentration curves for both cores were then plotted against mud depth (Figure 4). The curves indicate nearly identical charcoal concentration trends observed in the two Lightning Lake cores. While not every value is exactly the same, the concentration curves increase and decrease at the same depths, often to the same values, with the exception of only a few samples (e.g., 20, 29, and 65 cm). This indicates a high

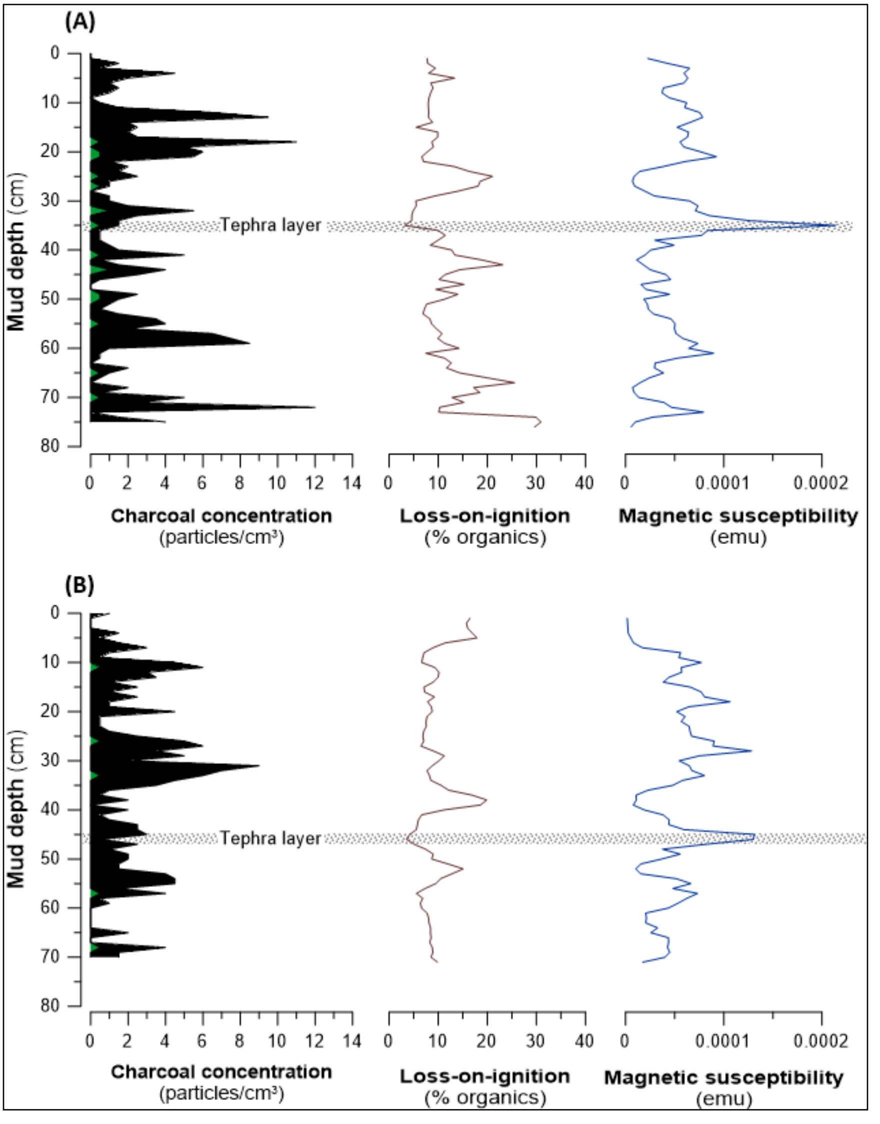

Figure 3.—Charcoal concentration (particles/cm3; black curve=total charcoal, green curve= herbaceous charcoal), loss-on-ignition (% organics), and magnetic susceptibility plotted against mud depth (cm) for the (A) LNL19A and (B) LNL19B cores. The gray horizontal bar indicates the depth of an unknown tephra layer (most likely the Mount St. Helens 1980 eruption).

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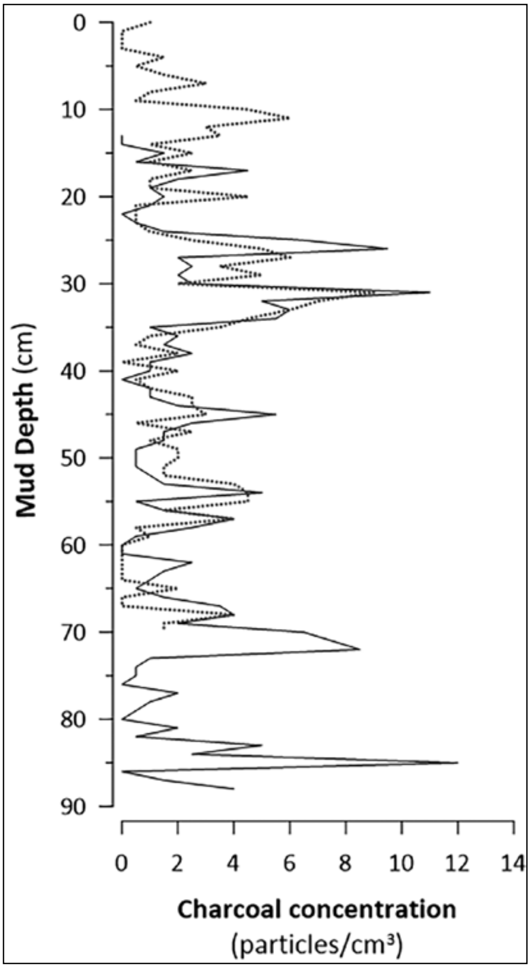

Figure 4.—Total charcoal concentration (particles/cm^3) from the Lightning Lake LNL19A (gray dashed line) and LNL19B (black solid line) cores plotted against mud depth (cm).

level of reproducibility in the charcoal data from the two sediment cores. Additionally, because the cores were offset from each other in depth, this allowed for a longer overall record of fire history at this site.

Objective 2*: To test whether multiple analyses of the same sediment record, conducted by different student researchers, produce similar trends in the charcoal data.*

MCA of the four sediment cores recovered from Camp Lake was used to address objective 2. Figure 5 shows the eight charcoal concentration curves with the counts and recounts for each of the four cores overlain on top of one another. In general, the results are mixed in terms of the similarity between the Camp Lake counts/recounts for each core. For example, the CALA18A results show nearly identical charcoal trends, except for the large rise in concentration shown in one curve but not the other between ~56–67 cm. For CALA18B, the curves are generally more similar, but again one curve indicates a larger rise in concentrations than the other does between ~40–50 cm. The CALA18C curves are the least similar out of all the comparisons, with one curve systematically rising to much higher levels of charcoal

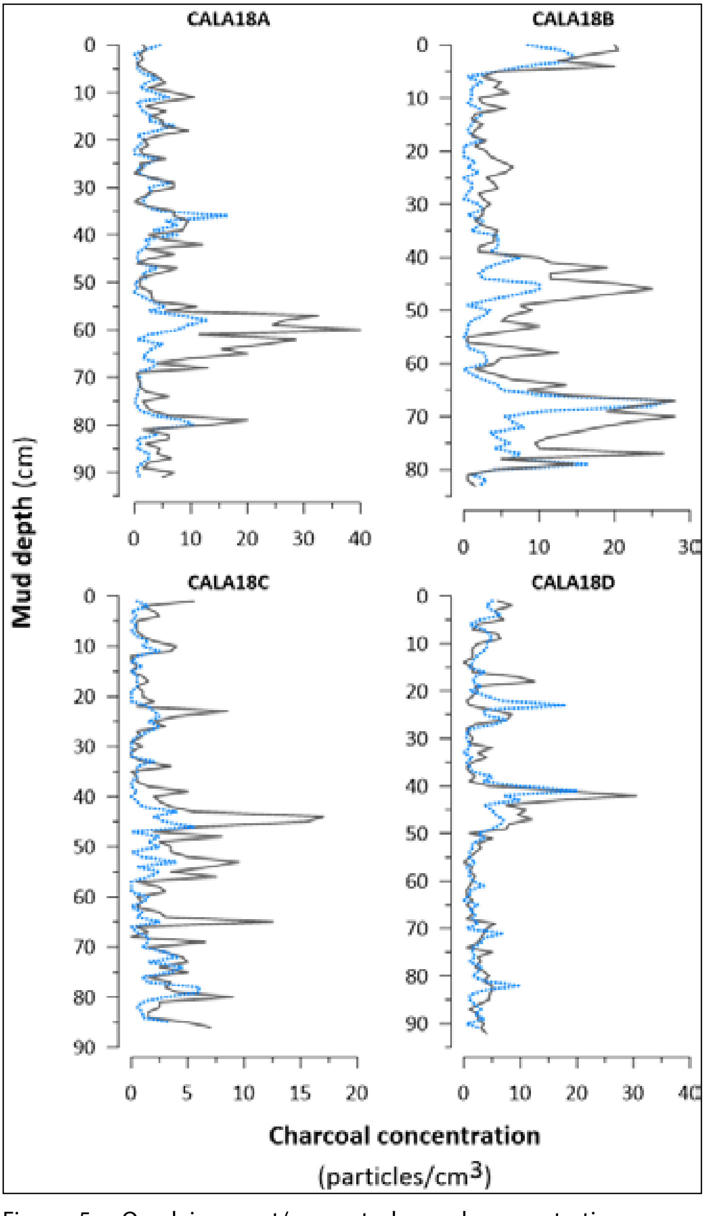

Figure 5.—Overlain count/recount charcoal concentration curves (particles/cm^3) for Camp Lake plotted against mud depth (cm). Note: counts versus recounts of the cores are purposely not identified as to not critique the performance of any individual student researcher.

concentration than the other. This is particularly true between ~43–47 cm. CALA18D, on the other hand, shows generally good agreement between the two charcoal concentration curves, with the only major discrepancies occurring at depths of ~17 and 23 cm. It is important to note that for many of the Camp Lake counts/recounts, the increases in charcoal concentration observed by the different student researchers are similar in timing, but rise to different magnitudes.

***Objective 3**: To test whether multiple analyses of multiple sediment records from the same study site, conducted by different student researchers, produce similar trends in the charcoal data.*

MCA of the four sediment cores recovered from Camp Lake was also used to address objective 3. Figure 6 shows the “best” charcoal concentration curve as well as the MS curves from each core overlain on top of one another from the CALA18A and CALA18B cores, which both captured the sediment-water interface (Figure 6A), and the CALA18C and CALA18D cores, which did not capture the sediment-water interface (Figure 6B). In this case, “best” was defined as the curve that included the most pronounced trends in charcoal concentration. Using the MS curves from CALA18A and CALA18B, it was determined that the core depths were offset by 9 cm. As a result, the starting depth of core CALA18A was adjusted downward by the same amount so that the sample depths matched those of CALA18B. Based on the MS curves from CALA18C and CALA18D, it was evident that the sample depths from these cores did not need to be adjusted. However, note that the sedimentation rate of these cores, as indicated by the MS curves, varies slightly between the two records at a few different depths (Figure 6B-right panel). This implies that the charcoal concentration curves for cores CALA18C and CALA18D should not be completely synchronous.

While not identical, the trends observed in the CALA18A and CALA18B cores are generally similar and show good agreement, both in terms of charcoal concentration values and the timing of major increases and decreases. The largest period of discrepancy between the curves occurs at a depth of ~40–50 cm, where CALA18B records much higher values than those in CALA18A, and to a lesser extent between ~15 and 25 cm. However, the largest rise in charcoal in both records occurs between 65 and 75 cm and to nearly identical concentration values. Note that only core CALA18B captures the rise in charcoal near the top of the record, which most likely results from the Jolly Mountain Fire that burned the watershed in 2017.

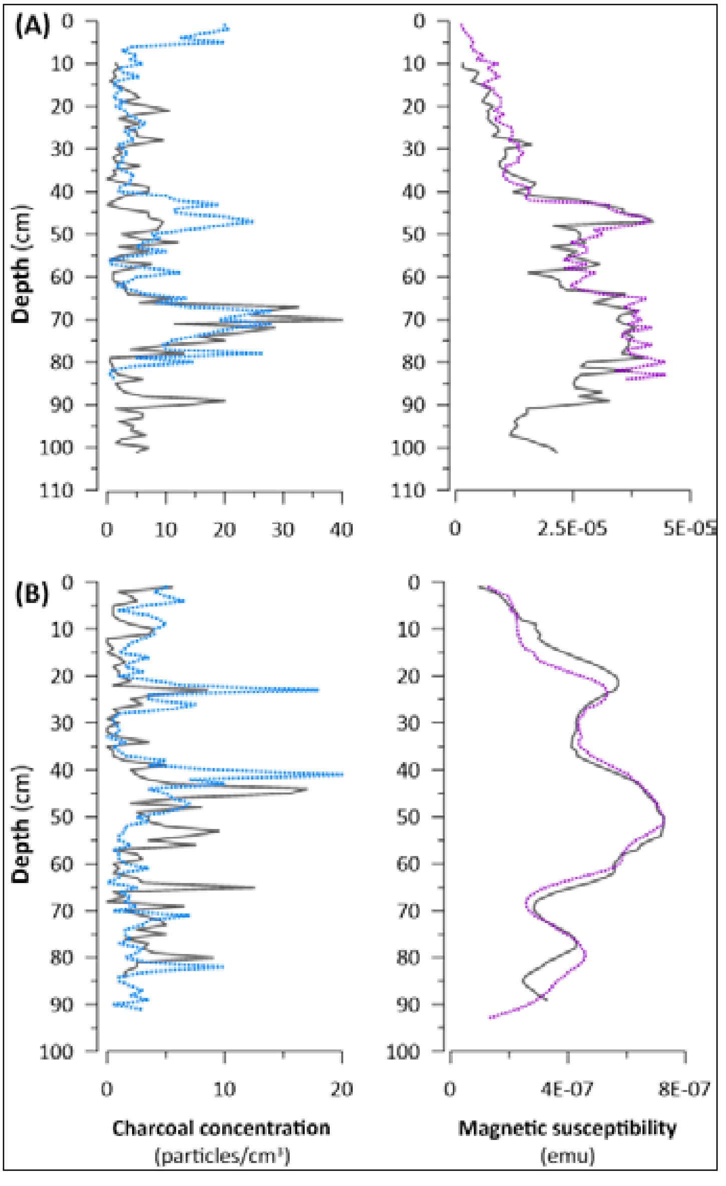

Figure 6.—Overlain charcoal concentration (particles/cm^3) and magnetic susceptibility curves for (a) CALA18A (solid lines) and CALA18B (dashed lines) and (b) CALA18C (solid lines) and CALA18D (dashed lines) plotted against depth (cm).

The CALA18C and CALA18D charcoal curves are also generally similar to one another, especially when the slight offset in the sedimentation rate of the records is taken into account. Most of the major increases and decreases in charcoal concentration are present in both records (e.g., at ~24, 42/45, and 80/84 cm); however, generally higher charcoal concentration values were recorded in the CALA18D core. A few discrepancies occur between the two charcoal curves, most notably at ~53–57 and 64–66 cm, with CALA18C recording much higher concentration values than those found in the CALA18D core.

Discussion

***Q1**: What do the charcoal data trends as shown by multiple records from a study site, analyzed both by the same and different student researchers, suggest about MCA data reproducibility?*

Overall, our study results are encouraging in terms of MCA data reproducibility. It is not entirely surprising that the most similar charcoal concentration curves come from the Lightning Lake cores, which were both analyzed by the same student researcher (Figure 4). However, even some of the Camp Lake curves indicate that different student researchers can analyze the same sediment record and produce nearly identical data (e.g., the CALA18D curves, Figure 6). Our results are similar to those of Schlachter and Horn (2010), who tested MCA data reproducibility on a single sediment core from Laguna Los Juncos, Costa Rica. Three counts of horizontally adjacent samples, in this case analyzed by the same researcher, reveal similar but not identical trends. The authors suggest that at least some of the between-count variability may stem from the fact that charcoal is not necessarily deposited evenly across the bottom of a lake, a concept that is supported by previous research (Tolonen 1986; Whitlock and Millspaugh 1996). This means that samples taken from the same layer in a sediment core may simply not contain the same number of charcoal particles. However, there are other important factors to consider when explaining charcoal data variability. As discussed in the following section, neither of our study sites are "ideal" in terms of their characteristics, which likely had some influence on the observed between-core, and potentially within-core, charcoal data variability. If this study were to be repeated on a more "ideal" lake, for example, one with deeper water, more regular bathymetry, and/or less bioturbation, this could potentially increase the degree of similarity between the charcoal records.

Our results also show that the analysis of multiple sediment cores from the same study site, both by the same and different student researchers, can produce generally similar charcoal trends. Edwards and Whittington (2000) completed a similar effort to ours on four sediment cores from Black Loch in eastern Scotland. However, their study analyzed microscopic charcoal particles found on pollen slides instead of wet-sieved macroscopic charcoal. Nonetheless, their results show similar charcoal trends between the four different records, but illustrate that the actual charcoal values varied considerably between the cores. A handful of other studies have used MCA to indirectly address questions of data reproducibility on multiple sediment cores from the same study site, including Walsh, Duke, and Haydon (2018), whose study evaluated charcoal accumulation in both a long and short sediment core from Fish Lake in the north-central Cascade Range of Washington. Their results indicate nearly identical trends in charcoal accumulation curves between the top portion of the long sediment core and the entirety of the short sediment core, but similar to Edwards and Whittington (2000), the overall magnitudes of the observed charcoal varied considerably between the records. All of these studies suggest that the overall trends in the charcoal data are more important than the absolute values recorded, and further encourage us trust our study results.

***Q2**: What do the charcoal data trends suggest about the use of "less-than-ideal" study sites in MCA (i.e., fire history) research?*

Given the nature of charcoal accumulation in water bodies and the processes that tend to blur or confound charcoal deposition, including sediment mixing due to wind or other disturbances and sediment focusing/slumping, researchers try to pick the most ideal sites in terms of lake bathymetry, lake surface to watershed ratio, and watershed topography (Tolonen 1986; Patterson et al. 1997; Whitlock and Anderson 2003). This means that often in the Pacific Northwest, "ideal" sites are located in remote, high-elevation, alpine environments with limited access (Walsh et al. 2015). However, because of the constraints associated with taking undergraduate students into the field, such as limited time, site access with available vehicles, and risk of injury, study sites are often chosen out of convenience rather than picking the "best" sites in terms of their physical characteristics (Walsh 2014). This means that many sites available for students to work on end up being "less than ideal."

Lightning and Camp Lake definitely fall into the category of less-than-ideal study sites for MCA. Lightning Lake has a steep cliff on one side and is only a few meters deep, which means that the sediment is likely subjected to some amount of mixing from either geomorphic events or wind (Swanson 1981). The site also has many aquatic organisms living in it, which could be a source of bioturbation (Larsen and MacDonald 1993). Camp Lake is also not an ideal study site, as it has a substantial inflow and outflow (Tolonen 1986) and appears to be rapidly infilling with sediment as it approaches the end of its lifespan as an open water body. In addition, relatively steep slopes surround the site and it has historically experienced landslide activity (personal observation). Our results suggest, however, that even though Lightning and Camp lakes are not ideal coring sites, the data derived from them seem to be credible in terms of reproducibility. This implies that scientists should not exclude sites just because they do not meet the typical site-selection standards. We argue that there are still valuable taphonomic and methodological lessons to be learned from performing MCA on sediment cores from nearly any study site, even if a usable fire history is not produced. However, we recommend that multiple cores are extracted and analyzed from "less-than-ideal" study sites in order to address these issues and construct a more reliable fire history.

Q3*: What do the study results suggest about the inclusion of undergraduate researchers in fire history research using MCA?*

Our study results support the inclusion of undergraduate student researchers in fire-history research using MCA. The students successfully participated in the field, laboratory, and data analysis portions of the research, with little to no previous experience in field- or laboratory-based science. It is important to point out, however, that this study was not designed to test how well students performed MCA, but was instead an evaluation of whether student researchers' efforts could lead to charcoal data reproducibility. The results from Lightning Lake, and to a lesser extent Camp Lake, show that data reproducibility is possible using student researchers. However, the within-core discrepancies in the Camp Lake records seem to indicate that not every student researcher identifies charcoal particles the same. From the lead author's observation of the students and the data produced, it appears that some students tend to be too exclusionary in their identification of charcoal particles. Anecdotally, it seems that the students who ask more questions while counting tend to identify a higher number of charcoal particles. Alternatively, other factors may influence within- and between-core data discrepancies, such as those mentioned above, or perhaps methodological choices made regarding sample size and sediment processing procedures (Schlachter and Horn 2010; Constantine and Mooney 2021). Future research suggested below could help elucidate the source of some of these discrepancies.

Conclusions and Future Research

This study shows that a high degree of data reproducibility is possible using MCA of multiple sediment cores from "less-than-ideal" study sites, performed by both the same and different student researchers. The study results presented here are unique in that, perhaps for the first time, student researchers used MCA to evaluate four sediment cores from the same site, and we are seemingly the first to employ multiple MCA analyses of the same sediment core by different student researchers. The students' efforts clearly show that at both Lightning and Camp Lakes, the analysis of multiple sediment cores from the same study site produced nearly identical charcoal concentration curves. Our results also suggest that a good level of data reproducibility is possible for multiple analyses of the same sediment record by different student researchers, in particular when overall trends instead of absolute values are considered.

However, in an attempt to further explain why the observed data discrepancies occurred, future research will include the same student researcher analyzing multiple charcoal samples from the same sediment core, similar to Schlachter and Horn (2010). This could help clarify whether within-core discrepancies in the charcoal data resulted from the varying ability of student researchers to correctly identify charcoal particles, or whether they resulted for other reasons. Important to note, however, is that part of the process in this study involved keeping the results of the first analysis hidden from the students who were performing the second analysis, so that the previous students' results did not influence their own. If a student does analyze samples from the same sediment core twice, it would be good to randomize the sample order the second time so there is less chance of bias. We encourage other researchers to ask similar methodological questions and design comparable studies that will continue to improve best practices for MCA and allow for better interpretation of fire-history data.

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