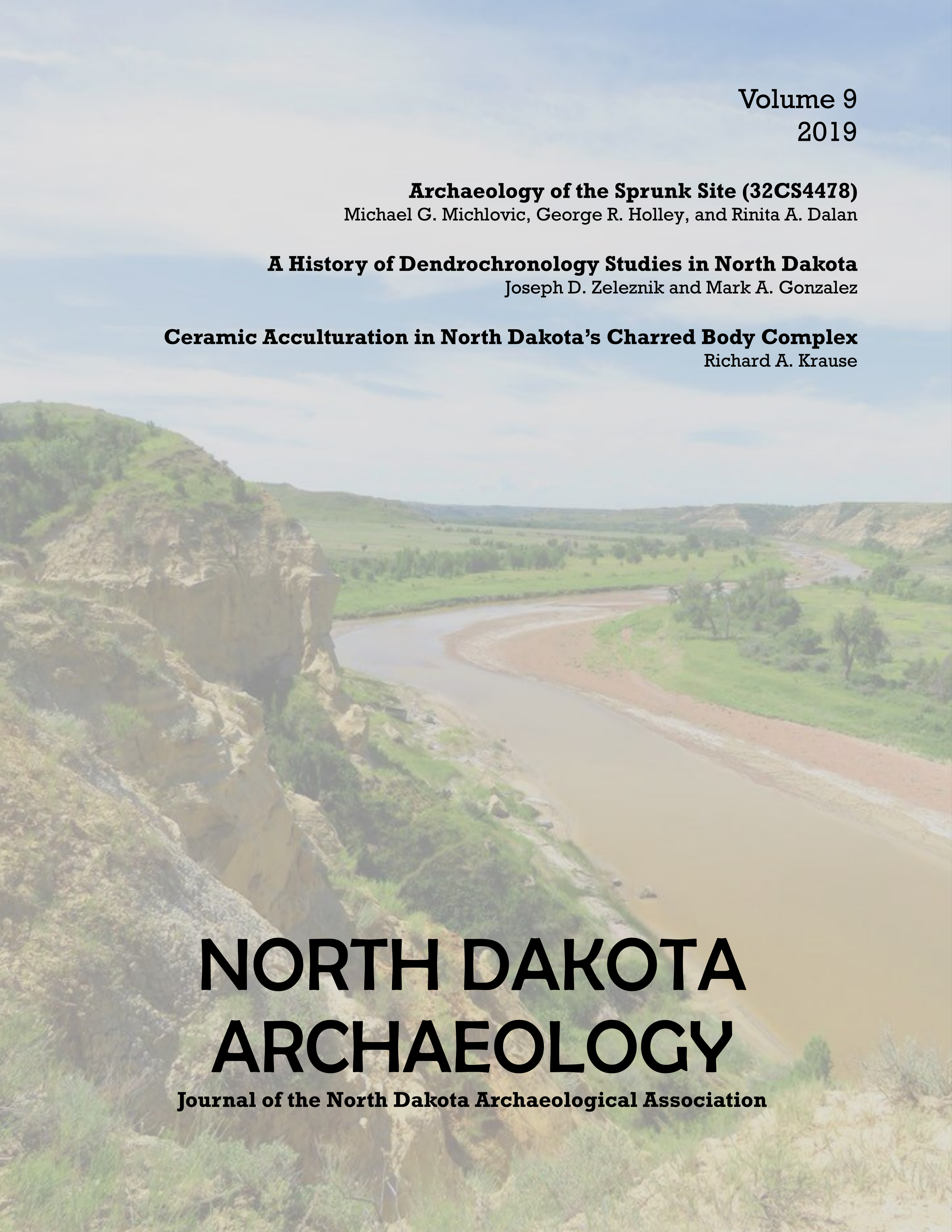

Volume 9
2019

Archaeology of the Sprunk Site (32CS4478)

Michael G. Michlovic, George R. Holley, and Rinita A. Dalan

A History of Dendrochronology Studies in North Dakota

Joseph D. Zeleznik and Mark A. Gonzalez

Ceramic Acculturation in North Dakota's Charred Body Complex

Richard A. Krause

NORTH DAKOTA ARCHAEOLOGY

Journal of the North Dakota Archaeological Association

A History of Dendrochronology Studies in North Dakota

Joseph D. Zeleznik
North Dakota University Extension, Forestry Specialist

Mark A. Gonzalez
US Department of the Interior, Bureau of Land Management

Abstract

Although dendrochronology – tree-ring analysis – has not been used much in archaeological studies in North Dakota, a number of studies have taken place in the state and the region, often focused on environmental or ecological questions. This paper provides an exhaustive overview of the dendrochronology studies, surveys and reports that have taken place in North Dakota, along with a brief discussion of how those studies can apply to archaeology, anthropology and history. One section is focused on the work of George F. Will, who made the first attempts at dendrochronology studies in the state; the remaining sections are focused on the various applications of tree-ring analysis such as ecology and natural history, disturbance ecology, dendrogeomorphology, dendroclimatology, dendrohydrology, and dendroarchaeology. Suggestions for future research directions are given.

Dendrochronology is the analysis of tree rings for the purposes of dating events or archaeological artifacts. Many species of trees produce one tree ring each year. Therefore, a count of tree rings formed in the trunk of a tree can provide a date, in many cases to the exact year and sometimes to the exact season, for the occurrence of various phenomena, such as the date of tree harvest, tree establishment, ecological disturbances or other events.

Dendrochronology also includes detailed analysis of the width, anatomical features, and growth patterns within and among tree rings to reconstruct past climatic conditions and environmental events, including drought, seasonal or annual precipitation, flooding, seasonal or annual stream discharge, lake level, fire occurrence, insect outbreaks, pesticide application and other events. Anthropologists commonly use environmental information to provide context for understanding or inferring cultural behavior or response to natural phenomena. Few archaeological or anthropological dating methods (e.g. radiocarbon dating, pottery and textile analysis, architectural styles, etc.) provide annual, and even sub-annual, dating precision. Dendrochronology is a tool that can provide both high-resolution dating and a high-resolution reconstruction of historical and prehistoric climatic conditions and environmental events.

With modern analytical statistical methods, the tree-ring record can be extended from living trees to long dead trees through a process known as cross-dating in which overlapping years of young trees and those of older trees are recognized from a variety of tree-ring characteristics (Figure 1). Cross-dating makes possible a high-resolution dating tool for events within the past few hundred to a thousand years or more in some cases (Stambaugh and Guyette 2009).

Most scientists do not think of dendrochronology as a viable tool in the sparsely treed state of North Dakota. The native ecosystems of the Great Plains are predominantly prairie whereas forests are often confined to a few isolated stands, some woody draws, and riparian areas along rivers and streams (cf. Severson and Sieg 2006). Additionally, when European traders and settlers came into the region in the 1800s, many trees were harvested for fuel or timber (Fenn

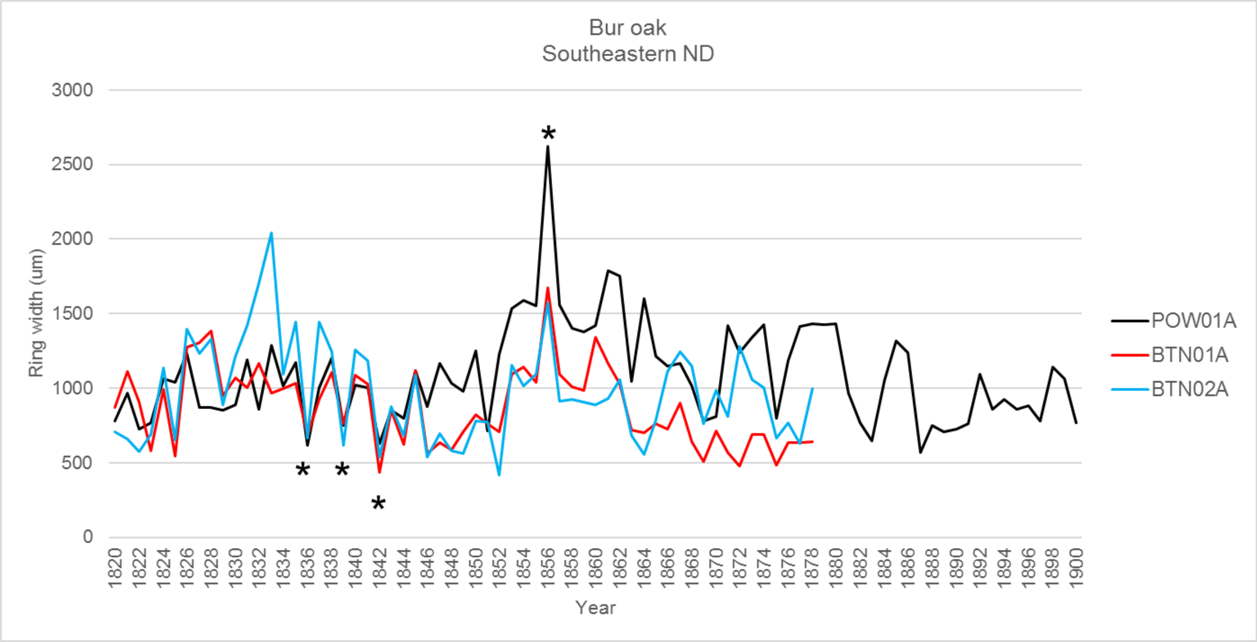

Figure 1. Example of crossdating using the Powell oak – POW01A, a standing tree harvested in 2006 (see Figure 2) – and two logs (BTN01A and BTN02A) from the Brunton cabin in Lisbon, North Dakota. Trees used in the Brunton cabin were harvested in 1878. Note the marker years (*) that show consistently narrow rings (1836, 1839 and 1842) or a large ring (1856). The Powell oak and the Brunton cabin trees grew approximately 25 miles away from each other.

Figure 2. A portion of the Powell oak, cut down in 2006 on the bank of the Sheyenne River, south Leonard, North Dakota. The T-square in the photo is three feet long; the green markers in the upper left portion of the sample denote 50-year increments, beginning in the year 2000. The innermost ring, from 1556, pre-dates the oldest rings found in numerous log buildings constructed in the 1870s in North Dakota.

2014), which resulted in a great loss in potential study materials. Nevertheless, a few researchers have identified old buildings and have found long-lived stands of trees that are well suited to dendrochronological research in North Dakota. Some individual trees provide samples that extend to the 1600s and even 1500s. Many nineteenth-century log buildings contain wood that grew in the 1600s, and a few contain wood from the 1500s. With persistence and some targeted sleuthing, we hope that future excavations of subfossil logs will extend the chronologies back even further.

Dendrochronology is a tool that can greatly augment archeological and anthropological studies. We provide a review of the existing dendrochronological studies in North Dakota so that they may be better used by the archaeological community. The applications of these studies are numerous, and we have organized them into broad categories such as ecology and natural history, disturbance ecology, dendrogeomorphology, dendroclimatology, dendrohydrology, and dendroarchaeology. We include one section devoted exclusively to George F. Will, who completed the first dendrochronology studies in North Dakota. Many of the documents cited here could be included in more than one category. Some of the documents are highly detailed scientific studies while others simply provide an estimate of tree age, presumably based on ring count. Table 1 summarizes the various chronologies and studies referenced herein. Readers who would like to learn more about the basics of dendrochronology techniques are referred to Stokes and Smiley (1968); for more specific information and examples about the application of dendrochronology to archaeology, refer to Kuniholm (2001).

George F. Will

The history of dendrochronology in North Dakota begins with George F. Will and his seminal publication "Tree ring studies in North Dakota" (1946a). This was a broad ranging document that attempted to bring together various applications of dendrochronology including archaeology, climatology and disturbance ecology. Parts of this work were re-published in other venues (Will 1946b; see also Dietrich 1965) and additional data from South Dakota were combined with the original study and published elsewhere (Will 1948, 1949).

At the time of his study, Will was President of the State Historical Society of North Dakota (SHSND), which gave him access to many archaeological sites and artifacts. He collected more than 50 samples from at least 14 sites throughout the state. Bur oak (*Quercus macrocarpa*) and "cedar" (likely Rocky Mountain juniper, *Juniperus scopulorum*) comprised the bulk of his samples, though he also mentioned both cottonwood[1] and hackberry (*Celtis occidentalis*) in the document.

A thorough reading of Will's publications leaves us with a number of questions, mostly involving methodology and statistical reliability of his results. Unfortunately, Will was rather vague when discussing his techniques and conclusions. Although most of the modern measurement and statistical techniques were not available in Will's day, skeleton plotting was well-established, and it is unclear whether or not Will used this technique correctly. Skeleton plotting involves assessing, by eye, the relative width of each ring and plotting those relative widths over time (years). This technique is applied to each sample in a given area, and then those individual plots are combined into a Master Plot. A review of Will's files and documents in the North Dakota State Archives suggests that he was unaware of how to skeleton plot correctly. Additionally, one of Will's documents lists a cutting date of one sample as "very probably 1720," wording which does not engender much confidence in those results. A regional-level comparison of dendrochronological dates with radiocarbon dates and ceramic ordinations can be found in Johnson (2007).

Will's methods and interpretations were criticized by at least one of his contemporaries (Bell 1948) and more recent scholars have echoed similar concerns (Caldwell and Snyder 1983). Weakly's (1971) results from archaeological sites in South Dakota were similarly called into question (Johnson 2007). Nevertheless, Will's main accomplishment is the collection of many samples from throughout North Dakota, and most of these samples are still held in storage at the SHSND. Two of Will's most well-known samples include:

---

[1] Note that different authors have used different common and scientific names to refer to cottonwood or Plains cottonwood (*Populus deltoides*) while others refer to Plains cottonwood (*P. sargentii* or *P. deltoides* ssp. *monilifera*). We believe that all names are referring to the same species. Therefore, the names are used interchangeably herein to be consistent with their reference in the source materials.

Table 1. Summary of dendrochronological studies in North Dakota, arranged chronologically.

Reference	Location – County	ITRDB† Record	Tree Species*	Interval (Years AD)	Comments
Will 1946a	Burleigh		QUMA, JUSC	~1567-1940	Dendroclimatology
Will 1946b					Selection from Will (1946a)
Will 1948					Dendroarchaeology – added South Dakota sites
Will 1949					Very similar to Will (1948)
Harrison and Reid 1967	Turtle River State Park – Grand Forks		PODE, ULAM	1909-1966	Paleohydrology; flood reconstruction
Everitt 1968	Theodore Roosevelt National Park (TRNP), North Unit – McKenzie		PODE	~1710-1965	Dendrogeomorphology
Johnson et al. 1976; Johnson et al. 2012	Garrison reach of Missouri River between Garrison Dam and Lake Oahe – Burleigh, McLean, Mercer, Morton, Oliver		PODE, ULAM, FRPE, ACNE2, QUMA	1892-2006	Dendrogeomorphology and riparian ecology; forest response to dam construction and operation
Reily and Johnson 1982	Garrison reach of Missouri River between Garrison Dam and Lake Oahe – Burleigh, McLean, Mercer, Morton, Oliver		PODE, ULAM, FRPE, ACNE2, QUMA	1915-1977	Dendrogeomorphology and riparian ecology; forest response to dam construction and operation
Stockton and Meko 1983	Slope		PIPO	1700-1977	Dendroclimatology
Sieg et al. 1996	Burning Coal Vein – Slope	ND001	PIPO	1592-1990	Dendroclimatology
	Cross Ranch, Sanger Unit – Oliver	ND002	QUMA	1788-1990	Dendroclimatology
	Icelandic State Park/Pembina Hills – Pembina, Cavalier	ND003	QUMA	1830-1992	Dendroclimatology
	Killdeer-Dvirnak – Dunn	ND004	QUMA	1777-1990	Dendroclimatology
	Masonic/Bear Islands – Bottineau	ND005	QUMA	1676-1990	Dendroclimatology
	TRNP, South Unit – Billings	ND006	JUSC	1630-1991	
Gonzalez 2001a, 2001b	Logging Camp – Slope		PIPO	1525-1991	Dendroclimatology
	Toms Wash – Billings		PODE	1816-1996	Dendrogeomorphology
	Dantz Cr. – Billings		PODE	1784-1996	Dendrogeomorphology

Table 1, cont.. Summary of dendrochronological studies in North Dakota, arranged chronologically.

Reference	Location – County	ITRDB† Record	Tree Species*	Interval (Years AD)	Comments
Gonzalez 2001a, 2001b	Bear Cr. – Billings		PODE	1784-1996	Dendrogeomorphology
	Paddock Cr., TRNP – Billings		PODE	1833-1996	Dendrogeomorphology
	Jones Cr., TRNP – Billings		PODE	1868-1996	Dendrogeomorphology
	Jules Cr., TRNP – Billings		PODE	1868-1996	Dendrogeomorphology
Beckers 2007	Logging Camp – Slope		PIPO	1570-2004	Fire history
Slotten and Zeleznik 2009	Various – Ransom, Richland		QUMA	1567-2005	Dendroarchaeology
Zeleznik et al. 2010	Various – Cass		QUMA	1730-2010	Dendroarchaeology
Zeleznik and Walla 2010	TRNP, South Unit – Billings, Bowman		FRPE	1885-2010	Disturbance ecology
Vanstone 2012	Camp Grafton – Ramsey		QUMA	1725-2008	Streamflow reconstruction
	Cross Ranch – Oliver		QUMA	1769-2008	Streamflow reconstruction
	Graham's Island – Benson, Ramsey		QUMA	1841-2008	Streamflow reconstruction
	Killdeer – Dunn		QUMA	1899-2008	Streamflow reconstruction
	Lake Metigoshe – Bottineau		QUMA	1748-2008	Streamflow reconstruction
Wertz et al. 2013	Pembina Golf Course – Pembina	ND007	QUMA	1856-2010	Paleohydrology; flood reconstruction
	Riverside Park – Grand Forks	ND008	QUMA	1865-2010	Paleohydrology; flood reconstruction
	Lincoln Park – Grand Forks	ND009	QUMA	1854-2010	Paleohydrology; flood reconstruction
	Oak Grove Park – Cass	ND010	QUMA	1878-2010	Paleohydrology; flood reconstruction
	Red River Trail – Cass	ND011	QUMA	1886-2010	Paleohydrology; flood reconstruction
	Lindenwood Park – Cass	ND012	QUMA	1870-2010	Paleohydrology; flood reconstruction
Edmondson et al. 2014; Meko et al. 2015	TRNP, North Unit – McKenzie		PODE	1643-2010	Dendrogeomorphology; streamflow reconstruction
Zeleznik 2015	Biesterfeld site – Ransom				Dating of archeological site

†ITRDB – International Tree Ring Data Bank: https://www.ncdc.noaa.gov/data-access/paleoclimatology-data/datasets/tree-ring.

*ACNE2 = *Acer negundo*, boxelder; FRPE = *Fraxinus pennsylvanica*, green ash; JUSC = *Juniperus scopulorum*, Rocky Mountain juniper; PIPO = *Pinus ponderosa*, ponderosa pine; PODE = *Populus deltoides,* Plains cottonwood; QUMA = *Quercus macrocarpa*, bur oak; ULAM = *Ulmus americana*, American elm.

- Will's "Master Oak" – A 373-year-old bur oak that was cut down in 1940 from a coulee located approximately six miles northwest of Bismarck. Will did not list the exact date the tree was cut, and it is not clear if the last year of growth is 1940 or 1939. An attempt to crossdate this sample with a bur oak chronology for the Cross Ranch-Sanger area (30 miles away) was unsuccessful. Additionally, both authors have independently studied this sample and the growth of this tree was somewhat complacent. That is, there is not much year-to-year variability in the ring widths. The quantitative measure of this is called sensitivity. The Master Oak has a sensitivity of <0.18 (data not shown), limiting its usefulness in climate reconstruction studies. However, the sample may be useful for cross-dating, especially for those samples dating to earlier than 1700.
- Biesterfeldt (site 32RM1) – In 1938, an archaeological excavation was performed at the Biesterfeldt site in Ransom County, 15 miles east of Lisbon. The research was first discussed briefly by Strong (1940) and later more thoroughly by Wood (1971). Neither George Will nor dendrochronology are mentioned in Strong's paper, but Will is briefly mentioned in Wood's (1971) document. Will (1946a:17) also mentions a sample collected from the "old village site of the Cheyenne Indians on the Sheyenne River." This is the sample that Will concluded was cut in "very probably 1720." A specimen (A3690) located in the George Will collections at the SHSND is tagged as "Cheyenne Village" and is presumably the same sample mentioned above. Zeleznik (2015) thoroughly analyzed this sample and was unable to come to a firm result regarding the years of its growth. The two sides of the samples contain only 27 and 41 rings, far too few for good crossdating.

Ecology and natural history

The simplest method used in dendrochronology is a ring count. Because trees in this region generally produce a single growth ring each year, ring count will reveal a tree's age. Completing a ring count across a number of individual trees at a given site can also tell us about the age of a stand. This information often leads to conclusions about stand establishment or the natural history of a site.

Humans have impacted forest stands in North Dakota for a long time. Will (1946a) recounts the story of Scattered Corn, a Mandan woman who had the knowledge and right to build earth lodges. According to Scattered Corn, oak was specified to be used in the construction process, and only when oak timber supplies became exhausted because of growing populations did builders switch to using cottonwood. Additionally, Native Americans are assumed to have established the isolated limber pine (*Pinus flexilis*) stand found in southwestern North Dakota (Beckes et al. 1982; Potter and Green 1964a). Although Potter and Green (1964a) speculated about the origin of the stand and discuss its natural history (see below), Beckes et al. (1982) associated a number of nearby archaeological sites with the limber pine.

When Europeans moved into North Dakota, they harvested timber for fuel and construction materials. The vast majority of "old" bur oak trees found in the Red River Valley date to the 1870s or 1880s (cf. Wertz et al. 2013), though a few older trees are found on rare occasion (Zeleznik et al. 2016). In Beckers's (2007) study of fire-killed ponderosa pine, his sampling targeted those trees presumed to be the oldest in the area. Over one-third of the trees he sampled had been established in the 1860s and 1870s, suggesting that a large amount of timber was harvested at that time, allowing young seedlings to establish and grow.

Another application of using simple ring counts in determining stand age has been with cottonwoods to determine the timing of sediment deposition and land formation and the impacts of those deposition/formation processes on ecosystems (e.g., Dixon et al. 2012; Johnson et al. 2012). Additional discussion of dendrogeomorphology studies is found below.

Two studies (Beckes et al. 1982; Potter and Green 1964a) used the ring count technique to determine the ages of trees in an isolated limber pine stand in southwestern North Dakota. Beckes et al. (1982) cored 45 trees and found a maximum age of 208 years; Potter and Green (1964a) cored 50 trees and found the oldest to be 208 years old. Beckes et al. (1982:13) declared that, "an examination of decadent growth and decay rates suggests an estimate of 600 years as the maximum possible age of the stand," but they do not offer any details as to what that examination or analysis entails.

Murdoff (2010) measured diameter and counted rings on bur oak stumps to determine if size and/or age of the harvested tree affected the sprouting ability of the stump. All size classes of trees, from less than 12" diameter to greater than 24" diameter, had good sprouting ability if the trees were harvested in the winter. For those trees harvested during summer, sprouting ability was good between 12" and 24" diameter, but declined in the smallest and largest size classes. We caution against extrapolating these results as this was a single study at a single site.

How old is old?

Trees in North Dakota face a number of stressors each year. Extremes are found from summer drought and heat to bitterly cold temperatures in the winter. Ecological disturbances come in the forms of wildfire, floods and windstorms. Despite these challenges, a number of individual trees have survived to a surprisingly old age.

- Bur oak – In 2005, a landowner near Sheldon began plans to remove a very large bur oak from his property (Figure 2). He contacted North Dakota State University to determine if there was interest in collecting a cross-section from the tree. In January 2006, the tree was removed and a sample collected. The cross-section was solid nearly to the center of the tree and contained 450 rings (Slotten and Zeleznik 2009). The cross-section was useful in crossdating samples from two historic log cabins in the region, though we were not able to successfully crossdate an archaeological specimen collected within 15 miles of this tree (Zeleznik 2015). Nelson (1948) showed a photo of a large bur oak on Masonic Island in the Turtle Mountains and claimed its age to be 570 years old. However, no methodology or hard data are presented in the document. Samples collected by Sieg et al. (1996) in this area dated one tree on Masonic Island to 1834 (156 years old at the time of sampling) and another at Lake Metigoshe State Park to 1676 (314 years old). Potter and Moir (1961) took a sample of a single bur oak tree in the Turtle Mountains, determining it to be 193 years old.
- Green ash (*Fraxinus pennsylvanica*) – A study completed by Murdoff (2010) included a section on the ability of bur oak trees of various ages to sprout from the stumps following harvest. Out of 115 samples, one turned out to be green ash. This tree was 184 years old when harvested, the oldest green ash that we can find any hard data for. The oldest green ash from Zeleznik and Walla's (2010) study in the North Dakota Badlands was 125 years old.
- Ponderosa pine (*Pinus ponderosa*) – In the North Dakota Badlands, Gonzalez (2001a, 2001b) collected a core in 1996 with a pith date of 1526 (470 years old). It is unknown if this tree is still alive following the Deep Creek fire as mentioned in Beckers's (2007) study. Beckers (2007) found two samples that were approximately 430 years old, dating to the 1570s. Though these were less than half the age of the oldest ponderosa pine ever reported – 929 years (Utah) (OLDLIST 2018) – the ages were nonetheless impressive.
- Cottonwood – Many people believe that fast-growing trees tend to be short-lived. While some species or hybrids certainly fit this generalization, others do not. Edmondson et al. (2014) collected cores from 383 cottonwood growing along the Little Missouri River in western North Dakota. The oldest tree in their study was 370 years old, the oldest Plains cottonwood ever recorded.

Tree size vs. age

A common misconception is that tree size and age are closely correlated. Hard data show mixed results. For example, in Edmondson et al.'s (2014) study of cottonwood in the Little Missouri Badlands of North Dakota, the correlation between tree size – DBH, diameter at breast height – and age showed an R^2 value of 0.79. While this correlation is relatively high, there is increasing variability as trees get older and larger. For example, a 100-year-old tree in their study could be as small as 35 cm or as large as 80 cm DBH. A 200-year-old tree could range from 60 cm to 140 cm DBH. Harmon (2010) studied bur oak savannah in eastern North Dakota and northwestern Minnesota. Age-diameter correlation in that study showed an R^2 value of less than 0.20; however, there were only 24 trees included in that calculation and the overall age range was only 86 years.

Potter and Green (1964b) tried to correlate age with DBH in ponderosa pine in western North Dakota, but were unable because 88% of their samples were less than 50 years old. However, they were able to show that the majority of ponderosa pine stems had eccentric growth, with wider rings on the east and southeast sides. The authors attributed their results to the prevailing northwest winds in the area. Surprisingly, Potter and Green (1964b) noted no false rings in any of their samples, which included a single increment core from each of 100 trees, plus 111 cross-sections.

Together, the above-mentioned studies indicate that humans have had a major impact on North Dakota's forests. Though some forests have been impacted more than others, several very old individual trees still remain in North Dakota, scattered across the state. Additionally, more hard data are needed from the various species and sites in order to draw broader, landscape-level conclusions regarding climate, disturbance or other ecological processes.

Disturbance ecology: fires, flooding and human impacts

Ecological disturbances such as fire, flooding and landslides leave their imprints on both individual plants and on ecosystems. With trees, some type of scar or wound is often created, and new tissue (callus) grows over the damaged area (Figure 3). In North Dakota, trees document disturbances in a number of ecosystems.

In 2004, the Deep Creek fire traveled through the native ponderosa pine forest found in northern Slope County. The fire burned through the crowns of trees, killing them. While devastating for the ecosystem, this also created an opportunity for researchers to collect samples from trees that recorded previous injuries in their growth rings and scars. By analyzing these injuries, Beckers (2007) concluded that the average fire-return interval before 1900 was 28.5 years. After 1900, the timespan increased to more than 50 years between fires. The conclusion was that modern fire-prevention and fire-management policies resulted in less frequent wildfire. One of the major challenges highlighted in this study was which scars to include in the dataset. That is, wounds occur for many reasons, including damage due to wildlife or livestock, and differentiating the causes of these diverse wounds is not easy.

Ice or other debris in floodwaters often wounds trees located next to rivers and streams. Harrison and Reid (1967) used flood scars from ash trees growing along the Turtle River in Grand Forks County to reconstruct the flooding history of the area. The first part of their study involved proof-of-concept, in which they correlated floods of known depth and timing to the height and age of wounds on one cottonwood and two elm trees located in the river floodplain. While the authors recognized that their technique was not 100% accurate in reflecting flood magnitude, they found enough consistency among the trees to conclude the method was sound. The second goal of their study was to model flood magnitude and return interval, based on either stream gauge data or information from scarred trees. Generally, they found good correlation between the two techniques.

Flooding can also produce unique internal growth even when no external wounds are created. Vessels are large cells created early in the growing season in trees such as oak, ash and elm. If an early season flood occurs as the vessels are forming, they are much smaller in diameter (Yanosky 1983) or their production may drag out later into the growing season than is normal (Wertz et al. 2013). Following the 1997 floods on the Red River, a number of studies capitalized on this phenomenon to determine the flooding history of the Canadian portion of the river (cf. St. George and Nielsen 2000, 2003). The authors found flood signatures in bur oak timbers on the Red River dating as far back as the year 1510. Wertz et al. (2013) applied this same technique to standing bur oak trees on the United States stretch of the Red River. The oldest flood ring they found dated to 1862, but the oldest tree in their study dated to only 1853. Surprisingly, the 2010 Red River flood, the fifth-largest (by peak stage) since 1900, resulted in few or no flood rings in Wahpeton, Fargo and Grand Forks.

The results of the Canadian studies on the Red River were incorporated into plans for the expansion of the Red River Floodway around the city of Winnipeg, Manitoba (Brooks and St. George 2015). Similar studies could be used to help planners and engineers in their designs for the Fargo-Moorhead diversion. Though a similar study is underway for the U.S. portion of the Red River, it has not been completed at the time of this publication.

In the late 2000s in the South Unit of Theodore Roosevelt National Park (TRNP), employees began noticing dieback on green ash trees (Zeleznik and Walla 2010). In 2010, researchers from North Dakota State University surveyed several sites within the park and one outside location in an attempt to determine the cause(s). Part of the survey work included collecting increment cores from both affected and non-affected sites. There were many stressors and no overall pattern was observed in the dieback, though it was later determined that the affected areas had received herbicide treatments in late 2007 to control noxious weeds. Trees from both treated and untreated sites had small rings in 2008, with larger rings in both 2009 and 2010. In some trees, the 1947 ring showed abnormal growth that could have been caused by a flood of the Little Missouri River. The oldest tree sampled in that survey dated to 1885.

Dendrogeomorphology

Geomorphologists study the processes that construct and destroy landforms. Although aerial photography provides a valuable tool to reconstruct recent geomorphic events dating back to the 1930s, trees can provide evidence of deposition and landform construction as well as erosion and landform destruction for periods of a few to several hundred years in certain circumstances.

A seminal study in dendrogeomorphology was performed by Everitt (1968) in the North Unit of Theodore Roosevelt National Park (TRNP) in McKenzie County. Everitt collected increment cores from Plains cottonwood trees. Everitt (1968) used the prevailing ecological assumption that Plains cottonwood generally establishes on recent stream deposits near the channel margin to reconstruct the 225-year history of Little Missouri River channel and valley bottom in part of the North Unit. Therefore, where one finds a sapling, one is generally along a channel margin, whereas older trees provide the data to reconstruct the former position of a stream channel. By coring and dating trees across the valley bottom, Everitt (1968) was able to construct a map showing the ages of alluvial sediments and by extension the position of the Little Missouri River channel over a 225-year span from approximately the 1740s to the mid-1960s. The ability to reconstruct the geomorphic history of the valley bottom permitted a number of estimates regarding the evolution, destruction, and age of fluvial landforms. In particular, tree-ring data permitted the calculation of:

- The rate of lateral channel migration across the valley bottom;

Figure 3. Ponderosa pine sample collected from southwestern North Dakota following the Deep Creek fire in 2004 (Beckers 2007). Note the callus tissue growing at the bottom left and bottom right of the sample following an earlier wound. A smaller wound, created even earlier is just to the right of the pith.

- The rate at which new floodplain was constructed and existing floodplain was destroyed;
- The rate by which floodplain surfaces aggraded vertically;
- The relation between tree age and floodplain elevation;
- The residence time of alluvium in the valley bottom;
- The approximate age of the valley bottom landforms, which he established as largely formed in the past few hundred years, in stark contrast to previous studies that suggested formation around the end of the Wisconsinan Stage around 10,000 years ago.

A more recent study (Miller and Friedman 2009), compared the dendrogeomorphic approach of Everitt (1968) with an image-comparison method to test some of Everitt's findings and to gain greater understanding of the relations between flood magnitudes and the rates of floodplain formation and destruction. The Miller and Friedman study (2009) was set in the North Unit of TRNP as well and used a series of eight aerial photographs that were taken approximately a decade apart (spanning 1939-2003) to create a higher resolution examination of the influence of flood frequency and magnitude on fluvial geomorphic processes. This work is important because it largely corroborates the approach Everitt (1968) used, thereby validating the dendrogeomorphic approach to reconstruct fluvial history well beyond the timeframe of aerial photographs.

Gonzalez (2001a, 2001b) reconstructed fluvial history in several tributary streams of the Little Missouri River in Billings County using the dendrogeomorphic approach. The objectives of these studies were to determine the timing and probable causes of channel incision in these tributary streams and to develop a process-response model to illustrate the formation and evolution of streams in the Little Missouri Badlands. Gonzalez (2001a, 2001b) cored approximately 350 cottonwood trees along seven Badlands streams (Jules Creek, Jones Creek, Talkington Draw, Paddock Creek, Bear Creek, Dantz Creek, and Toms Wash). The oldest tree in this dataset had an approximate establishment date of 1770. Nearly two-thirds (65%) of the sampled trees established during a 40-year interval from 1861 through the 1890s; half the samples (51%) established in just a 20-year interval from 1861 through 1880.

In addition to providing some temporal constraints on the likely timing of channel incision, the spatial patterns of tree establishment on different landforms (i.e., terraces and inset floodplains) revealed a detailed pattern of headcut erosion and concurrent downstream aggradation (Figures 4 and 5). This meant that as the point of channel incision migrated upstream, sediment generated from the downcutting process was transported downstream. In some downstream reaches the sediment volume exceeded the transport capacity and sediment was deposited across the valley bottom leading to floodplain aggradation. Cottonwood trees that are buried by floodplain deposition by five or more meters establish that the channel and floodplain in some reaches of a stream can aggrade at the same time that the channel is incising or downcutting in other reaches.

One of the earliest applications of dendrogeomorphology in North Dakota was performed by Aronow (1957) in his analysis of lake level fluctuations in the Devils Lake and Stump Lake basins, Ramsey County. Though it is a stretch to call this a *dendro*-geomorphology study, the author did collect a single bur oak stump from Stump Lake which contained approximately 100 rings. Radiocarbon dating of the sample (see Broecker et al. 1956) indicated the sample was 500 ± 400 years old. (Curiously, Aronow listed the results of the radiocarbon analysis as 500 ± 200 years old.)

Despite the wide range of potential ages for that single sample, Aronow postulated that trees established in well-watered positions along the shoreline of Stump Lake during dry periods when lake level declined but were killed by rising lake levels during a shift to wetter climatic conditions. He used the radiocarbon age (loosely defined as 500 ± 200 years before present) of a tree stump to speculate that trees established at a comparatively low lake level during a dry period; then these trees were submerged by rising lake levels, presumably coincident with a moister period from about 1440 to 1850, a period also referred to as the Little Ice Age. Aronow indicated that Will (1946a) had produced a chronology from another bur oak from Stump Lake, but Will's Stump Lake sample and chronology have not yet been examined or verified by modern dendrochronological techniques. Aronow's sample from Stump Lake is currently housed in the F.D. Holland, Jr. Geology & Geological Engineering Library at the University of North Dakota.

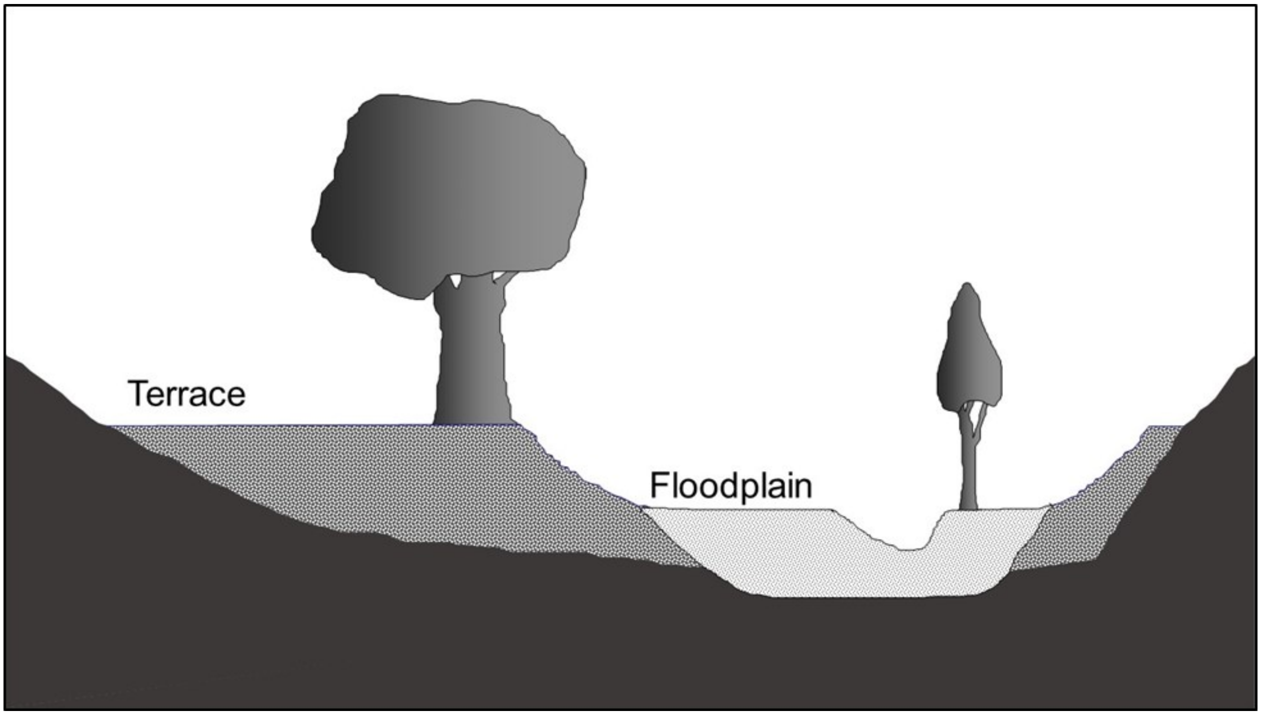

Figure 4. The time of stream incision within a given reach is constrained by the age of the youngest cottonwood tree on the abandoned surface (i.e., terrace) and the oldest tree on the inset active floodplain surface. Adapted from Gonzalez (2001b).

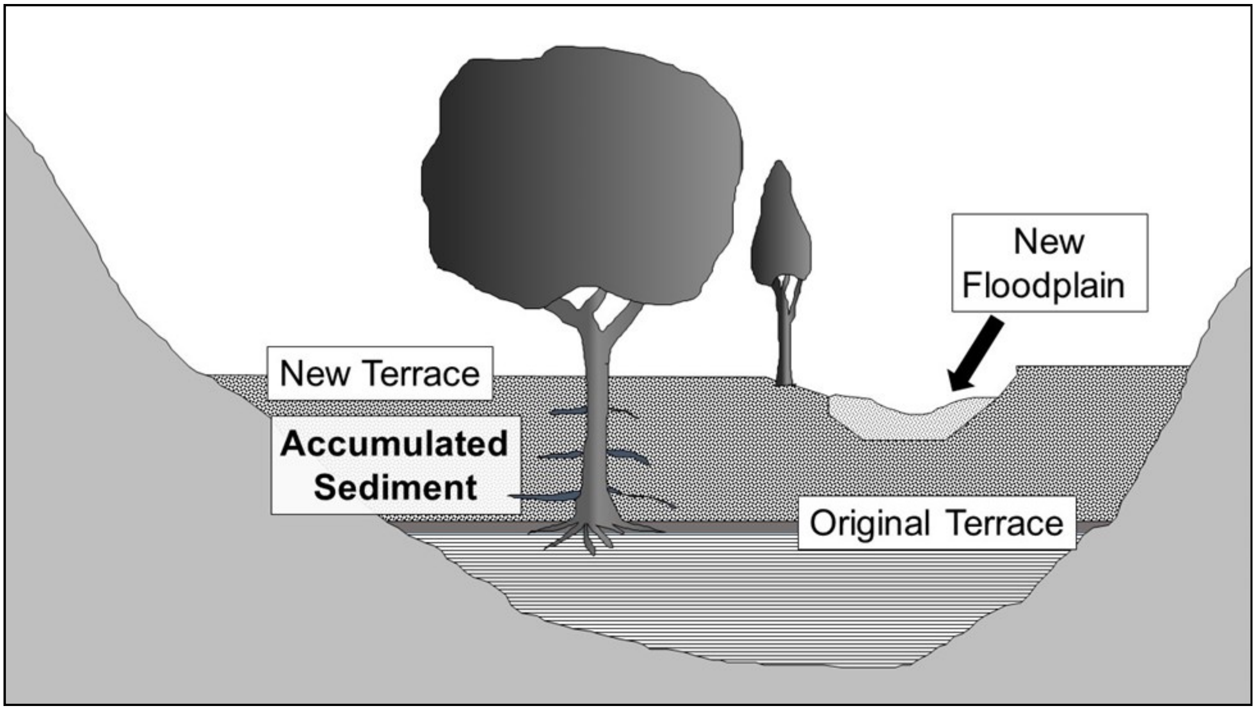

Figure 5. In an aggrading system where sediment is being stored and the valley floor elevation has risen, established trees become partially buried. Cottonwood trees send out adventitious roots from the buried trunk into the encasing sediment as a way to survive partial burial. Young and old trees appear to occupy the same geomorphic surface, though the older trees established on a surface that has become buried since the establishment of the younger cottonwood tree. Adapted from Gonzalez (2001b).

Dendroclimatology and dendrohydrology

Climatic variability, particularly the frequency and severity of drought across the northern Great Plains, and the great dependency of the region's agricultural economy on precipitation makes analysis and understanding of climate patterns extremely important. Historical weather records for the northern Great Plains are comparatively short (few stations have data preceding the 1880s), so the ability to put historical droughts, such as the Dust Bowl era of the 1930s, into a long-term perspective is limited for the region. Dendroclimatology uses the annual growth characteristics of trees to reconstruct climatic conditions over decades or centuries and to extend understanding of climatic patterns and drought conditions well beyond historical records.

The northern Great Plains is sparsely treed, which presents inherent challenges in finding suitable specimens for dendroclimatology. The few trees that do establish and grow in the area are subjected to fire, drought, herbivory, floods, and human impacts leaving few trees of suitable age for dendroclimatic analysis. Nevertheless, several dendroclimatic studies have been initiated or completed in North Dakota (Edmonson et al. 2014; Gonzalez 2001a, 2001b; Meko et al. 2015; Sieg et al. 1996; Stockton and Meko 1983). Most of these studies have examined the tree-ring record and climatic response of ponderosa pine, bur oak, and Rocky Mountain juniper. Recently, Edmondson et al. (2014) successfully demonstrated the utility of Plains cottonwood for reconstruction of streamflow and precipitation.

As previously mentioned, George Will attempted some early dendroclimatic analysis in the 1940s. Will's studies did not have the benefit of modern dendrochronological techniques or computer analysis; therefore these works were imprecise. The first dendroclimatic study in North Dakota to use modern research techniques was performed by Stockton and Meko (1983). They collected increment cores from 17 sites across eight states (Arkansas, Iowa, Montana, Nebraska, North Dakota, Oklahoma, South Dakota, and Wyoming). The Burning Coal site in Slope County was the only site in North Dakota included in the study. The Burning Coal data set contained 20 samples with tree rings as far back as 1900, 18 samples to 1800, eight samples to 1700, and one sample back to 1600 or earlier. Stockton and Meko (1983) found that the annual tree-ring indices from sites across the Great Plains, including the Burning Coal site, were most strongly correlated with the precipitation from September of the previous year through August of the current tree-ring year. This means that annual tree rings may not accurately reflect short-lived weather events, such as individual summer storms, but they do well in reconstructing the fluctuation of annual moisture from the end of the preceding growing season to the end of the current growing season (September through August). At the Burning Coal site, the coefficient of determination, R^2, indicated that the variation in annual precipitation (from September of the previous year through August of the current tree ring) can account for 44 percent of the variation in the tree-ring record. Stockton and Meko (1983) also illustrated that drought years and non-drought years tend to cluster. At their sites, tree-ring records indicated major droughts during the mid-1930s, the mid-1890s, the 1860s, the early 1820s, and the late 1750s.

Gonzalez (2001a, 2001b) conducted a preliminary analysis of cores and slabs from 82 living and dead ponderosa pine trees from private ranches and U.S. Forest Service lands in Slope County and near the Burning Coal site of Stockton and Meko (1983). The oldest tree in the Gonzalez (2001a) study had an inner tree ring from 1526. This sampling effort found a greater number of older trees to study than did Stockton and Meko (1983). Of the 30 trees selected for analysis, all 30 had tree rings as far back as 1800, 28 samples to 1700, and eight radii (cores) from three trees to 1600.

Drought comparable to, or more severe than, the historic Dust Bowl drought of the 1930s occurred approximately three to four times per century throughout the tree-ring record (Figure 6). The dendroclimatic signal found by Gonzalez (2001a) was similar to that reconstructed by Stockton and Meko (1983).

Sieg et al. (1996) sought to enhance the dendroclimatic data from the northern Great Plains by collecting increment core samples from trees at 23 sites throughout North Dakota, South Dakota, and Iowa. Six of these sites were in North Dakota (see also Table 1), including:

- Masonic Island (Bottineau County) – bur oak chronology back to 1676
- Bear Island (Bottineau County) – bur oak chronology back to 1782
- Cross Ranch (Oliver County) – bur oak chronology back to 1788
- Killdeer Mountains (Dunn County) – bur oak chronology back to 1777

- Theodore Roosevelt National Park (Billings County) – Rocky Mountain juniper chronology back to 1597
- Burning Coal Vein (Slope County) – ponderosa pine chronology back to 1592.

The tree ring widths from all sites were analyzed by correlating ring width with either "annual" precipitation or "seasonal" precipitation (three-month time frames). Annual precipitation periods can be from September of the previous year through August of the current year, or perhaps July of the previous year through June of the current year. The Burning Coal Vein site produced the longest tree-ring chronology in North Dakota and had the strongest climate correlation. Specifically, tree ring width was highly correlated (r = 0.70) with annual precipitation (September of the previous year through August of the current year), although the correlation for the April through July precipitation record was only slightly lower (r = 0.66). The Theodore Roosevelt tree-ring chronology for Rocky Mountain juniper had similarly strong correlations to annual precipitation (r = 0.62 for preceding July through June of tree-ring year) and seasonal precipitation (r = 0.59 for April through July).

The bur oak chronologies for the most part tended to be comparatively short, lacked sample depth beyond the mid-1800s, and displayed a much weaker correlation to precipitation records. Sieg et al. (1996) concluded that oak sites in North Dakota will require additional old trees to produce reliable tree-ring information much beyond the period of instrumental weather records. Interested readers should know that the tree-ring chronologies produced by Sieg et al. (1996) have been catalogued in the International Tree Ring Database (see Table 1) and can be accessed through the web at: https://www.ncdc.noaa.gov/data-access/paleoclimatology-data/datasets/tree-ring.

A recent paper by Edmondson et al. (2014) examined the utility of Plains cottonwood in dendroclimatic and paleo-streamflow reconstructions. Their study took place in the North Unit of TRNP in McKenzie County and included the same stand that Everitt examined in his 1968 publication. Among the discoveries in this work were some major revelations. First, this study showed Plains cottonwood trees at this latitude contained a strong climatic and streamflow signal. The annual tree-ring indices were strongly positively correlated with local growing season (April-July) precipitation and soil moisture conditions (r = 0.69). Also, the tree-ring chronology was significantly correlated with June-July PDSI (Palmer Drought Severity Index) of the northern Great Plains and could possibly reconstruct nearly 50% of the variability in summer PDSI. Second, Edmondson et al. (2014) found a stand of cottonwood that was remarkably old. The oldest tree in their sample was 370 years old, making it the oldest Plains cottonwood ever documented (Edmondson et al. 2014). They found numerous trees greater than 150 years old, with enough to produce a reliably strong climatic signal back to 1744. Third, their tree-ring record successfully detected known droughts during the instrumental period (e.g., droughts of the mid-1930s and early 1980s) and earlier droughts documented by other paleoclimatic studies (e.g., the droughts of 1816-1823 and 1856-1865).

Prior to the Edmondson et al. (2014) study, most tree-ring specialists had assumed that riparian trees, Plains cottonwood included, would have a complacent annual tree-ring record because growing season moisture would be fairly constant in an environment near perennial streams and near the water table. Also, many had dismissed cottonwood as a potential source of pre-historic climatic information because it was widely assumed that (1) this species is not particularly long-lived; (2) annual growth rings can be indistinct; and (3) the forest containing cottonwoods have typically been greatly impacted by agriculture, floodplain inundation by reservoirs, water table lowering, flow alterations from operation of dams, and livestock grazing (Edmondson et al. 2014; Johnson et al. 1976), along with fuel use for early steamboat travel on the Missouri River during the nineteenth century (Fenn 2014).

VanStone (2012) also attempted a streamflow reconstruction utilizing tree rings. Her study used bur oak in the Souris River basin in Saskatchewan (five sites), Manitoba (four sites) and North Dakota (five sites). Analyses showed that streamflow was more closely correlated with latewood (part of annual growth ring developed when rate of annual radial growth declines; latewood is typically the darker part of the annual growth ring) width than to total ring width. With this technique, VanStone was able to reconstruct streamflow values back to 1726; the earliest gauge records (from Saskatchewan) for the Souris River date to only 1931.

Dendroarchaeology

As European settlers moved into the northern Great Plains, the demand for fuelwood and construction

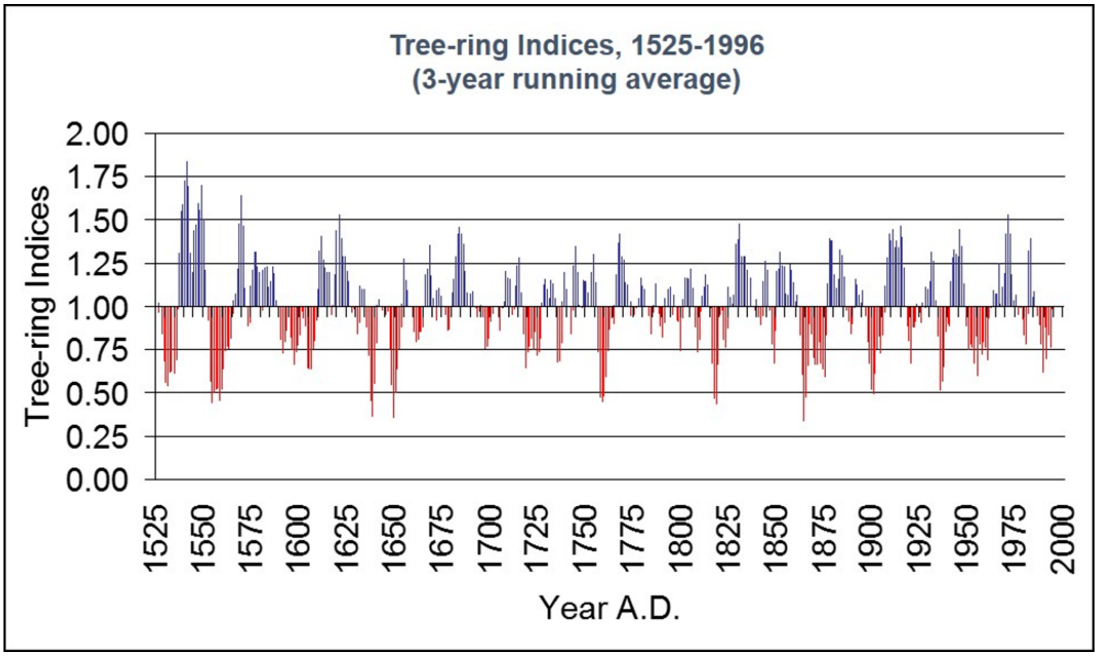

Figure 6. Record of three-year running-average tree-ring indices from ponderosa pine in Slope County, North Dakota. Indices near 1.0 indicate near-normal annual moisture conditions. Indices greater than 1.0 correlate to years of above average precipitation and indices less than 1.0 to dry years (from Gonzalez 2001a). Indices from 1607 and earlier considered tentative due to small sample depth.

materials was enormous. Oak was the preferred construction material for both the new settlers and for Native Americans when constructing earth lodges (cf. Will 1946a). However, when oak was not available, people switched to whatever other materials were available. For example, Native American earth lodge builders switched from oak to cottonwood when supplies of the former were depleted (Will 1946a). Will also mentions that, when a village was moved by native peoples, logs from the old village were sometimes re-used in the construction of the new village. In central and western North Dakota, ponderosa pine, Rocky Mountain juniper and cottonwood were used as construction material. Green ash and American elm (*Ulmus americana*) were used on occasion, though very few buildings made of these materials still exist. All of these species, except for American elm, tend to crossdate well and lend themselves to dendrochronology studies.

Using tree ring analysis to date construction materials or other wooden items is one of the applications of dendroarchaeology. As mentioned earlier, George Will (1946a) attempted to apply dendrochronology techniques to the dating of many logs collected from Native American sites. A modern assessment of a single log collected from the Biesterfeldt site was not able to confirm Will's conclusions on the growth years of the sample (Zeleznik 2015).

Standing historic architecture is also an excellent source of data for dendrochronologists. While many samples have been collected from log buildings in North Dakota, much of the work remains unpublished (Zeleznik 2017). A log building that originated from Horace, North Dakota is mentioned in a report on log buildings from neighboring Clay County, Minnesota (Zeleznik et al. 2016; Figure 7). Additionally, a 450-year-old bur oak tree was used to crossdate samples from two log buildings near Lisbon, North Dakota (Slotten and Zeleznik 2009). Interestingly, the earliest rings from that bur oak tree pre-date any sample collected from log cabins, even though the buildings were constructed from trees harvested in the 1870s.

Many old log cabins were moved and repaired/restored in the 1970s and 1980s. A number of these can be found in city parks or at local county museums. Additionally, at least five North Dakota State Historic Sites contain standing log buildings or their remnants:

- Wadeson (32BA32) – Kathryn, Barnes County. The Wadeson Cabin was built in 1876 along the Sheyenne River of hand-hewn bur oak. It was restored in 1981.
- Gingras Trading Post (32PB101) – Walhalla, Pembina County. Two log buildings stand at

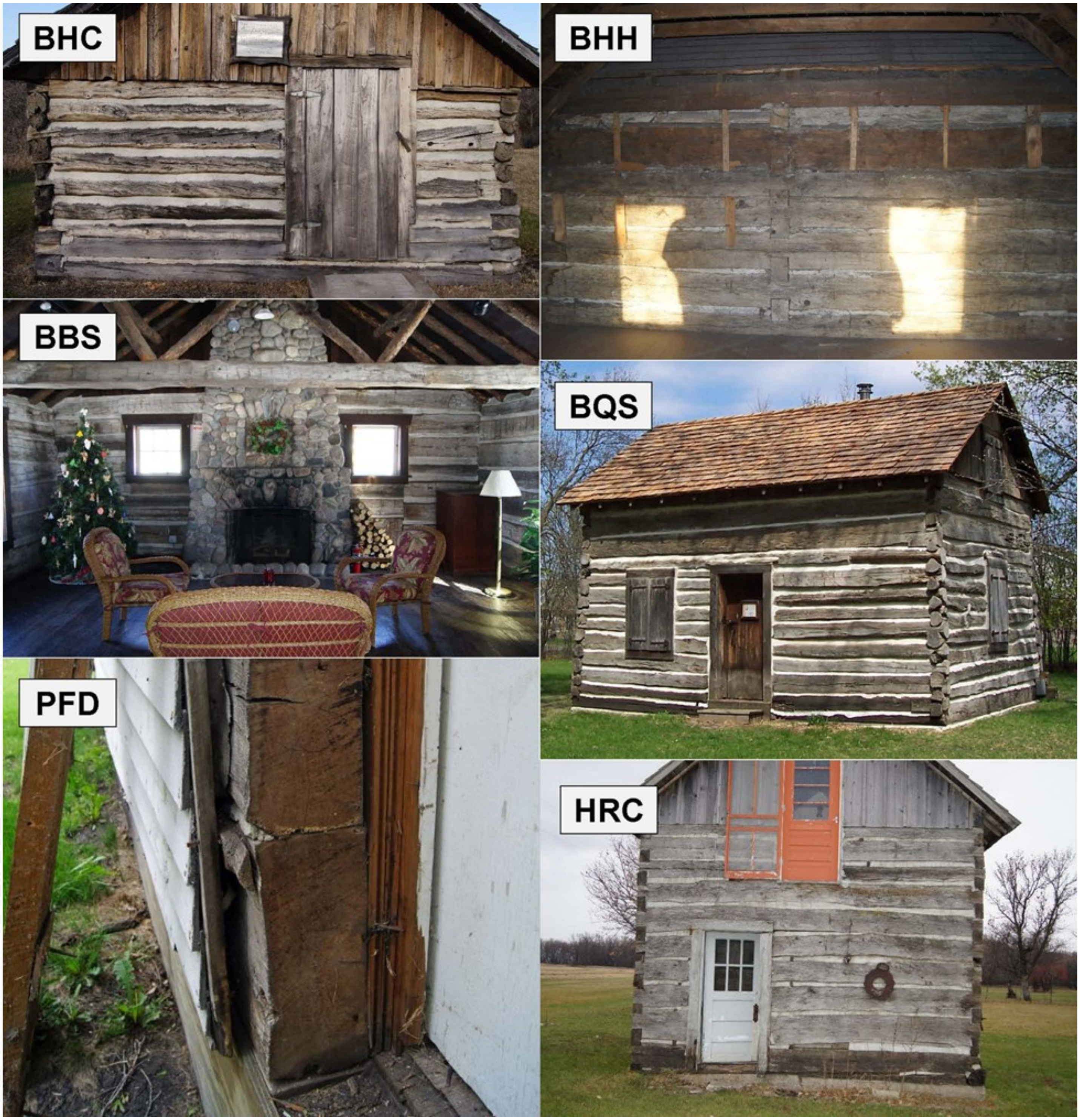

Figure 7. Examples of log buildings that remain in the Red River Valley region of North Dakota and Minnesota. BHC – Bernhardson Cabin (NRHP – 80002011), BHH – Bernhardson House, BBS – Burbank Station (a.k.a. Historic Log Cabin), BQS – Bergquist Cabin (NRHP – 80002014), PFD – Probstfield House (NRHP – 80002019), HRC – Horace. From Zeleznik et al. (2016).

the Gingras State Historic Site, a two-story trading post and a one-story house. Both buildings have been restored but only the trading post has exposed logs. The trading post is the oldest standing building in North Dakota, constructed in 1844.

- Walhalla State Historic Site (a.k.a. Kittson) (32PB66) – Walhalla, Pembina County. This building was constructed in 1852 by Norman W. Kittson in what is present-day Walhalla. The building was moved to its current location in 1904.
- Camp Hancock (32BL26) – Bismarck, Burleigh County. A log headquarters building still stands, though the logs are hidden by clapboard siding. A few logs are visible in one corner; we believe that they are cottonwood. Located at 101 East Main Avenue.
- Fort Abercrombie (32RI777) – Abercrombie, Richland County. The log guardhouse at Fort Abercrombie is original, constructed in 1862. However, the three blockhouses are replicas, constructed in a Works Progress Administration project in 1939-1940.

Where dendrochronological techniques have been unsuccessful (cf. Zeleznik 2015), researchers may want to consider using radiocarbon dating to determine the ages of wood artifacts or construction materials. Caution must be exercised, though, as direct comparisons between the two techniques in this region have not been done. Johnson (2007) compared results on dendrochronology studies to radiocarbon dates for several archaeological sites in the region and found that the radiocarbon dates were often 200-500 years older than those suggested by tree-ring analysis. It is unclear what specimens were used to establish those radiocarbon dates. Additionally, the single bur oak sample that was radiocarbon dated in Aronow's (1957) study of Stump Lake suggested that the wood was 500 ± 400 years old, a rather large error range.

Opportunities

Dendrochronology research in North Dakota has a long a history and diverse applications. Though some of the studies have been simple, others have been more in depth and all offer insights into various aspects of North Dakota's natural landscapes and its history. Forests in North Dakota are found mainly in riparian areas and in those locations dominated by rugged topography; thus, there are often large distance gaps among the various study sites. Nevertheless, there are myriad opportunities for future research.

The long-term goal of our current efforts is to build a series of localized master chronologies that cover North Dakota geographically, and extend back in time as far as possible. Those local master chronologies would provide a basis for dating artifacts or samples for which calendar dates are unknown. An example where this would be used is in future excavations of Native American village sites, or perhaps as part of a re-analysis of previously excavated items. A number of local bur oak chronologies have been started by the senior author; most of them are in eastern North Dakota.

Additionally, such a series of local chronologies could be combined together as part of a broader analysis on past climatic conditions of North Dakota. Drought recurrence is a very important topic in this agriculture-dominated state. In addition to the region-wide drought of the 1930s, a severe drought occurred in the early 1860s (Zeleznik et al. 2016). This drought was one of the factors involved in the Dakota War (Clodfelter 1998). Future research could help elucidate other climatic conditions that contributed to regional growth, migration or conflict among native peoples.

One of the biggest challenges to reaching this goal is the paucity of "old" samples that are currently available. Standing trees often provide samples dating into the 1800s or even late 1700s. Rarely do modern trees date into the 1600s and, amazingly, four tree samples in North Dakota have dated to the 1500s. Samples from log cabins or Native American village sites strengthen chronologies in the 1800s and extend to the early 1700s, with a few logs dating into the 1600s.

It will be difficult, but not impossible, to find further samples beyond that time frame. For example, we currently are working on expanding the flood history of the Red River of the North in eastern North Dakota. As part of this project we are searching for sub-fossil logs, those buried in sediments along the river. On the Canadian portion of the Red River, sub-fossil logs have dated into the late 1200s (cf. St. George and Nielsen 2003).

References

Aronow, S. (1957) On the Postglacial History of the

Devils Lake region, North Dakota. *Journal of Geology* 65(4): 410-427.

Beckers, J.M. (2007) *Fire History of the Ponderosa Pine Stand in Southwestern North Dakota*. Unpublished Master's thesis, North Dakota State University.

Beckes, M.R., B.K. Jagler, T.L. Burge, and T.G. Love (1982) Possible cultural origin of an isolated stand of *Pinus flexilis* in the Little Missouri Badlands. *Journal of the North Dakota Archaeological Association* 1:9-20.

Bell, R. E. (1948) Review: Tree Ring Studies in North Dakota. George F. Will. *American Anthropologist* 50:104-108.

Broecker, W.S., J.L. Kulp, and C.S. Tucek (1956) Lamont Natural Radiocarbon Measurements III. *Science* 124 (3213):154-165

Brooks, G.R., and S. St. George (2015) Geomorphic Approaches to Integrated Floodplain Management of Lowland Fluvial Systems in North America and Europe. In *Geomorphic Approaches to Integrated Floodplain Management of Lowland Fluvial Systems in North America and Europe,* edited by P.F. Hudson and H. Middelkoop, pp. 87-117. Springer, New York.

Caldwell, W.W., and L.M. Snyder (1983) Dendrochronology in Plains prehistory: An assessment. *Plains Anthropologist* 28:33-40.

Clodfelter, M. (1998) *The Dakota War: The United States Army Versus the Sioux, 1862-1865.* McFarland & Company, Inc., Jefferson, North Carolina.

Dietrich, I.T. (1965) What Rainfall Records Tell. *NDSU Extension Circular* A-479.

Dixon, M.D., W.C. Johnson, M.L. Scott, D.E. Bowen, and L.A. Rabbe (2012) Dynamics of Plains Cottonwood (*Populus deltoides*) Forests and Historical Landscape Change along Unchannelized Segments of the Missouri River, USA. *Environmental Management* 49:990–1008.

Edmondson, J., J. Friedman, D. Meko, R. Touchan, J. Scott, and A. Edmondson (2014) Dendroclimatic Potential of Plains Cottonwood (*Populus deltoides* Subsp. *monilifera*) from the Northern Great Plains, USA. *Tree-Ring Research* 70:21-30.

Everitt, B.L. (1968) Use of the cottonwood in an investigation of the recent history of a flood plain. *American Journal of Science* 266:417-439.

Fenn, E. (2014) *Encounters at the Heart of the World: A History of the Mandan People*. Hill and Wang, New York.

Gonzalez, M.A. (2001a) *Recent Fluvial History and Environmental Change of Some Ephemeral Streams in the Little Missouri Badlands of Southwestern North Dakota*. North Dakota Geological Survey Report of Investigation No. 101.

Gonzalez, M.A. (2001b) Recent formation of arroyos in the Little Missouri Badlands of southwestern North Dakota. *Geomorphology* 38(1-2):63-84.

Harmon, M.D. (2010) *Composition of oak savanna in Clay County, Minnesota and Ransom County, North Dakota*. Unpublished Master's paper, North Dakota State University.

Harrison, S.S., and Reid, J.R. (1967) A flood-frequency graph based on tree-scar data. *Annual Proceedings of the North Dakota Academy of Science* 21:23-33.

Johnson, C.M. (2007) *A Chronology of Middle Missouri Plains Village Sites*. Smithsonian Contributions to Anthropology, Number 47. Smithsonian Institution Scholarly Press, Washington, D.C.

Johnson, W.C., R.L. Burgess, and W.R. Keammerer (1976) Forest overstory vegetation and environment on the Missouri River Floodplain in North Dakota. *Ecological Monographs* 46:59-84.

Johnson, W.C., M.D. Dixon, M.L. Scott, L. Rabbe, G. Larson, M. Volke, and B. Werner (2012) Forty Years of Vegetation Change on the Missouri River Floodplain. *BioScience* 62(2):123-135.

Kuniholm, P.I. (2001) Dendrochronology and Other Applications of Tree-ring Studies in Archaeology. In *The Handbook of Archaeological Sciences,* edited by D.R. Brothwell and A.M. Pollard, pp. 35-46. John Wiley & Sons, Ltd., London.

Meko, D.M., J.M. Friedman, and J. Scott (2015) Alternative standardization approaches to improving stream flow reconstructions with ring-width indices of riparian trees. *The Holocene* 25 (7):1093-1101.

Miller, J.R., and J.M. Friedman (2009) Influence of flow variability on floodplain formation and destruction, Little Missouri River, North Dakota. *GSA Bulletin* 121 (5/6): 752–759.

Murdoff, M.T. (2010) *The interactions of early-fall prescribed burning, different cutting techniques and white -tailed deer browsing on bur oak regeneration in eastern North Dakota: Phase II*. Unpublished Master's thesis, North Dakota State University.

Nelson, C.N. (1948) *Forestry program for North Dakota*. Unpublished typescript report. On file at the North Dakota Forest Service.

OLDLIST (2018) Electronic document, http://www.rmtrr.org/oldlist.htm, accessed April 20, 2018.

Potter, L.D., and D.L. Green (1964a) Ecology of a northeastern outlying stand of *Pinus flexilis*. *Ecology* 45:866-868.

Potter, L.D., and D.L. Green (1964b) Ecology of ponderosa pine in western North Dakota. *Ecology* 45:10-23.

Potter, L.D., and D.R. Moir (1961) Phytosociological study of burned deciduous woods, Turtle Mountains, North Dakota. *Ecology* 42:468-480.

Severson, K.E., and C.H. Sieg (2006) *The Nature of Eastern North Dakota: Pre-1880 Historical Ecology*. North Dakota Institute for Regional Studies, North Dakota State University Press, Fargo.

Sieg, C.H., D.M. Meko, A.T. DeGaetano, J.R. Miller, Jr., M.J. Bunkers, and W. Ni (1996) An Analysis of Drought in the Northern Great Plains: Summary of Progress. In *Interior West Global Change Workshop. April 25-27, 1995, Fort Collins, CO*, edited by R.W. Tinus (technical editor), pp. 20-22. USFS RM-GTR-262.

Slotten, M., and J.D. Zeleznik (2009) Lessons learned from a 450-year-old bur oak (*Quercus macrocarpa*). Poster presented at the Society of American Foresters 2009 National Convention, Orlando, Florida.

St. George, S., and E. Nielsen (2000) Signatures of high-magnitude 19th-century floods in *Quercus macrocarpa* tree rings along the Red River, Manitoba. *Geology* 28:899-902.

St. George, S., and E. Nielsen (2003) Palaeoflood records for the Red River, Manitoba, Canada, derived from anatomical tree-ring signatures. *The Holocene* 13:547-555.

Stambaugh, M.C., and R.P. Guyette (2009) Progress in Constructing a Long Oak Chronology from the Central United States. *Tree-Ring Research* 65 (2):147-156.

Stockton, C.W., and D.M. Meko (1983) Drought recurrence in the Great Plains as reconstructed from long-term tree-ring records. *Journal of Climate and Applied Meteorology* 22:17-29.

Stokes, M.A., and T.L. Smiley. (1968) *An Introduction to Tree-Ring Dating*. University of Chicago Press, Chicago, IL.

Strong, W.D. (1940) From History to Prehistory in the Northern Great Plains. In *Essays in Historical Anthropology in North America*, pp. 353-394 + 10 plates. Smithsonian Miscellaneous Collections, Vol. 100.

USDA-NRCS (2018) The PLANTS Database, National Plant Data Team, Greensboro, North Carolina. Electronic document, http://plants.usda.gov, accessed July 23, 2018.

Vanstone, J. (2012) *Investigation and reconstructions of the hydroclimatic variability of the Souris River Basin*. Unpublished Master's thesis, Department of Geography, University of Regina.

Wertz, E.L., S. St. George, and J.D. Zeleznik (2013) Vessel anomalies in *Quercus macrocarpa* tree rings associated with recent floods along the Red River of the North, United States. *Water Resources Research* 49:630-634.

Will, G.F. (1946a) *Tree Ring Studies in North Dakota*. North Dakota Agricultural College, Agricultural Experiment Station, Bulletin 338. Fargo.

Will, G.F. (1946b) 540 Years of Dakota Weather. *The Northwest* 20(12):3-6.

Will, G.F. (1948) Additional notes on dendrochronology in the Dakotas. *Plains Archeological Newsletter* 1(4):68-70.

Will, G.F. (1949) Dendrochronology in the Dakotas. *University of Nebraska, Laboratory of Anthropology Notebook*. 1(4):114-116.

Wood, W.R. (1971) *Biesterfeldt: A post-contact coalescent site on the northeastern Plains*. Smithsonian Contributions to Anthropology, Number 15. Smithsonian Institution, Washington, D.C.

Yanosky, T.M. (1983) *Evidence of floods on the Po-*

tomac River from anatomical abnormalities in the wood of flood-plain trees. U.S. Geological Survey, Professional Paper 1296. Washington, D.C.

Zeleznik, J.D. (2015) Biesterfeldt oak post sample – Results. Report submitted to State Historical Society of North Dakota, Bismarck.

Zeleznik, J.D. (2017) Towards a Master Chronology for Bur Oak in the Northern Great Plains. Poster presented at the Plains Anthropological Society conference, October 4-7, 2017, Bismarck, North Dakota.

Zeleznik, J., C. Quiring, and A. Swanson (2016) Survey of Settlement-era Buildings and Remnants in Clay, Becker, and Norman Counties. Report submitted to the Minnesota Historical Society.

Zeleznik, J.D., and J.A. Walla (2010) Summary of observations on dieback of ash trees: Theodore Roosevelt National Park (South Unit), August 2010. Report submitted to the National Park Service, Theodore Roosevelt National Park.