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Using Historic GLO Data and GIS to Assess the Potential for Local Bison Bison Near Two Wisconsin Late Prehistoric Oneota Localities

Andrew Michael Saleh
University of Wisconsin-Milwaukee

USING HISTORIC GLO DATA AND GIS TO ASSESS THE POTENTIAL FOR LOCAL *BISON BISON* NEAR TWO WISCONSIN LATE PREHISTORIC ONEOTA LOCALITIES

by

Andrew Michael Saleh

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ABSTRACT

USING HISTORIC GLO DATA AND GIS TO ASSESS THE POTENTIAL FOR LOCAL *BISON BISON* NEAR TWO WISCONSIN LATE PREHISTORIC ONEOTA LOCALITIES

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Andrew Michael Saleh

The University of Wisconsin-Milwaukee, 2019
Under the Supervision of Jean Hudson, Ph.D.

Bison (Bison bison) remains are rare in the archaeological record of Wisconsin. This thesis uses a Geographic Information System (GIS) to better understand native vegetation near sites with reported bison bone to assess their ecological viability to support local bison herds. The distribution of bison bone recovered in archaeological contexts in Wisconsin can be summarized as follows: few sites report bison remains, the archaeological contexts that do report bison are clustered in a few Late Prehistoric period locations (approximately A.D. 1300-1650), and bison remains are rare in comparison to other fauna at those sites (Arzigian et al. 1989; Boszhardt 1989, 2000; Boszhardt and McCarthy 1999; Brown and Sasso 2001; Dirst 1985; Gibbon 1970; Jeske et al. 2017; Kreisa 1986; McQuin 2010; Peske 1966, 1971; Sasso 1993, 2014; Scott 1994; Shay 1978; Stevenson 1994; Stoltman 1973; Theler 1994b, 2000; Theler and Boszhardt 2003, 2006; Theler and Pfaffenroth 2010). Sasso (1993, 2014) summarizes three major hypotheses about how bison were acquired by Wisconsin's prehistoric and historic native residents: local hunting, non-local hunting, or trade acquisition. One comparative approach to assessing the viability of a local hunting hypothesis versus other hypotheses is to consider the vegetative needs of a bison herd, and to model local vegetation around the sites where bison *bones have been recovered. This thesis attempts that by considering historic accounts of vegetation, bison biological needs, and GIS modeling.*

To my mother, Mary Jean Fonk, you are my superhero.

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Chapter 1: Introduction

At the genus level, bison bones appear in western Great Lakes archaeological contexts during different times when humans are present in the region. This genus includes the extant *Bison bison* species, as well as the extinct *Bison antiquus* and *Bison occidentalis* (Boszhardt et al. 1993; Hawley et al. 2007, 2011; Hill et al. 2014; Kuehn 2009; Sasso 1993, 2014; Theler 1994a). In terms of specimen count and reporting, at a species level, *Bison bison* bones and evidence attributed to Late Prehistoric Oneota contexts in Wisconsin show the most abundance (Arzigian et al. 1989; Boszhardt 1989, 2000; Boszhardt and McCarthy 1999; Brown and Sasso 2001; Dirst 1985; Edwards IV 2017; Gallagher et al. 1985; Gibbon 1970; Hall 1962; Jeske et al. 2017; Kreisa 1986; McQuin 2010; Peske 1966, 1971; Sasso 1993, 2014; Scott 1994; Shay 1978; Sterner 2018; Stevenson 1994; Stoltman 1973; Theler 1994b, 2000; Theler and Boszhardt 2003, 2006; Theler and Pfaffenroth 2010). This thesis suggests that even with modern techniques, much labor is required to understand this elusive species. At the same time, it also suggests that the labor involved is worth it.

Recently, Sasso (2014) synthesized historic documents and archaeological grey literature or site reports tied to Late Prehistoric period bison in Wisconsin. Using these data he proposed three possible frameworks for the acquisition of bison as food or tool options by Late Prehistoric period residents: local, non-local, and trade. Local refers to the hunting of local bison herds or individual animals within a reasonable distance of residential sites. Historic evidence for bison in Wisconsin supports the possibility of local herds in prehistoric times, and it is difficult to imagine a prehistoric hunter ignoring bison if it were directly available (Henning 1992; Hornaday 1887; Sasso 1993, 2014; Schorger 1937; W.DNR 2006). Non-local refers to traveling to hunt distant bison herds in locations closer to the Great Plains, such as western Minnesota, western Iowa, or further west (Boszhardt and McCarthy 1999; Sasso 1993; Theler and Boszhardt 2006). Blair (1911), Lehmer (1963), and Radin (1923) show that non-local "communal" bison or elk hunting may have occurred seasonally in the western Great Lakes and eastern Great Plains. The term "communal" as used here is not always clearly defined; sometimes it is used in the sense of many members of the human community participating in a long-distance trek, at other times it is used in the sense of shared access to large hunting regions by members of multiple human communities. Kreisa (1986), Sasso (1993), Theler and Boszhardt (2006), and others suggest that bison remains attributed to the Lake Winnebago or La Crosse area Oneota groups may be a result of this practice prehistorically.

Defining local versus non-local hunting distances, or distinguishing between a local subsistence strategy versus a non-local "communal" strategy for the acquisition of bison, is seen as a difficult task in terms of currently available archaeological data. Arguments for one or the other typically rely on historic or ethnographic analogies, with some consideration of the number of bison bones at a site and the particular bison elements represented (Kreisa 1986, Sasso 1993, Theler and Boszhardt 2006).

Trade refers to obtaining bison meat, bone, or hide through exchange with hunters of other groups. Discussion has focused on trade between Oneota groups, specifically between the La Crosse area and other localities (Kreisa 1986; Martin 2014; McQuin 2010; Peske 1971; Sasso 1993, 2014). For example, Martin (2014) examines the idea of the La Crosse area as an Oneota hub along the Mississippi River that potentially facilitated trade to places further away from major bison source locations like northeastern Illinois. In Figure 1.1, one can see the general Holocene (0-10,000 Y.A.) archaeological bison bone site distribution relating this discussion at a continental scale (FAUNMAP 2019). The date range is that of the data set itself. It is clear that the Holocene data is widely distributed across the Great Plains area of North America, present but rare east of the Mississippi River, present but rare in Wisconsin in particular, and more abundant in Illinois just to the south.

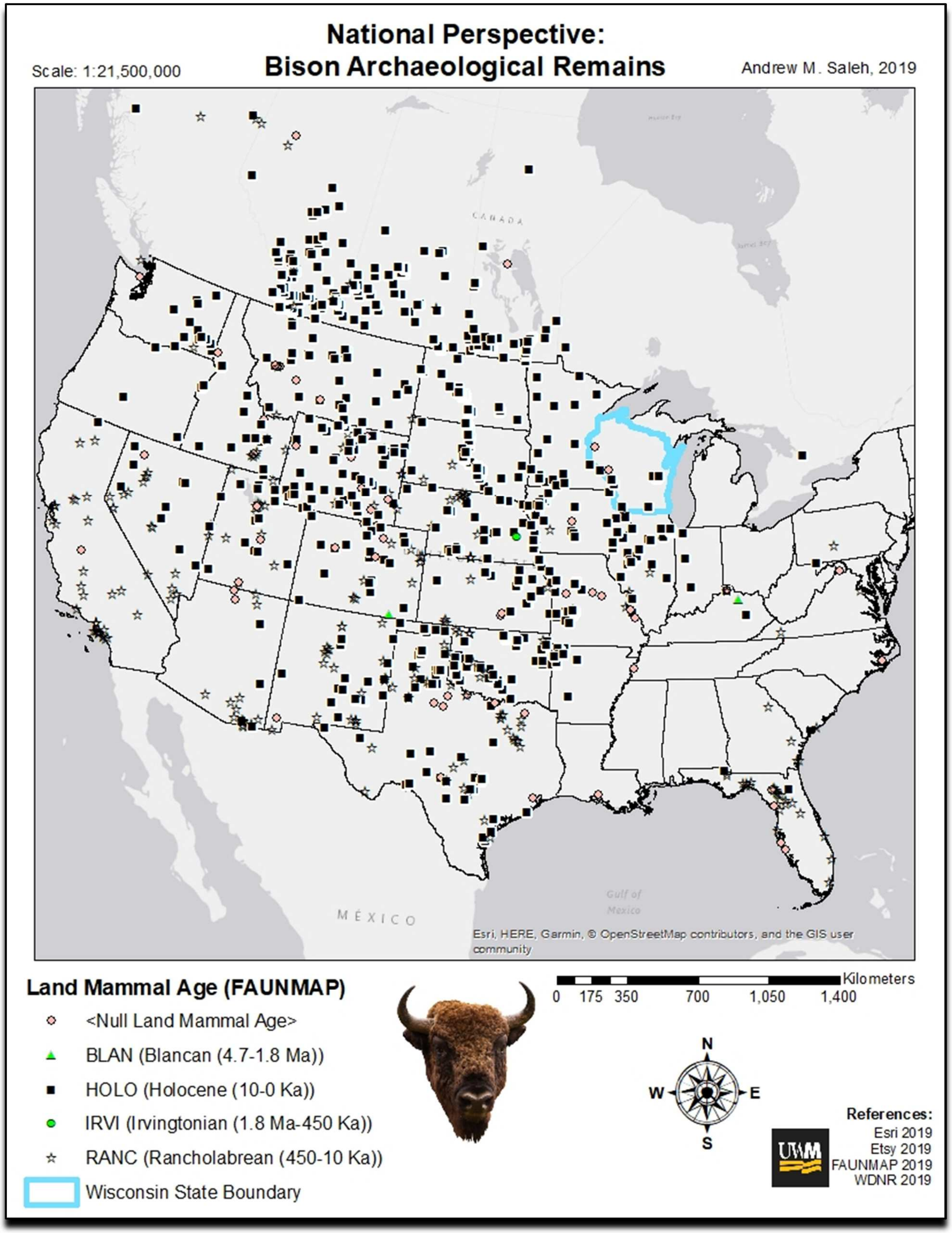


Figure 1.1: FAUNMAP (2019) catalogs most archaeological sites in North America where bison bone is reported.

It has been proposed that most bison remains in Wisconsin from prehistoric contexts should be attributed culturally to an Upper Mississippian "Oneota" presence in the western Great Lakes region, regardless of how they were obtained (Jeske et al. 2017; Rodell 1997; Kreisa 1986; Sasso 1993, 2014; Theler and Boszhardt 2006). Oneota is a term used by archaeologists to refer to a prehistoric cultural group defined materially by pottery, lithics, domesticated plants, and permanent villages. Potential Oneota contexts are noted from Kansas to Ohio, with temporal and spatial variability in Late Prehistoric bison acquisition evidenced archaeologically (Blakeslee et al. 2001; Edwards IV 2010; Hall 2007; Jakle 1968; Martin 2014; Mcmillan 1996, 2006, Ritterbush 2002, 2006; Sasso 2014; Tankersley 2005; Wilford 1945). The Oneota contexts in Wisconsin have been generally conceived as localities organized into agricultural village clusters or sites that are linked together; localities where bison remains occur fit this site-cluster settlement pattern (Brown and Sasso 2001; Edwards IV 2010, 2017; Gallagher and Sasso 1987; Gibbon 1972; Hall 1962; Mason 1993; Overstreet 1976, 1978, 1987; Peske 1966, 1971; Sasso 1993, 2014; Sterner 2018; Theler and Boszhardt 2006).

Some Oneota localities cross modern state boundaries, especially in the Mississippi River valley (Sasso 1993, 2014). All Oneota localities in Wisconsin do not exhibit the same exact cultural practices or occur during the same time periods; inter-locality lithic comparisons have proven this (Sterner 2012, 2015, 2018). Oneota contexts in Wisconsin have been viewed temporally in somewhat confusing phases and horizons depending on the Oneota locality. For example, multiple La Crosse locality phases such as "Orr" or "Valley View," are chronologically broken down quite often and defended successfully; yet, Lake Koshkonong shows mixing pottery styles and phases, while Lake Winnebago shows the "Lake Winnebago" phase as defendable (Boszhardt 1989; Brown and Sasso 2001; Carpiaux 2017; Clair 2013; Edwards IV 2017; McQuin 2010; Jeske et al. 2017; Richards 1992; Schneider 2015; Sterner 2018; Theler and Boszhardt 2003, 2006). Many agree that at the very least, there were earlier Oneota phases starting around A.D. 1000, and later Oneota phases starting around A.D. 1400. The "Orr" phase from the La Crosse locality, and the "Lake Winnebago" phase in Lake Winnebago locality potentially align temporally from AD 1300-1650 based on pottery. These two phases are thought to be the ones most associated with Oneota bison acquisition and potential inter-locality trading or hunting (Brown and Sasso 2001; Kreisa 1986; Martin 2014; Mason and Mason 1992; Peske 1971; Richards 1992; Sasso 2014).

Generally, Upper Mississippian Oneota cultural signatures in Wisconsin are defined archaeologically by the presence of shell-tempered pottery within contexts near large waterways (Brown and Sasso 2001; Edwards IV 2010, 2017, 2017; Gibbon 1972; Hall 1962; Jeske 2000, 2003; Jeske et al. 2017; Kreisa 1986; Sasso 1993; Schneider 2015; Sterner 2012, 2015, 2018; Theler and Boszhardt 2006). Middle Mississippian archaeological sites in the state, most notably Aztalan, have also shown this general pattern, but a lot of the general comparisons end there (Goldstein and Richards 1991; Van der Heiden 2019). Shell-tempered pottery styles or motifs link Wisconsin's prehistoric Oneota archaeological contexts to those in neighboring states like Minnesota and Iowa, and to more distant states like Ohio (Blakeslee et al. 2001; Ritterbush 2002, 2006; Schneider 2015; Schulenburg 2010; Wilford 1941, 1945). Figure 1.2 provides one version of a chronological overview of Wisconsin Oneota prehistory. For the purposes of this thesis it is useful to note that the archaeological contexts with bison bones are associated primarily with post-A.D. 1400 ceramic types, although a few date somewhat earlier.

Model of Oneota Chronology	
Phase (Component)	Ceramic Type
Emergent period (A.D. 1000–1150)	
Silvernale (Silvernale, Bryan, Mero, Bartron)	Armstrong Trailed
Koshkonong (Carcajou Point, Crabapple Point)	Carcajou Curvilinear
Fisher (Fisher A)	Fisher Trailed
Developmental period (A.D. 1150–1400)	
Brice Prairie (Olson, North Shore, White Camp II, Grant, Tremaine)	Perrot Punctate
Bold Counselor (Norris Farms, Crable)	Diamond Bluff Trailed
Blue Earth (Sheffield, Humphrey, Vosburg)	Blue Earth Trailed
Grand River (Grand River)	Grand River Trailed
Burlington (Schmeiser)	Fifield Trailed
Langford (Fisher B, Zimmerman)	Langford Trailed
Developmental/Classic period (A.D. 1400–1500)	
Pammel Creek (Pammel Creek, Jim Braun, Sand Lake, Tremaine)	Perrot Punctate
Early Orr (McKinney)	
Kelley (Kelley, McKinney?)	
Vulcan?	
Huber (Huber)	Huber Trailed
Early Classic period (A.D. 1500–1600)	
Valley View (Valley View, OT, Tremaine, Overhead)	Allamakee Trailed
Lake Winnebago (Lasley's Point, Overton, McCauley)	Lake Winnebago Trailed
Berrien (Mocassin Bluff, Schwerdt)	Berrien Trailed
(Late) Orr (McKinney)	Midway Incised
Oak Forest (New Lenox, Oak Forest, Palos Hills)	Huber Trailed
Late Classic period (A.D. 1600–1750)	
Orr/Yucatan (Lane Enclosure, Farley, Yucatan Village)	Allamakee Trailed

Figure 1.2: Timeline of Wisconsin Oneota Prehistory (adapted from Boszhardt (1989) and Brown and Sasso (2001)).

On the topic of Oneota in Wisconsin, it is worth considering that prehistoric conceptions of landscape and community may have crossed modern state boundaries. Of specific relevance to this thesis, Sasso (1993) conceived the entirety of the La Crosse area Oneota locale as dispersed agricultural village clusters that may have extended beyond Wisconsin into Iowa and Minnesota. Historically, the Chiwere Siouan-speaking Ioway and Oto peoples may be tied to the Oneota of this region as likely descendants (Boszhardt 2000; Griffin 1937; Henning 1992a, 1992b; Sasso 1993). While Peske (1966, 1971) shows a similar agricultural village pattern around Lake Winnebago, the Oneota here may be predecessors of the historic Winnebago (Kay 1990; C. Mason 1992; R. Mason 1992; Richards 1992; Overstreet 1997).

Sasso (1993) conceived the whole La Crosse locality as approximately 650 square kilometers, extending along the Mississippi River. Sometime around A.D. 1250, the Oneota occupation in this locality started and it lasted until the late A.D. 1600s and possibly into the Early Historic (See Figure 1.2) (Brown and Sasso 2001; Boszhardt 1889; Sasso 1993). In Iowa and Minnesota, Early Historic French period artifacts have been found above Oneota contexts, but not on the Wisconsin side, suggesting possible abandonment of the Wisconsin sites prior to historic French trade. This unfortunately highlights a common issue in Wisconsin: the Oneota are hard to link to specific Early Historic period tribes in the state (Brown and Sasso 2001; Overstreet 2000; Richards 1992; Sasso 1993).

Two points to be considered in the comparison of bison acquisition patterns at the La Crosse and Lake Winnebago localities are 1) their relative physical proximity to and/or potential social connections with people who had direct access to Plains bison herds, and 2) their shared subsistence identity as agricultural villagers. The latter is especially relevant because bison scapula was a popular source bone for hoes, and hoes were an essential tool for ridged-field agriculture (Brown and Sasso 2001; Boszhardt et al. 1985; Gallagher et al. 1985; Gallagher and Sasso 1987; Overstreet 1987). Temporal aspects may also come into play; Dirst (1985:88) has argued that bison scapula hoes are diagnostic artifact for Classical period Lake Winnebago phase Oneota.

Pertaining to this study, a key subsistence pattern noted amongst Oneota contexts has been described as mixed hunting and farming, with farming based on the cultivation of core staples of maize (corn), beans, and squash in ridged fields, often using bison or elk scapula hoes for cultivation (Brown 1982; Gallagher and Stevenson 1982; Gallagher et al. 1985, 1987; Sasso 1993; Sasso et al. 1985). In terms of the hunting aspect of the subsistence, Sasso (1993) conceives the large mammal hunting focus of the La Crosse area Oneota as centered on deer, elk, or bison. At the same time, Richards (1992:286) notes the general paucity of large mammals in Oneota archaeological contexts. Shay (1978:202), unknowingly balancing these ideas, shows that in southern Wisconsin in the Late Prehistoric period, although large mammals do not have a high representation, when represented, the mean percentage of identified bison remains (9.7%) is almost the same as deer (10.1%) from the fourteen sites he analyzed throughout the western Prairie Peninsula, while elk was somewhat less (3.2%).

The archaeological data thus provide some evidence for bison bone in Oneota sites, but also some ambiguity and debate about their importance to subsistence and the way in which they were acquired. This thesis offers an alternative approach, a Geographic Information System (GIS), to answer the question: could Wisconsin support local bison as individuals or herds during the Late Prehistoric period. It models environmental variables such as vegetation, terrain, and waterways to assess the options for local hunting in two of Wisconsin's major Oneota localities, La Crosse and Lake Winnebago. The main driver of my vegetation modeling is the bison itself; how much land would be needed, with what mix of resources, to support local bison. To establish these parameters I review modern bison biology and ecology (Blackburn 2018; Brockman 2017; Burke 2016; Fortin et al. 2003; Gates et al. 2010; Hartnett et al. 1995; Hess et al. 2014; Illius and Farnsworth 1998; Jackson et al. 2010; Larter 1991; Lueck 2002; McDonald 1981; McHugh 1958; Meagher 1986; Middleton 2002a, 2002b; Nowak 1999; Nelson et al. 2007; Pearson et al. 1995; Raynor et al. 2015; Reynolds et al. 1978; Shay 1978; Senft et al. 1987; Trottier and Carbyn 1987; Turner et al. 1990; Ulman 2000; Wallace et al. 1995; Widga 1997, 2006, 2014; Widga et al. 2010).

Although bison became locally extinct east of the Mississippi River in the early 1800s, they were observed in Wisconsin until approximately 1832, and they were noted historically as far southeast as Florida (Belue 1996; FAUNMAP 2019; Hornaday 1887; Rostlund 1960; Sasso 1993, 2014; Schorger 1937; Widga 2006; W.DNR 2006). Combining historic faunal and ecological records provides evidence to understand what environmental parameters were suitable for bison living east of the Great Plains. Figure 1.3 shows the distribution of bison herds in eastern North America based on historic accounts compiled by Hornaday (1887). Figure 1.4 shows the distribution of bison herds in Wisconsin based on historic accounts compiled by Schorger (1937), incorporating and updating Hornaday (1887).

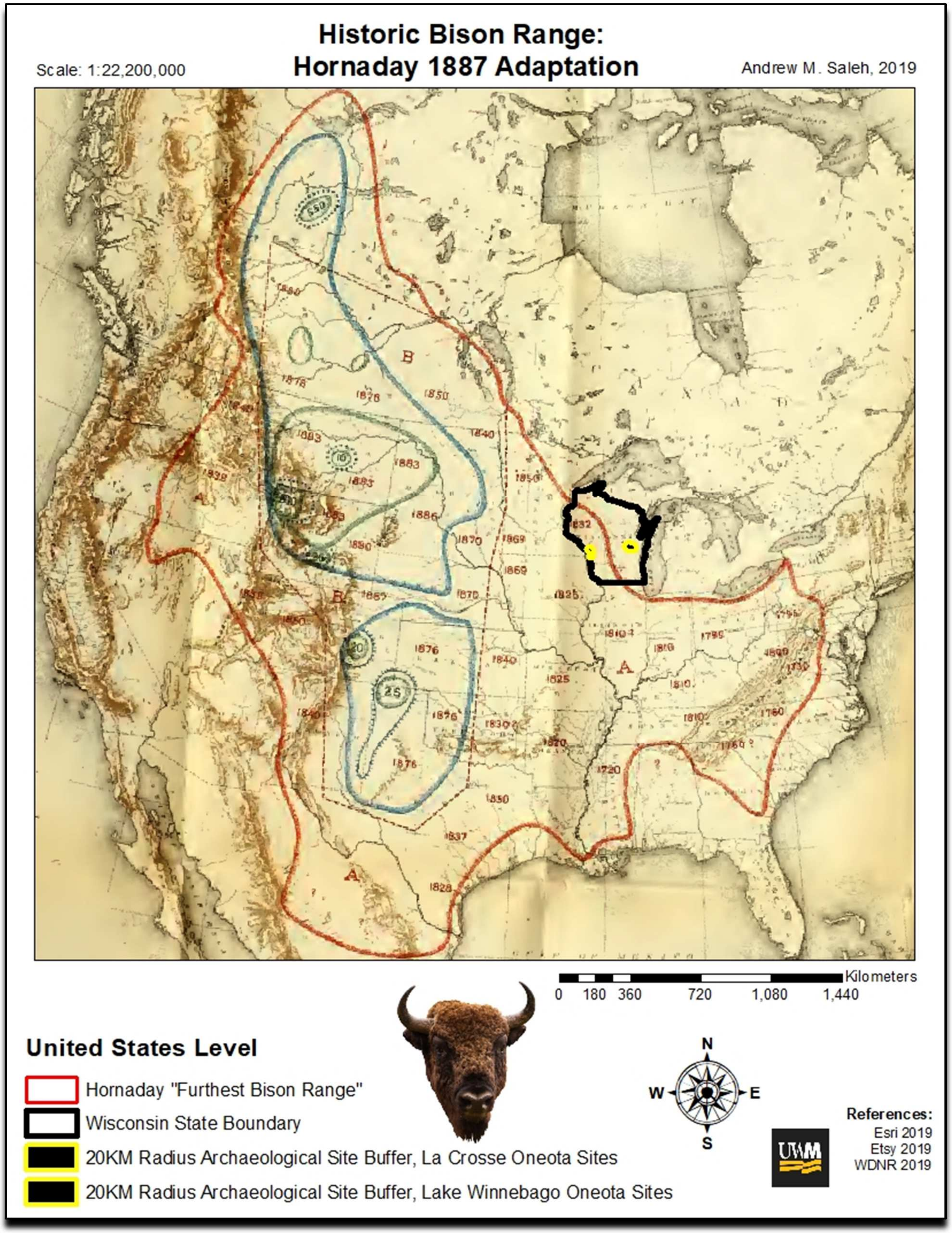


Figure 1.3: Historic distribution of bison in North America (adapted from Hornaday 1887).

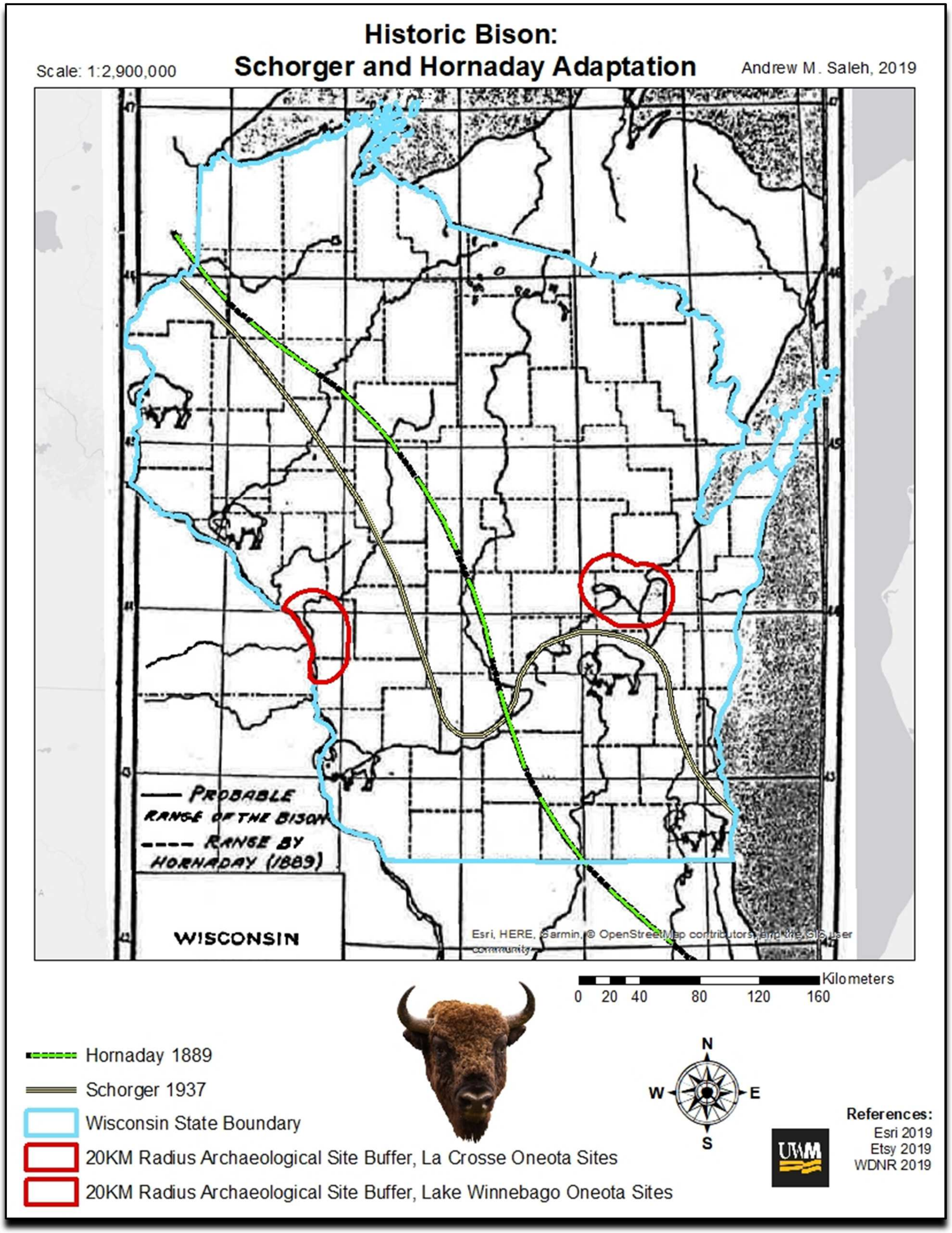


Figure 1.4: Historic distribution of bison in Wisconsin (adapted from Schorger 1937).

This GIS-centric study may contribute to a better understanding of the distribution of Early Historic and Late Prehistoric period bison populations in eastern North America. The La Crosse and Lake Winnebago Oneota localities were chosen for this study based on Sasso's (2014) summary of bison elements or specimens. Figure 1.5 shows the location of the two study areas in Wisconsin. Sasso (1993, 2014) identified the La Crosse and Lake Winnebago Oneota localities as being of high importance in terms of understanding the bison phenomenon in Wisconsin specifically. His reasoning was mostly based on differences in specimen counts and element types and contemporaneity of contexts between the regions. In the case of the La Crosse locality additional lines of prehistoric evidence have been suggested, including regional rock art (Boszhardt 2000; Salzer 1987, 1997; Shrab and Boszhardt 2018; Theler and Boszhardt 2003).

I approach these two Oneota localities as hunting catchments, focusing on potential human-large mammal interactions. The La Crosse area catchment is of special interest for multiple reasons, including bison specimen abundance and element diversity and the locality's relative proximity to the Great Plains. The Lake Winnebago area catchment provides a useful contrast to the La Crosse area in that it is located at a greater distance from the Plains. As illustrated in Figure 1.2 these localities appear to align temporally. Archaeologically, the Lake Winnebago area contains fewer Oneota sites with fewer bison remains. According to Kreisa (1986) and Sasso (2014), scapula are the only bison elements present there. Bison scapula were popular as hoes and thus potentially valuable as trade items. This raises the question of whether these two Oneota localities might represent two parts of Sasso's model for bison acquisition, Lake Winnebago representing the trade model and La Crosse representing the hunting model, either local or non-local hunting. Because my evaluation of the two localities focuses on their ecological suitability for local bison herds, it adds another line of evidence. Was the La Crosse area better suited ecologically for local bison than was the Lake Winnebago area?

Among the first steps in creating catchment maps relevant for Oneota time periods were to 1) determine which environmental variables were important and 2) choose the approach to reconstructing the prehistoric environment. For the first, three environmental variables seemed especially important when modeling habitat suitable to bison: vegetation, terrain, and waterways. For the second, while the time gap between Oneota occupations and the modern era is not huge, those centuries have certainly seen many changes in landscape use with the arrival of Euro-American settlers, the clearing of forest for timber and farms, the development of towns and cities, and a growing density of the resident human population. Thus, modern vegetation maps were not expected to be a good proxy for the Oneota landscape. One type of mapped vegetation data gathered in the 1800s, before many of the landscape changes began, was gathered by surveyors whose job it was to map the public lands of Wisconsin for future sale (BCPL 2019; Finley 1951). These surveyors were hired by the General Land Office (GLO), an agency of the United States government, and the work they did followed a method known as the Public Land Survey System (PLSS) (BCPL 2019; Bolliger et al. 2004; Finley 1951, 1976; Manies and Mladenoff 2000; Mladenoff 2019).

The hand-written records and plat maps that resulted from the GLO PLSS have since been developed into digital data. These data are widely used by scholars in fields such as historic ecology and archaeology to estimate prehistoric vegetation patterns across North America. GLO historic maps and notes have been applied in different ways in Wisconsin and at different spatial scales (Bolliger et al. 2004; Bolliger and Mladenoff 2005; Cogbill et al. 2018; Edwards IV 2010; Finley 1951, 1976; Liu et al. 2011; Manies and Mladenoff 2000; Mladenoff 2019; Mladenoff et al. 2008; Nelson et al. 2007; Shea et al. 2014; Stencil 2015).

The main types of data available in GLO PLSS records are hand-written field notes and associated sketch and plat maps. These include descriptions of major land features, ecotone changes, timber-centric vegetation information, and soil information. Details were recorded according to distances measured by surveyor's "chains" and "links" relating to section lines; a section was a one-mile by one-mile square that served as the standard unit of record keeping in the field notes (BCPL 2019; Finley 1951; Manies and Mladenoff 2000; Mladenoff 2019).

Although GLO field notes represent the original source data, they can be used in different ways, resulting in diverse reconstructions of past vegetation. This diversity often reflects the research goals of the particular study. For example, this thesis focuses on the ecological needs of bison, particularly the contrasts between forage-rich grasslands and forage-poor forests. It combines this with a spatial scale relevant to a human hunter traveling and returning to an Oneota residential site. It also *only* considers GLO vegetation, GLO or modern waterways, and modern terrain in modeling bison viability at a statistical level. Other non-bison GLO studies in Illinois or Wisconsin relating to the Prairie Peninsula have brought in additional or alternative factors like soil or barometric readings (Bourdo Jr. 1956; Curtis 1959; Edwards IV 2010; Finley 1951; Jeske 1990; Kilburn 1955). The basic spatial scale of data that has been adapted from the original GLO PLSS comes from townships (six-mile squares) and sections (one-mile squares within a township). Some scholars use these to model broad state-wide patterns while others target much smaller areas, such as one-mile catchments (Bolliger et al. 2004; Edwards IV 2010; Finley 1951; Nelson et al. 2007).

Catchment analysis is one approach to evaluating resources in a region. Archaeologists and other scientists often apply the concept to model human or animal use of prehistoric, historic, or modern landscapes, typically identifying a residential site as the hub and the catchment as the area surrounding it, scaling the size and shape of the catchment to the research question (Arroyo 2009; Calenge 2007; Ebert 2004; Edwards IV 2010; Host et al. 1996; Hunt 1992; Nolan and Cook 2010; Mysterud et al. 2012; Morgan 2008; Pendleton et al. 1998; Schaefer and Messier 1995; Scurry 2015; Stencil 2015; Supernant 2017; Tiffany 1982; Vita-Finzi and Higgs 1970; Wheatley and Gillings 2002). For example, Edwards (2010), when studying horticultural catchments for Oneota sites, used one- and two-kilometer radii from residential sites to evaluate garden resources. My thesis uses twenty-kilometer radii because I am studying large game hunting. My goal is to model a distance suitable to that type of hunting and a same-day or next-day return to the Oneota residential site (Bamforth 1981; Binford 1983, 2001; Green 2008; Morgan 2008; Theler and Boszhardt 2006).

The acquisition of large mammals in upper western Great Lakes states by prehistoric peoples has usually been weighted by white-tailed deer (Odocoileus virginianus); but, in the Driftless Area in southwestern Wisconsin, archaeologists have noted that a transition from the Late Woodland to the Upper Mississippian time period includes a new large mammal staple within this study's catchments, bison (Brown 1982; Brown and Sasso 2001; Pfaffenroth 2009; Richards 1992; Sasso 1993, 2014; Stencil 2015; Theler and Boszhardt 2006). Some scholars suggest that as human populations increased in areas like southern Wisconsin through the Late

Prehistoric period, their hunting ranges may have become smaller and more contested (Edwards 2017; Sterner 2018; Theler and Boszhardt 2006). Theler and Boszhardt (2006) state that settlement patterns may have been particularly tight during the Late Prehistoric period in La Crosse due to the density of people per kilometer over the settled landscape. Near Lake Koshkonong, Edwards IV (2017) and Sterner (2018) suggest Oneota movement was even more restricted regionally in the Late Prehistoric period. Near Lake Winnebago, Koziarski (2012) shows faunal acquisition patterns relating to Upper Mississippian contexts at the Bell Site were potentially affected by conflict, which may have restricted many aspects of Oneota lifeways in Wisconsin in general.

This consideration of the clustered Oneota settlement patterns, prehistoric hunting ranges, and bison biology all factored into the catchment sizes I chose to use for the GIS portion of this study. Within these catchments, statistical scenarios are presented for the landscape's viability for bison. A "custom" La Crosse area vegetation dataset, one that I constructed from the original GLO notes, is included as part of this thesis as a way to critically evaluate the impacts of GLO translation and research-specific coding and choice of spatial scale on GIS-based interpretations of prehistoric ecology. It is distinct from Kay's (1990) use of the reconstructed prehistoric vegetation of Wisconsin to model prehistoric game distribution; Kay did not include bison and relied on the vegetation reconstruction provided by Finley (1976).

This thesis is organized as follows. Chapter 2 provides background on three topics: archaeological evidence for bison in Wisconsin, bison biology as it relates to suitable habitats for bison, and the use of GLO data with GIS to reconstruct prehistoric environments. Chapter 3 reviews the methods I used to translate GLO data into GIS catchment maps, and how I used modern bison biology to establish criteria for evaluating catchment suitability for local bison herds. Chapter 4 presents my results for both the La Crosse and Lake Winnebago study area catchments. Chapter 5 reviews and compares the results from these two localities in terms of their ecological suitability for local bison herds, evaluates the use of GLO data in GIS modeling, and discusses my interpretations.

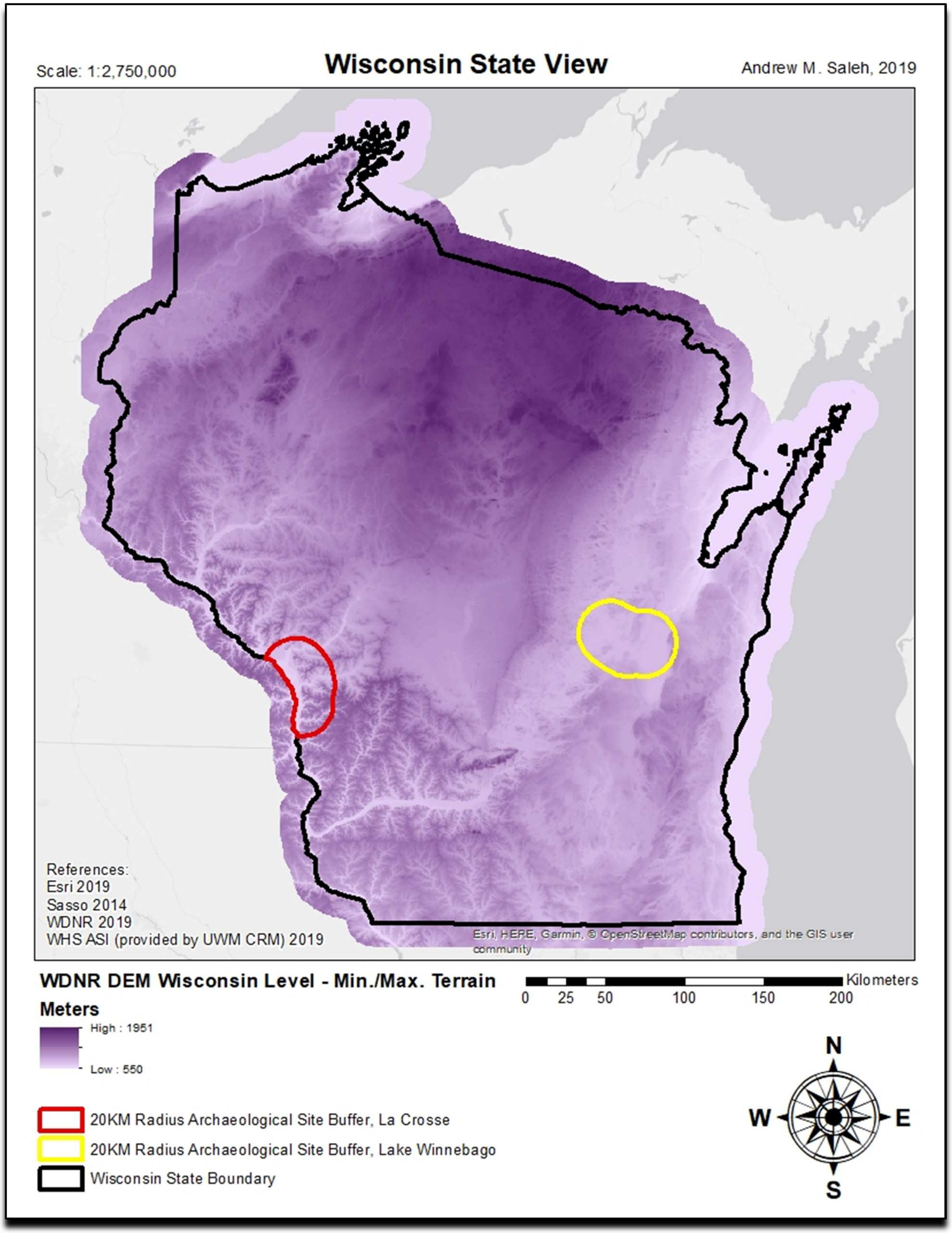


Figure 1.5: Map of Wisconsin terrain showing the location of the two study areas.

Chapter 2: Background

In this chapter the background literature on three topics will be reviewed. These are: bison remains in the archaeological record of Wisconsin, the biology of bison as it relates to evaluating habitats in Wisconsin that could have sustained local herds, and the use of GLO and GIS as approaches to reconstructing prehistoric environments in Wisconsin.

Bison in the Archaeological Record of Wisconsin:

In 2014, Dr. Robert F. Sasso synthesized years of archaeological finds and inquiries relating to Late Prehistoric Oneota Wisconsin archaeological sites containing bison remains, combining data from published literature, historic literature, grey or site literature, and personal communication. His study was divided into four geographic areas containing bison remains: “La Crosse,” Western “Upper Mississippi” Wisconsin, “Lake Winnebago – Middle Fox,” and “Lake Koshkonong.” Figure 2.1 shows Sasso’s geographic areas and their related archaeological site locations.

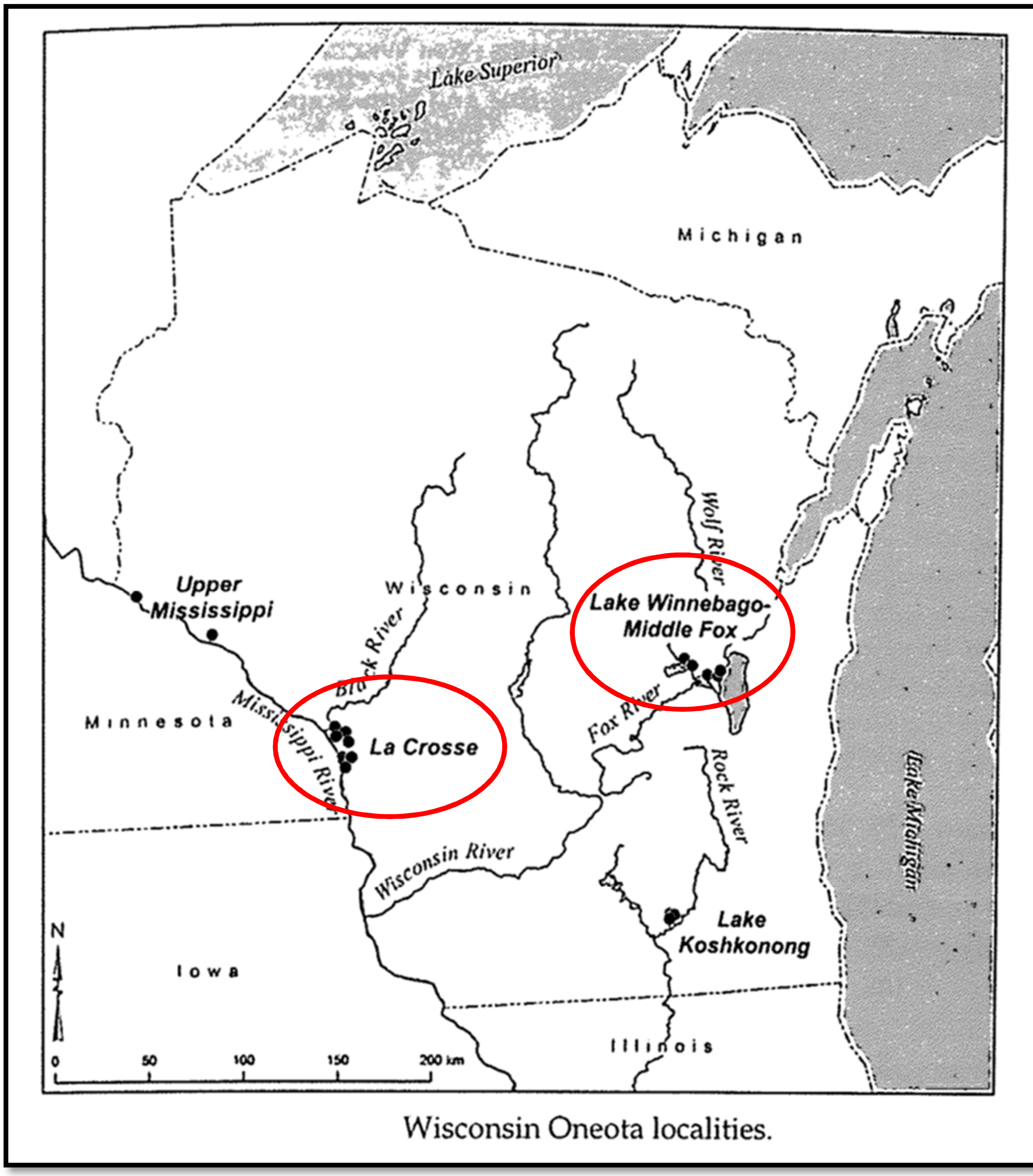


Figure 2.1: The four Oneota locales known to have bison remains in Wisconsin. The two that are the focus of this thesis are circled in red (map adapted from Sasso 2014:175).

Based on Sasso's tabled data, these remains represent a total Number of Identified Specimens (NISP) of between 182 and 215; in some cases, the source reports noted presence but not quantity, or noted a minimal number or a range, resulting in the total NISP range given here. Most of these represent confirmed bison identifications, with a small number of tentative identifications. These remains are distributed among 26 Oneota sites and clustered in the four localities mapped in Figure 2.1.

One point of special interest is that bison scapulae make up the majority of the total reported NISP; 125 out of 182, using the minimal end of the range of NISP values. Most of the scapulae identified were modified. Bison scapulae are known to have served as hoes, useful for Oneota Late Prehistoric agricultural practices (see Figure 2.2 and 2.3) (Sasso 1993, 2003, 2014). In the Lake Winnebago area scapulae are the only type of *Bison bison* element identified within Oneota contexts.

This spatial patterning and overwhelming preference for scapulae has been argued by some as strong evidence for the trade hypothesis of bison acquisition. Dirst (1985) argued that bison and elk scapula are diagnostic of the Orr phase Oneota represented at the La Crosse locality, and the Lake Winnebago phase Oneota represented at the Lake Winnebago locality. Peske (1971) and Kreisa (1986) argue that beyond pottery, trade between Oneota localities can also be evidenced by bison scapula appearing in contexts at the Lake Winnebago locality. Both of these phases fall within the same Oneota horizon, the Classical period (A.D. ~1300-1650), the last temporal horizon of the Upper Mississippian period that led into the Early Historic period in Wisconsin (Figure 1.2).

Figure 2.2: Pammel Creek bison scapula hoe cash (one of Sasso's reported bison sites in the La Crosse area). *Provided by the Mississippi Valley Archaeology Center online, excavated in 1983.*

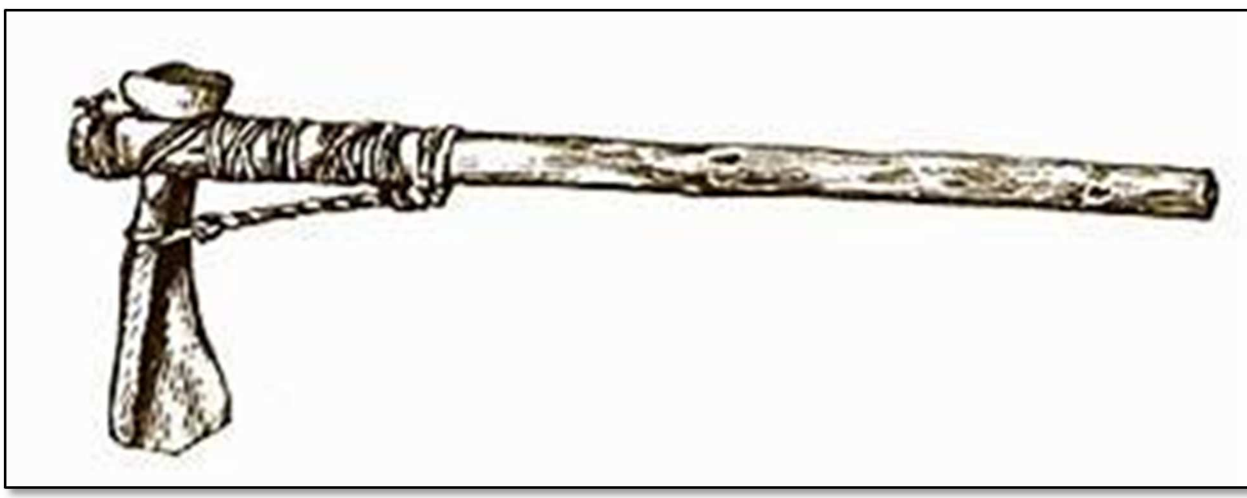


Figure 2.3: Scapula hoe drawing example. *Provided by the Illinois State Museum online.*

Sasso (1993, 2014) entertains the idea that bison were present in Wisconsin throughout the Upper Mississippian period but suggests that acquisition of bison most likely picked up during the Classical period horizons in the southern half of the state. Although rarer, some non-scapula elements were recovered from three of the four locales, Lake Winnebago being the exception. These elements included horn cores, humerus, radius, ulna, carpals and tarsals, metacarpals, phalanges, ilium, vertebrae, ribs, and a tooth. Some of these were modified, including an incised rib and an incised vertebra, but most were not.

This patterning of elements contributes to Sasso's three alternative explanations for Oneota bison acquisition. Element diversity – or lack of it – matters in the interpretation of hunting versus trade. In zooarchaeological modeling of large game transport from a kill site to a residential site two arguments are typically made (Bamforth 1988; Bamforth et al. 2005; Reitz and Wing 2008; Speth 1983). One is that the more complete the representation of all possible skeletal elements, the more likely that the animal was hunted nearby. The other is that an absence at a residential site of low food utility elements, such as cranial elements (e.g., horn cores and teeth) and distal limb elements (e.g., carpals and tarsals, metapodials, and phalanges) suggests that the kill site was at some distance from the residential site. For animals as large as the bison, these models can be complicated by the possibility that meat was flensed from bone at the kill site to reduce transport weight, resulting in few bones of any kind being transported to the residential site, a practice noted historically (Hennepin 1938; Lehmer 1963; Schorger 1937). It is thus of special interest that some Oneota sites in Wisconsin had not only scapula, but also low food utility elements like horn cores, carpals, tarsals, metacarpals, and phalanges, and high food utility elements like humerus, ilium, vertebrae and ribs.

Bison bones are still seen as rare from Oneota archaeological contexts in Wisconsin, and the La Crosse locality is the one that shows the most abundance in low utility elements. It also has some non-scapula high meat utility elements. This suggests the possibility of local kills and the use of local bison meat and hide in this locality. Modeling based on element frequency at this locality is slightly complicated by the description of several bison elements as modified. These include a thoracic vertebra described as engraved, a rib described as incised, another rib described as polished, and an ulna described as a paint applicator (Sasso 2014). This serves as a reminder that models based on meat utility capture only one of the ways that humans see and value animals.

Sasso (2014) and Edwards and Pater (2011) report that no bison scapula have yet been recovered in the Lake Koshkonong Oneota assemblages although this locality has yielded a few other elements, including some low utility items, such as a horn core and a tarsal, as well as some higher utility items, such as a vertebra and a distal radius. The Lake Koshkonong locality has been the subject of long-term and on-going research; when more complete faunal data become available, it will provide an important addition to our understanding of Oneota bison use. Jeske et al. (2017) consider bison as a part of the Lake Koshkonong Oneota subsistence pattern.

Rodell (1997), Sasso (2014), and Savage (1978) report that north of the La Crosse locality, in the area Sasso maps as Upper Mississippi, earlier Oneota contexts present at the Diamond Bluff (47PI2) site contain only scapula, while the Armstrong (47PE12) site has lower utility horn cores and some unidentified bison specimens. Rodell (1997:480) identifies Diamond Bluff as a potential hub for bison hide and bison parts, where native groups could send these goods down to the American Bottom via river trade. This conclusion is based on pottery from the contemporaneous Cambria phase found at sites in south-central Minnesota. These sites have high amounts of bison remains compared to Diamond Bluff but are thought to show evidence of Cambria and Diamond Bluff Oneota as direct trade partners through pottery. Essentially, the trade route proposed by Rodell (1997) is a line from south-central Minnesota to places like Cahokia, with Diamond Bluff as the northern-most trade outpost along the line.

Essentially, sites along the Mississippi River show a mix of scapulae and low and high meat utility elements. Lake Koshkonong shows a mix of low and high meat utility elements, but no scapula. And Lake Winnebago shows only scapulae. Thus, what Sasso's (2014) summary data show, when combined with Brown and Sasso's (2001) Oneota chronology (Figure 1.2), is that from approximately A.D. 1050 to 1700, low utility and high utility bison remains show up variably across the southern part of the state. This is the same part of the state where bison were observed historically (Schorger 1937).

One of the puzzles about the archaeological evidence for bison in Wisconsin is that there is so little of it. Bison are large animals with dense bones that are more likely to preserve better than those of many smaller animals. Sasso (1993, 2014) reviews some of the factors that might explain the relative lack of bison bone if bison were hunted locally in Wisconsin during Oneota times. He notes that large animals, such as bison, are more likely to be processed near the kill site, making their bones less likely to be found in residential sites. He also comments that kill sites may leave more ephemeral archaeological signatures due to their short use-life, and thus may be more difficult to find. This would be especially true of hunts that targeted single bison rather than entire herds. Sasso (2014) argues that a bison kill site - what McQuin

(2010) and others regard that as the almighty “smoking gun” - may yet be discovered in Wisconsin. Sasso (2014:178) also presents the idea that if we want to suggest scapula trade as the primary explanation for bison remains in Wisconsin, we need to investigate what items were offered in exchange for the scapulae. Whether from inside our modern Wisconsin borders or beyond them, other than pottery, nothing has yet to be overwhelmingly confirmed as a traceable trade item linking sites with bison scapulae to sites elsewhere that might have supplied them (Rodell 1997; Sasso 2014).

One additional issue that may impact the current visibility of bison bone in the archaeological record of Wisconsin is the challenge of identifying it when it does occur. Sasso (2014) and others note that fragments of very large mammals, such as elk, cow, moose, or horse can be difficult to distinguish from bison, especially in the field or without appropriate comparatives. Relatively few published osteological guides compare the elements of these taxa in a comprehensive or well-illustrated way (Balkwill and Cumbaa 1992; Brown and Gustafson 1990). This means it is possible that unreported bison remains exist in curated archaeological collections but have yet to be identified.

This thesis focuses on just two of the Oneota localities, La Crosse and Lake Winnebago. What follows is a more detailed account of the bison evidence at these two localities.

The La Crosse locality includes 16 of the 26 Oneota sites that Sasso identifies as having bison bone. As discussed here, the La Crosse locality refers to recognized Oneota sites on the Wisconsin side of the Mississippi River. Those with bison remains include the following sites: Filler (47LC149), Firesign (47LC359), Gunderson of the Sanford Archaeological District Locality

12 (47LC394), Herbert (47LC43), Holley Street (47LC485), Jim Braun (47LC59), Krause (47LC41), Midway Village (47LC19), Onalaska Village and Cemetery (47LC288), OT (47LC262), Overhead (47LC20), Pammel Creek (47LC61), Sand Lake (47LC44), State Road Coulee (47LC176), Tremaine (47LC95), and Valley View (47LC34). The OT site is seen as especially important, as up to twenty-nine recovered specimens were scapulae, but other elements were also represented, including humerus fragments (three), a magnum carpal, a metacarpal, and a lower molar (Sasso 2014). This suggests that sites like OT could have multiple acquisition styles, the abundance of scapula suggesting trade while the mix of other elements suggest local hunting. Kay (1990) notes that during historic times, both access to hunting grounds and hunting methods changed seasonally; this could potentially be a reason for multiple acquisition methods at one site. At sites like OT in the La Crosse locality, the zooarchaeological evidence of scapula and high and low meat utility elements suggests both trade and hunting were important, while the presence of low utility elements suggest local hunting was part of the total strategy.

In the Lake Winnebago locality there were five Oneota sites that yielded bison remains (Sasso 2014). These are: the Eulrich (47WN215), Furman (47WN216), Lasley's Point (47WN96), Overton Meadows (47WN106), and Sauer Resort (47WN207) sites. In all cases these remains are scapula. The number of scapula specimens per site ranges from one to five. This exclusive emphasis on scapula, and the lack of low utility elements, makes the Lake Winnebago locality a better fit for Kreisa's (1986), McQuin's (2010), Peske's (1971), and Sasso's (2014) trade hypotheses rather than a local hunting hypothesis. Kay (1990) notes that although historic Winnebago hunting grounds had shifted by A.D. 1810, they were quite large, sometimes involving almost half the state, with evidence of seasonal long-distance hunting. This is a reminder that Native groups were quite capable of traveling large distances in Wisconsin, whether for hunting or for trade.

Figure 2.4 locates the two Oneota study areas in relation to regional linguistic associations and named archaeological cultural areas during the Upper Mississippian period; although somewhat dated, it provides a wider context for considering regional interaction and trade. Do the bison scapula found in Lake Winnebago indicate trade? Figure 2.5 illustrates the background of waterways that connected different regions of the state, highlighting routes available to groups traveling by water. Tanner and Pinther (1987) show that by A.D. 1774, French fur traders would have been able to go from Green Bay to the northern mouth of the Mississippi with some ease. Kay (1990) shows that by A.D. 1810, historic Wisconsin tribes, including the Winnebago, were able to travel great distances along the rivers not only to trade, but also to travel to winter or communal hunting grounds. Figures 2.4 and 2.5 are seen as useful to conceiving possible inter-locality Late Prehistoric period exchange, especially when combined with what is currently understood about ceramic style distributions (Figure 1.2). As a way to imagine just what a Native American historic canoe party might look like, Schorger (1937:47) summarizing observations by De Beauharnois in May of A.D. 1730, describes the return of some twenty flat boat canoes of successful bison hunters of the Fox nation.

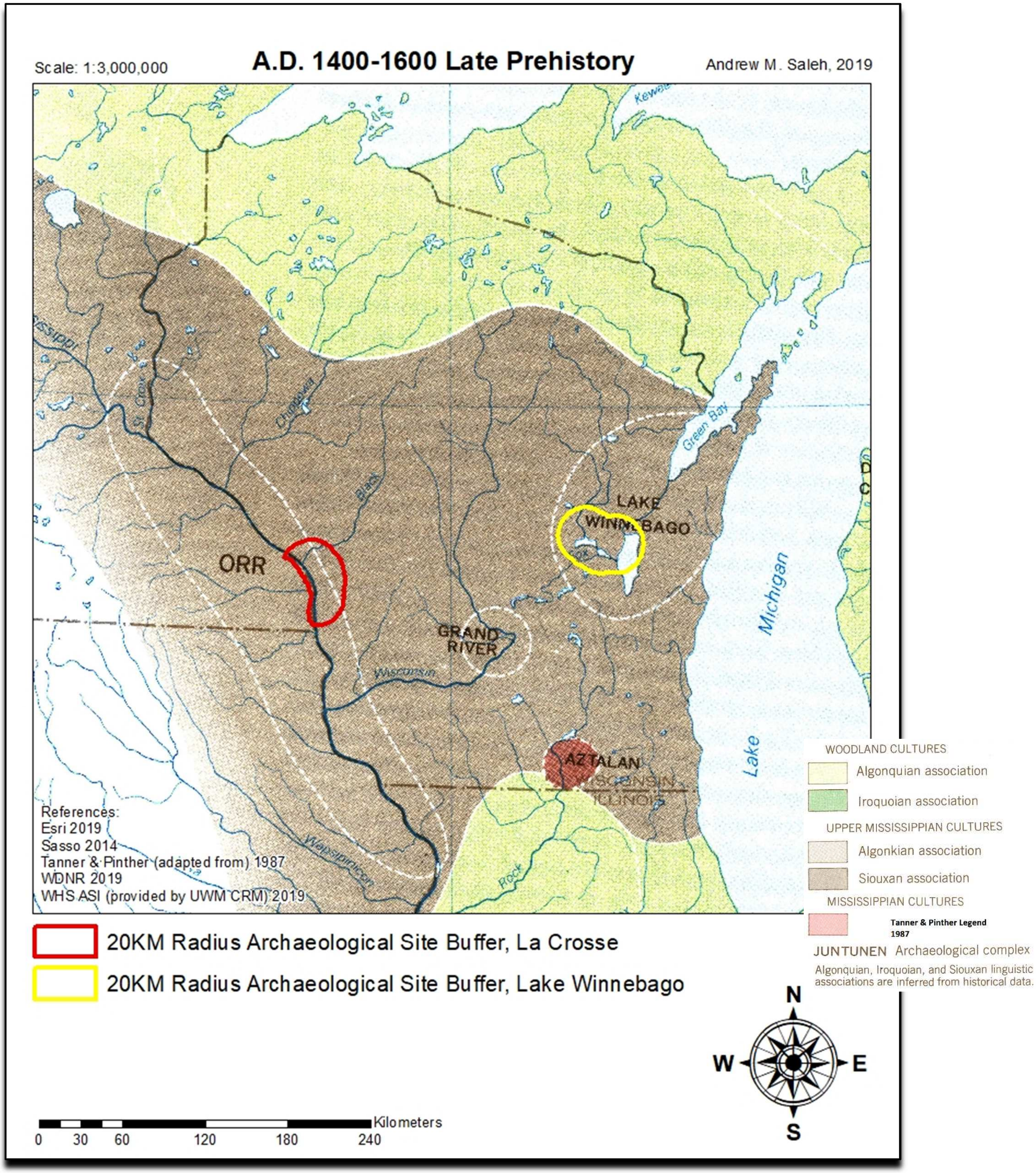


Figure 2.4: Historic cultural and linguistic distributions in Wisconsin. Adapted from Tanner and Pinther (1987).

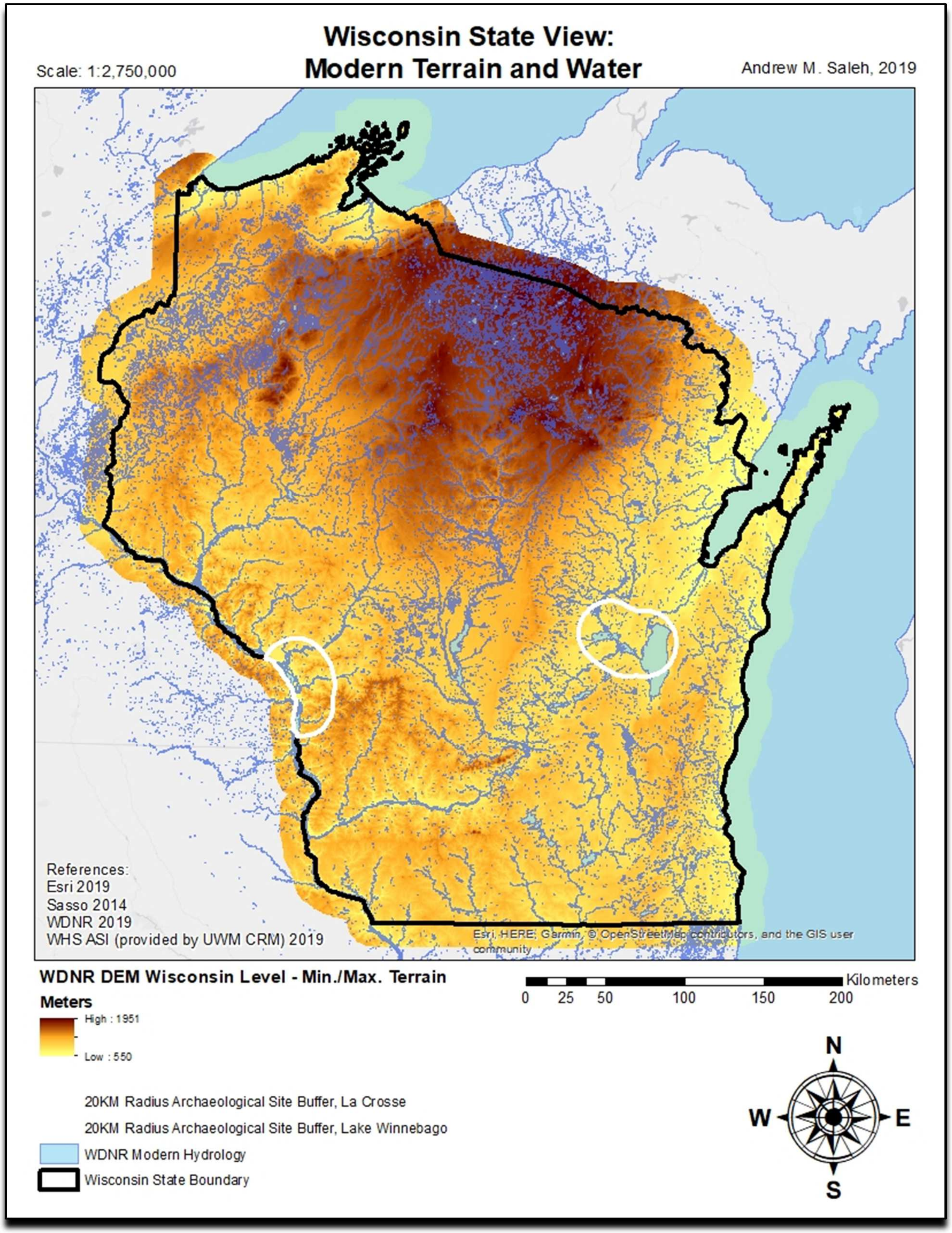


Figure 2.5: Two study areas in relationship to Wisconsin waterways and terrain.

The ecosystem known as the Prairie Peninsula is also argued to have played an important role in where and when prehistoric bison populations occurred (Sasso 1993; Theler and Pfaffenroth 2010). The Prairie Peninsula can be described as an eastern extension of the prairie grasslands of the Great Plains. Historic reconstructions typically center it in the state of Illinois, stretching north into Wisconsin and east into Indiana, with scattered patches in Kentucky and possible remnants in Ohio (Meszaros and Guy 2017). It has fluctuated in size through time (Ohio Plants 2019). Transeau (1935) attempted to map its estimated distribution at the time of Euro-American settlement (Figure 2.6) but noted that the ecological explanations for its location and extent were widely debated. Meszaros and Guy (2017) define it as a tallgrass prairie that occurs in the American Midwest, sandwiched between western shortgrass prairies and eastern deciduous forests. In Wisconsin this region has been reconstructed using factors such as soils and temperature (Curtis 1959; Finley 1951) and pollen samples (Nelson et al. 2007). Schorger uses historic accounts to map the extent of prairie in Wisconsin (Figure 1.4); significant to this thesis, he argues it extended into the Lake Winnebago region as well as along the upper Mississippi Valley in the La Crosse region. Anthropogenic factors in creating or maintaining grasslands, such as intentional burning by Native American groups, have also been discussed (Curtis 1959; Transeau 1935). This ecosystem is important in understanding why bison bones end up where they do (Meszaros and Guy 2017; Ohio Plants 2019).

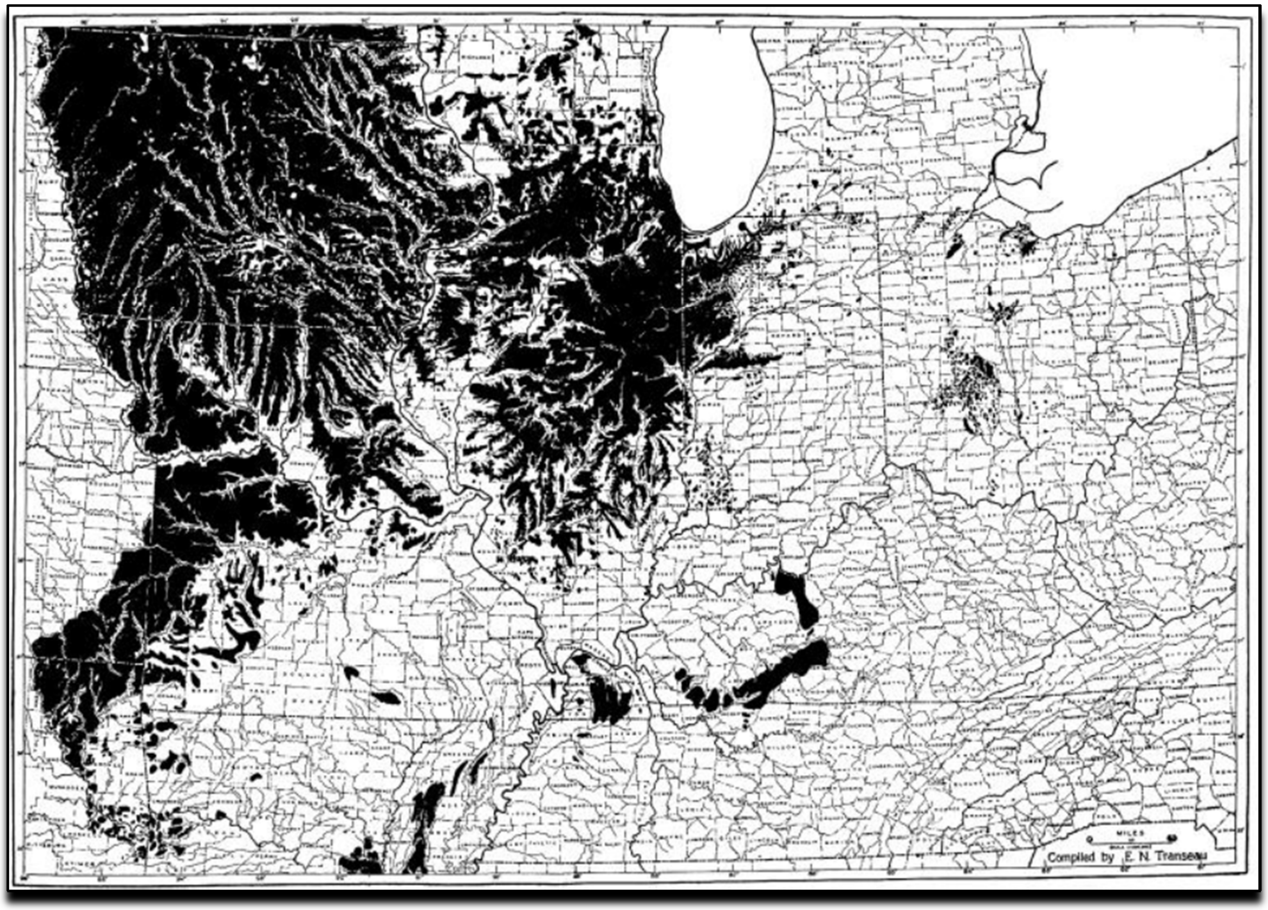


Figure 2.6: Prairie Peninsula as mapped by Transeau (1935); grasslands shaded black.

Sasso (1993) reviews research on climatic shifts in the Great Lakes region, noting the sequence of warmer regimes during the Neo-Atlantic Episode (A.D. 690-1100), drier regimes during the Pacific Episode (A.D. 1100-1550), and cooler and moister regimes during the Neo-Boreal Episode or Little Ice Age (A.D. 1550-1850). It is not clear exactly how these climatic shifts impacted the expansion or contraction of the Prairie Peninsula, but the time period associated with the Oneota overlaps the drier regimes of the Pacific Episode.

Sasso (1993) suggests that any local bison herds near the La Crosse area may have moved into these areas due to these climate shifts. Others have suggested that small local herds had established themselves in the area as early as A.D. 1100 in the wide Driftless Area river valleys near places like modern Buffalo County, Wisconsin (Henning 1992a, 1992b; Meine and Keeley 2017; Schorger 1937; W.DNR 2006). Boszhardt and McCarthy (1999) note the La Crosse area river valleys would be more favorable to large mammals than the Iowa or Minnesota river valleys, as the Wisconsin side has much wider bottoms and valleys. Bison may have already been in the La Crosse area before the Oneota populations settled (Sasso 1993; Theler and Pfaffenroth 2010). Figure 2.7 shows archaeological bison finds as documented by FAUNMAP (2019) superimposed on a georeferenced map of the Prairie Peninsula (National Geographic 1980); the overlap between the two in Wisconsin is striking. It is worth noting that this is true for the Lake Winnebago area as well as the La Crosse area.

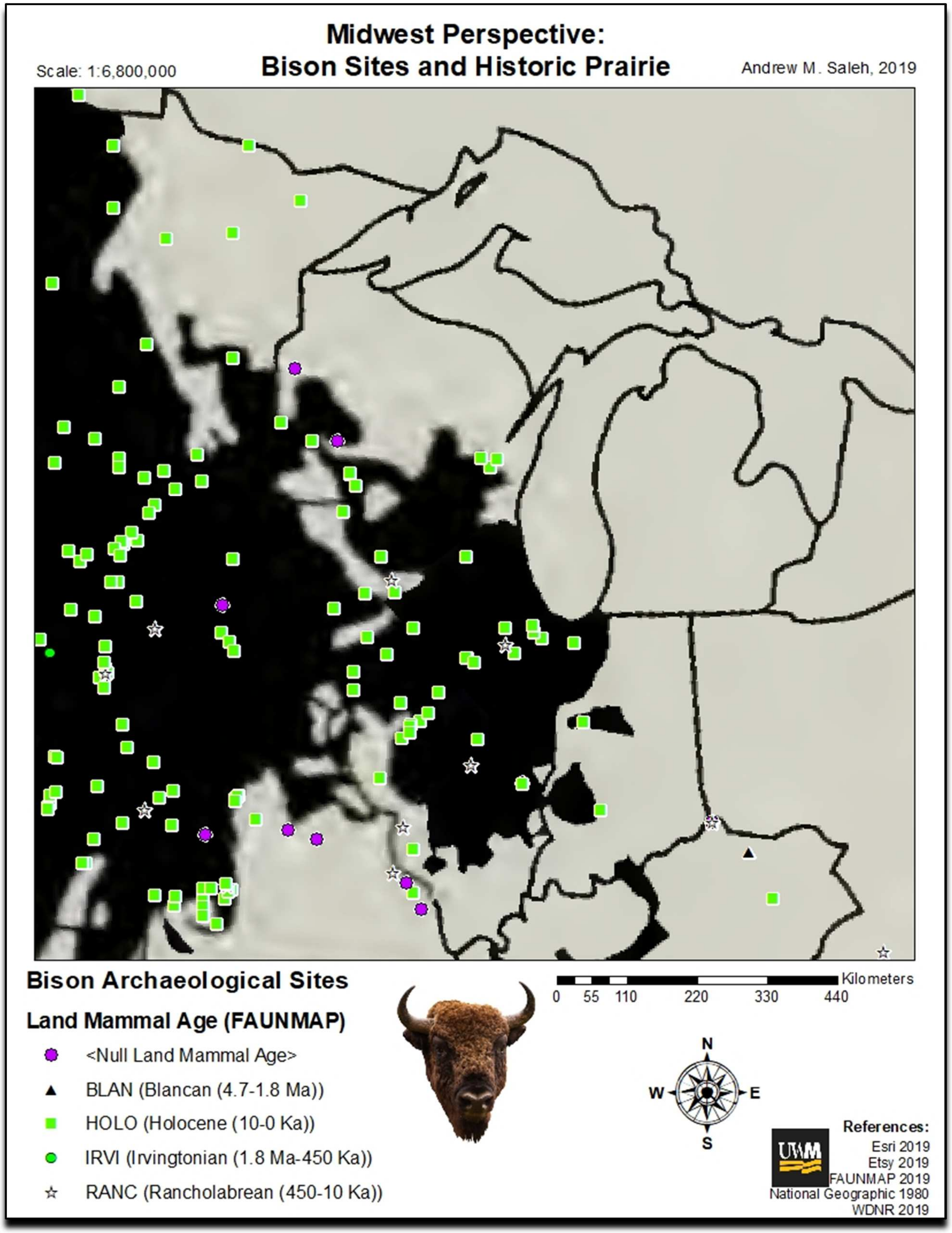


Figure 2.7: Archaeological sites with bison remains; the Prairie Peninsula is shaded in black.

Archaeological evidence provides direct observable bones of bison, so there is no doubt that bison somehow entered American Indian lives in prehistoric Wisconsin. Historic accounts of bison in Wisconsin and elsewhere in eastern North American provide another line of evidence. Archaeologists often use analogic reasoning, evaluating historic and ethnographic evidence to aid in understanding prehistory; this includes issues that involve hunter-animal relations (Bamforth et al. 2005; Binford 1967; Hudson 1991). It is important to recognize that it is problematic to try to link specific historic tribes to the prehistoric Oneota of the La Crosse area or Lake Winnebago area (Henning 1992a; Richards 1992). Setting aside any arguments of a direct historical connection, what can historic accounts add to our understanding of where bison could live, and when and where they could be hunted?

Although historic sites in Wisconsin are known to contain bison remains, they are not systematically reviewed here, given my focus on Oneota bison use. It would be useful to incorporate these historic sites in some future catchment study. For example, in the Lake Winnebago area, bison horn was reported for the Middle Historic period Bell site (Wittry 1963). There are also known historic locations of bison remains outside Wisconsin, such as at Starved Rock along the northern Illinois River, where thick layers of processed bison bones have been recovered in Early Historic period contexts (Martin 2014). For the purpose of the present thesis I will simply argue that such sites, in conjunction with historic journals and other documents, show compelling evidence of Early Historic period bison hunting in or near Wisconsin (Blair 1911; Hennepin 1938; Lehmer 1963; Martin 2014; Sasso 1993, 2014; Wittry 1963).

Schorger (1937) published a review of historic accounts pertaining to the range of bison in Wisconsin, using a mix of French and English accounts from the 1600s and 1700s as well as other sources. For example, Schorger (1937:47) cites Perrot's description that a Native group established a new settlement near modern Green Bay, Wisconsin around 1666, and after doing so, went to hunt bison, returning in a fortnight with grease and meat. Schorger (1937:46) hypothesizes that given the time needed to travel, hunt, and return, these bison could not have been much further than the prairies south of Lake Winnebago. He cites other sources for mentions of bison herds along Wisconsin's western border. These include Hennepin's observations in the late 1600s of bison near the Chippewa River and Lake Pepin, and settler's reports from the late 1700s of bison crossing near the mouth of the Wisconsin River in large numbers. He also calls attention to place names that refer to buffalo, such as Buffalo County in western Wisconsin and Buffalo Lake in central Wisconsin, and associated historic accounts of the presence of local herds in those two locations. He uses these accounts to build his mapped estimation of the historic distribution of bison in Wisconsin (Figure 1.4), which place bison from Lake Pepin near the northern Mississippi River in Wisconsin, southward to the mouth of the Wisconsin River, and eastward across the state to southern Lake Michigan.

In 1675, Father Louis Hennepin entered the western Great Lakes and northern Mississippi River regions; his notes include mention of cultural practices related to bison hunting as it was conducted by the Miami living then at the southern end of Lake Michigan near the Prairie Peninsula. His observations suggest that the Miami hunted bison heavily in the autumn with bow and arrow and the use of fire (Cross 1938:59). Important information can be pulled from his discussions: 1) some Native American groups seemed to manage grasslands and bison alike so that the animals would return to be hunted again, 2) women carried up to 300 pounds of bison meat away from kill sites, 3) bison wool was used to make bags that helped carry smoked or dried bison meat, 4) bison hides weighed 100 to 120 pounds, 5) meat could last three to four months, 6) many of the bison related items obtained in the autumn were used for subsistence through the winter, and 7) the bison of this region were noted to migrate seasonally, crossing rivers and creating traces. These animals seemed so important to Hennepin that he wondered why the calves were not taken from kill sites and domesticated (1938:62). Figure 2.6 shows the historic extent of the Prairie Peninsula; although the Miami that Hennepin observed were hunting south of my study areas, similar prairie habitats likely extended into Wisconsin.

Artistic representations of bison provide another line of archaeological evidence. Rock art attributed to Oneota time-periods in southwestern Wisconsin portrays bison possibly associated with hunting magic and the “heartline motif,” a motif which appears as far south as New Mexico and as far north as North Dakota in the same general form (see Figure 2.8) (Boszhardt 2000; McQuin 2010; Salzer 1987, 1997; Shrab and Boszhardt 2016; Theler and Boszhardt 2003). Lothson (1976) reports bovid petroglyphs associated with Upper Mississippian contexts in Minnesota, while Boszhardt (2000) and Salzer (1987, 1997) both report this as a common occurrence related to Driftless Area Upper Mississippian sites. Boszhardt (2000) also identified a possible bovid image (potentially with a heartline motif) at Hoxie Farms, an Oneota site in northern Illinois. A heartline motif was found on a catlinite tablet found at the Midway site in the La Crosse locality; the catlinite itself is thought to be from southwestern Minnesota. Thus, the distribution of petroglyphs and other artistic representations of bison, including those with the heartline motif, seem to match the distribution of bison bone and the historic accounts of bison, and suggest that bison were valued in symbolic ways. Others have extended this to the Late Historic period with historic Sauk art in modern northeastern Iowa (Boszhardt 2000; Torrence 1988; Musgrove and Musgrove 1974; Salzer 1987, 1997; Sasso 1993).

Another iconographic form is represented by bison effigy earthen works or "mounds" in Wisconsin (Schorger 1937). Schorger (1937) notes they once existed along prairies near modern Madison, Wisconsin. Birmingham (2009) states that evidence suggests effigy mounds were most intensely constructed from A.D. 700-1100. These mounds had social meaning beyond just representing animals, and potentially directly related to native ideology in the region. The Wisconsin Historical Society Archaeological Site Index (2019) supports the idea that there may only be one bison effigy mound left in Wisconsin, in modern Adams County. At some level, whoever built these specific mound types may have held the animal in some regard.

Another line of evidence that has been applied to location of bison herds is lithic analysis, specifically use-wear analysis and protein-residue analysis. Use-wear analysis has been used to argue against local hunting by some scholars; Boszhardt and McCarthy (1999) see the absence of wet-hide polish and the presence of dry-hide polish on end-scrapers as evidence that animals were killed elsewhere at some distance from the La Crosse locality. McQuin (2010:33) attempted protein residue analysis on end-scrapers from the same locality; none of the tools tested showed any bison residue, and was seen as supporting an interpretation that hunting was not local. Sterner provides some alternative lithic evidence. She conducted use-wear analysis on 200 tools from the La Crosse locality and found wet-hide and meat at a higher frequency than dry-hide polish; her tool forms were not restricted to end-scrapers (2018:163). Although neither Sterner (2018) nor Boszhardt and McCarthy (1999) used protein residue analysis in conjunction with use-wear studies for the La Crosse locality, Sterner did find protein residue evidence for bison hunting at the Lake Koshkonong Oneota locality (2018:172). Her analysis of “Tool 107,” a Madison point made from local chert indicates that the tool was used to shoot a bison, and was lodged in the wet-meat of the bison for quite some time. The Lake Koshkonong locality appears to have been occupied earlier than the La Crosse locality and is not one my study areas; it would have located in or near the Prairie Peninsula.

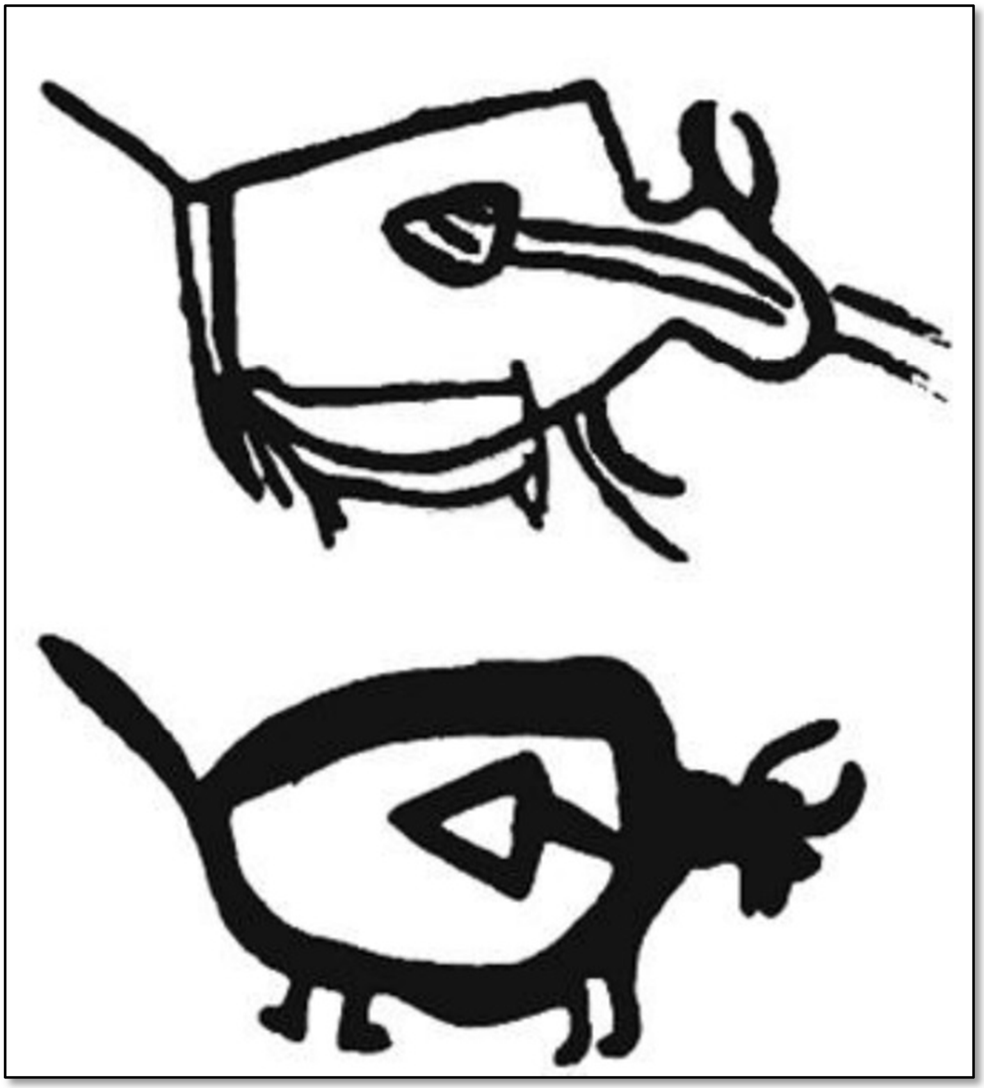


Figure 2.8: Bison depictions showing the heartline motif (from Boszhardt 2000; McQuin 2010).

The question in most of the eastern Prairie Peninsula states, regardless of the historic bison sightings or rock art, still seems to be: why the apparent lack of prehistoric archaeological evidence and enduring ecological impacts (Leach et al. 1999; Mcmillan 2006; Sasso 1993, 2014)? The recorded historic range of the bison extends well east of Wisconsin, with Daniel Boone journaling about bison presence near the Appalachian mountain range in the mid-1800s (Belue 1996). Rostlund (1960) reports historic bison sightings all the way down in Florida by the Spanish (See Figure 2.9). Therefore, examining some major Late Prehistoric period sites outside Wisconsin becomes important.

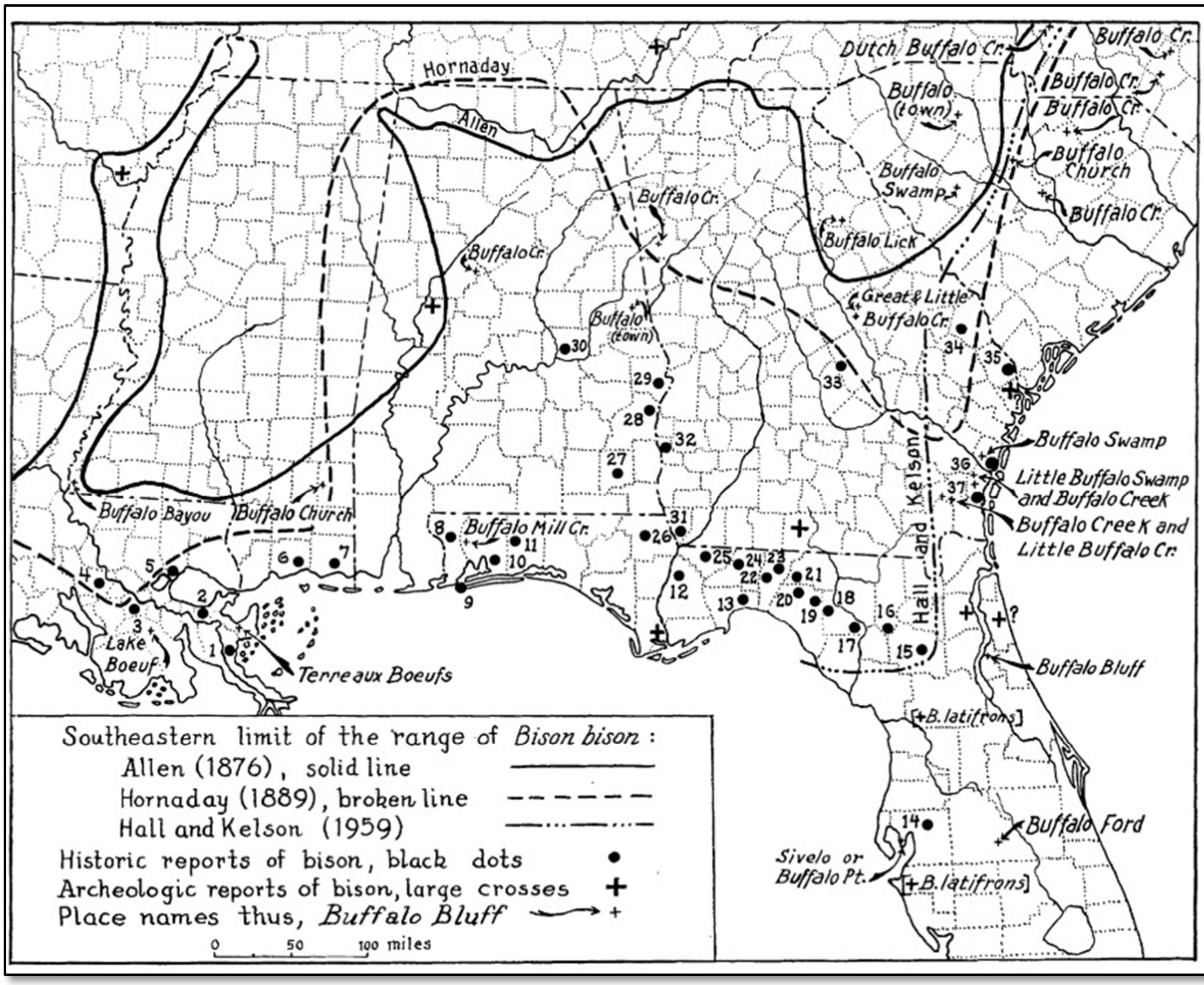


Figure 2.9: Evidence for bison in southeastern North America (Rostlund 1960).

Illinois archaeologists contend that bison persisted in that state regularly from the Early Archaic to the Early Historic period (Griffin and Wray 1945; Harn and Martin 2006; Martin 2014; Mcmillan 2006; Widga and White 2015). In Illinois and Indiana, unlike Wisconsin, evidence of bison “wallowing” areas and “traces” exist today to go along with the archaeological evidence (Jakle 1968; Tankersley 2005; Widga and White 2015). Wallowing refers to the bison habit of rolling in the dirt and thereby creating a large shallow pit (Hess et al. 2014; McDonald 1981; Widga and White 2015). Bison traces are essentially paths that have been created by repeated bison movement in a region (Jakle 1968; Widga and White 2015). Schorger (1938:47) provides the only mention of an historic account of bison wallows in Wisconsin, an observation made south of Green Lake, about 30 miles west of Lake Winnebago, sometime after 1840.

In Illinois, they have found the archaeological “smoking gun” that Wisconsin lacks. The Lonza-Caterpillar site was discovered along the Illinois River not far south of the modern Wisconsin state line in 2006 (Harn and Martin 2006). Interpretation of the natural and cultural aspects of the site are complex, but it is clear that it represents the presence of bison in this part of the Prairie Peninsula, both during the Oneota time span and long before it. It is a multi-component site, with AMS radiocarbon dates ranging from 305-420 B.C. to A.D. 1460. The site contains 522 fragments of bison bone, recovered in eight spatial clusters, representing a total of at least twelve individual bison. One of the clusters includes a broken projectile point in association with ribs that show wounding marks. Elsewhere on the site a bison thoracic vertebra has a chert fragment, interpreted as a point tip, embedded in it. Both these finds date to the earliest component of the site. This site is thus interpreted as a kill site, possibly serving that role multiple times. The authors note that hunting strategies in the upper Midwest may have included hunting along river banks where animals are vulnerable (Harn and Martin 2006).

In related research in Illinois, Martin (2014) conducted a metric study on bison scapula from three Oneota and Early Historic sites: Hoxie Farm, Palos, and Zimmerman. Figure 2.10 shows the location of these sites. These are Oneota village sites that show similar element distributions to the La Crosse Oneota locality in that scapula and low utility remains are found together. The goal of his study was straightforward yet elusive: to answer the bison acquisition question in northern Illinois. Essentially, the research was framed by the question: were bison scapulae found in Oneota sites in Illinois traded in from locations closer to the Great Plains, such as the La Crosse Oneota locality, or were they the results of direct local hunting? Martin (2014:186) hypothesizes that if La Crosse was a hub for trade, and controlled access to scapula coming in from the Great Plains, then they might keep the biggest and best for themselves, and release only the smaller and less desirable ones for trade to other Oneota communities.

While the metric results did not support this hypothesis, Martin presents valuable data on element frequencies at Hoxie Farm and Zimmerman, and compares these to White Rock, an Oneota site on the Plains in Kansas where bison hunting is well noted. Hoxie Farm (total bison NISP=62) shows a pattern similar to that seen in the La Crosse locality, with abundant scapula but a light mix of other elements represented as well, both high utility elements, like vertebrae and innominate, and low utility elements like phalanges. Zimmerman (total bison NISP=161) has a similar number of scapulae, but many more vertebrae and ribs, and almost every type of element represented to some degree. White Rock (total bison NISP=338) is like Zimmerman in terms of the diversity of elements represented, but with a higher frequency of scapula than either of the other two sites. The big take-away seems to be that Hoxie Farms does look different from Zimmerman and White Rock based on the mix of elements; Hoxie Farms has scapula and distal limbs, the other two localities have a full range of high-low utility elements, as expected with direct hunting.

This comparison revealed some trends: scapula hoes were important to Late Prehistoric period Great Plains White Rock phase Oneota just like they were to La Crosse locality, Lake Winnebago locality, Hoxie Farm, and Zimmerman Oneota. These site localities are all important because they all show the combination of low utility remains at varying rates with high utility remains. The addition of Martin's (2014) data is particularly revealing in that it shows similar patterns with fewer elements, potentially indicating that Oneota east of the Mississippi River near or in the Prairie Peninsula simply had less access to local bison.

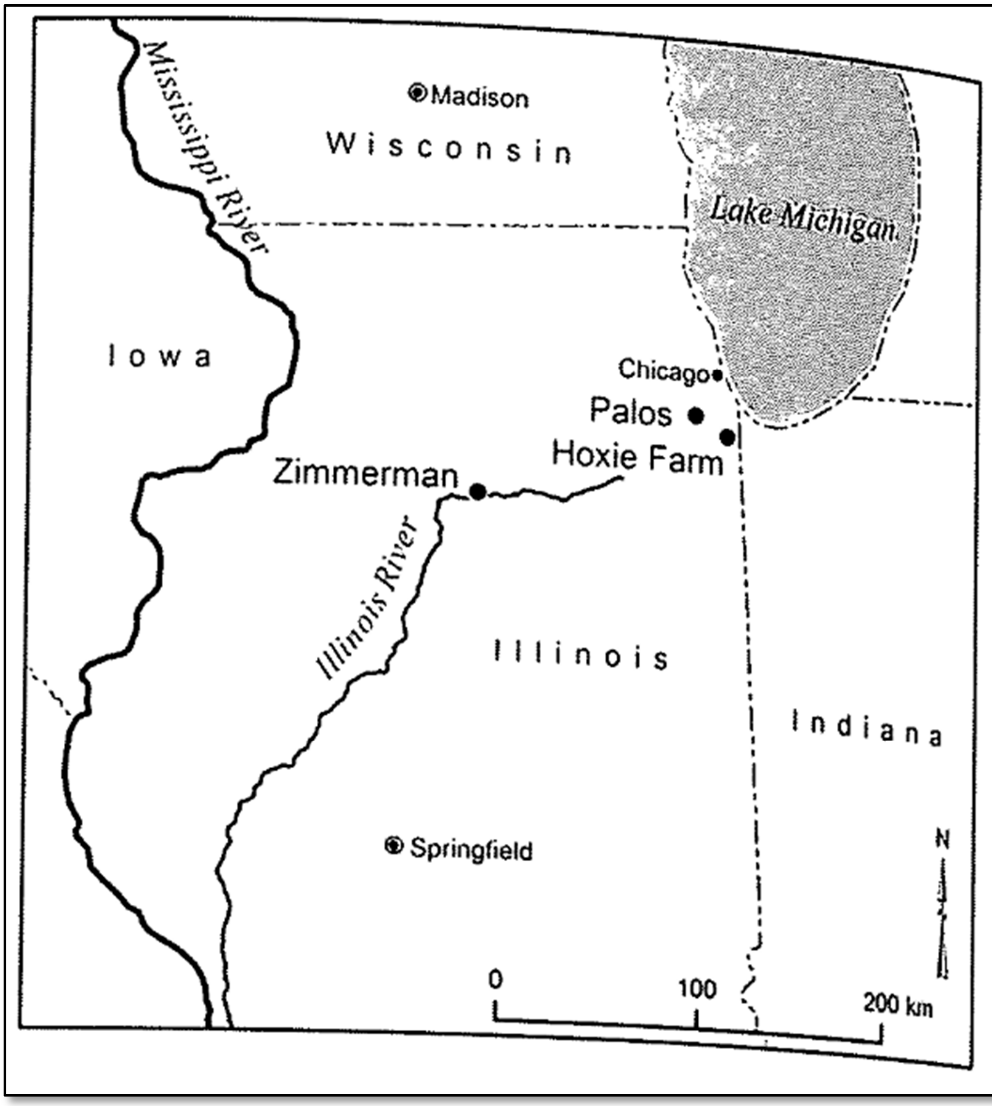


Figure 2.10: Illinois Oneota sites with bison remains (from Martin (2014:186).

Outside of Illinois and Wisconsin, Late Prehistoric period peoples near the intersection of southeastern Indiana, north-central Kentucky, and southwest Ohio also obtained bison (Jakle 1968; Tankersley and Adams 1991; Widga 2006a). These remains are attributed to another potential Upper Mississippian expression known as "Fort Ancient." Although it was not the goal of this thesis to synthesize Fort Ancient's relation to Oneota, the source location of the bison these groups were acquiring is well noted. Widga (2006a) and Tankersley (2005) have shown that people obtained bison from Big Bone Lick, a site in north-central Kentucky, and brought the parts back to Fort Ancient village sites to the north.

Widga (2006a:1243) was able to run isotopic analysis on Late Prehistoric (A.D. 1270-1640) period bison samples from Big Bone Lick. The results show that these bison were from the same herd. The herd had a ratio of one male to three females based on cranial elements, and sexually dimorphic limb elements like calcanei (Widga 2006a:1252). Morphologically, these bison were similar to their Great Plains counterparts, as demonstrated by Widga's (2006a) analysis of eighteen sites west of Iowa. Males and females in the Big Bone Lick herd were only slightly smaller. Based on the isotopic and tooth wear analyses, Widga (2006a:1252) shows the main difference between eastern and western bison was in their diet; the Kentucky bison supplemented their diet with a lot of woody browse. This provides useful insights into how Late Prehistoric period bison adapted to the Prairie Peninsula and mosaic environments.

This section began with a review of the archaeological evidence for bison in Wisconsin and expanded into other relevant evidence drawn from historic accounts and archaeological sites in Illinois and Kentucky. Archaeologists have often argued for the importance of non-local hunting and trade to explain the presence of bison bone in Oneota sites in Wisconsin. However, numerous lines of evidence support the possibility of local herds of bison in Wisconsin in the past and local hunting as another viable way to explain the Oneota access to bison. These include evidence based on the archaeological recovery of bison bone, the relative amount of that bone, the particular elements recovered, the analysis of lithic tools for use wear and protein residue, the analysis of Native American rock art and earthworks for depictions of bison, and historic accounts of bison herds in Wisconsin and elsewhere east of the Mississippi.

The Biology and Ecology of *Bison bison*

What do bison need to be "local" in Wisconsin? In particular, what constitutes adequate acreage of suitable forage to maintain a herd? Answering this important question involves considering the dynamic aspects of the ecology of bison as well as their biology and behavior. Here I will summarize general trends relating to the ecology of historic and modern bison as it has been reviewed (Brockman 2018; Knapp et al. 1999; Larter and Gates 1991; Leach et al. 1999; Nelson et al. 2007; McDonald 1981; Nowak 1999; Sasso 2014; Shay 1978; Widga 1997, 2006a, 2006b). As noted by Flores (1991), bison ecology can be seen as a complex interaction of biology and behavior, including population dynamics that involve predators (human and non-human) as well as seasonal variations in forage, temperature, and migration range.

There are two currently accepted living bison species, the North American bison, *Bison bison,* and the European bison, *Bison bonasus*. Both bison species are in the order *Artiodactyla*, the family *Bovidae*, and the genus *Bison*. Some scholars argue that there are two North American subspecies of *B. bison.* These subspecies are *Bison bison bison* and *Bison bison athabascae*, sometimes referred to as Plains bison and Woodland bison, respectively. The modern *B. b. bison* is now associated with the prairie lands of the Great Plains. The *B. b.*

athabascae form has a modern range in subarctic Alaska or Canada, associated with tundra and boreal forest, and has been observed as having a more general and adaptable dietary regime (Brockman 2017; Larter and Gates 1991; Meagher 1986). Some have argued that bison are not too dissimilar to what we know as cattle and belong in the genus *Bos* (Chapman and Feldhammer 1982; Nowak 1999; McDonald 1981; Van Zyll de Jong 1986; W.DNR 2006). The *Artiodactyla* as an order includes members such as *Cervidae* (deer) and *Antilocapridae* (pronghorn). *Bovidae* as a family includes antelopes, cattle, bison, water buffalo, goats, and sheep (Nowak 1999).

For the purposes of this thesis, *B. bison* as a species is the focus, with the full acceptance that Wisconsin could have potentially been home to both *B. b. bison* and *B. b. athabascae* at some point in the past, as well as extinct species. *B. bison* as a species most likely evolved from *Bison occidentalis*, *Bison antiquus*, or a hybrid of the two, and all most likely evolved from *Bison priscus* (Bamforth 1981; Boszhardt et al. 1993; Chapman and Feldhammer 1982; McDonald 1981; McMillan 2006; Nowak 1999; Speth 1983; Van Zyll de Jong 1986). Trace evidence of *B. antiquus* and *B. occidentalis* occurring during the Late Paleoindian to Early Archaic periods in Wisconsin exists, but sites where these species are found are seen as paleontological sites rather than archaeological sites (Hawley et al. 2011; Hill et al. 2014; Kuehn 2009b; Theler 1994a). The purpose of this thesis is not to argue the origins of *B. bison*, but rather to simply recognize that they are a species that evolved in North America sometime between 4,000 and 7,000 years before the present (Brockman 2017; Chapman and Feldhammer 1982; Hill et al. 2014; McDonald 1981; Nowak 1999; Van Zyll de Jong 1986).

Bison are the largest surviving land mammal in North America. *Bison bison* has a weight range of 350-1,000 kg and a shoulder height of 1.5-2 meters (Nowak 1999; Shay 1978). Males are commonly larger than females. Sasso (2014) and Jackson (1961) remark bison adult males on average weigh from 727 to 909 kg, while bison adult females on average weigh from 409 to 500 kg. In general, American bison are traditionally associated with prairies, but are noted to occur in mountainous areas and forests that are broken or open (Nowak 1999; Widga 2006a).

Bison are primarily grazers, favoring grasses and sedges, but they can browse on woodier plants as well. Of special relevance to this thesis are studies that focus on the foraging habits of bison living in mosaic habitats similar to those of prehistoric Wisconsin. These mixed habitats could include wetlands and forests as well as prairie. Studies of bison foraging habits have identified seasonal variations in the balance of grasses, sedges, and browse, as well as in the balance of C4 and C3 grasses. Studies of a modern bison herd at the Nachusa Grassland in Illinois indicate that they graze primarily on C4 grasses during the summer and fall, and C3 grasses during the spring and winter (Blackburn 2018). Besides C3 grasses, bison are also noted to forage on C3 sedges and woody species year-round to supplement their diets (Blackburn 2018; Morgan 2002a, 2002b; Meagher 1986; Ulman 2000). At Nachusa, it has been noted that bison preferably graze on big blue stem (*Andropogon gerardi*) and Indian grass (*Sorghastrum nutans*); these species would have been available in southern Late Prehistoric Wisconsin (Curtis 1959; Hess et al. 2014; Jackson et al. 2010; Meszaros and Denny 2017; Middleton 2002a, 2002b; Nelson et al. 2007; Shay 1978). Analysis of bison remains recovered from a Late Prehistoric period archaeological site in northern Kentucky proves woody species were relied upon quite frequently (Widga 2006a). C4 grasses are of a higher nutritional value, and therefore will be preferred by bison when available.

Behavioral observations of bison include wallowing and rubbing to get rid of parasites, using their acute sense of hearing or smell, running at speeds close to 60km/hr., and swimming across rivers over a kilometer wide (Nowak 1999). Wallowing is of special interest to ecologists and archaeologists trying to identify landscapes previously used by bison, as wallows can become recognizable and enduring features.

Bison are known as herd animals. Herd size is variable, with an average size of 57 individuals (Nowak 1999). Historic records provide relevant data. Herds numbering in the hundreds were noted in the extensive prairies of Great Plains, while in mosaic habitats east of the Mississippi herd sizes of 60 were recorded (Bamforth 1981; Belue 1996; Hornaday 1887; Schorger 1937; Widga 2006a). Rostlund (1960:398) notes multiple buffalo herds of 60 or more individuals as far southeast as Georgia in 1716. Schorger (1937:41) notes historic accounts of a Wisconsin herd near Lake Pepin herd of around 60 members.

This average herd size has been challenged by historic sources that list bison herds four times the size of this well east of Wisconsin (Belue 1996). In fact, bison were hunted regularly by historic Native Americans even in Florida. The idea is that confined herds reported throughout the modern United States, and their average herd sizes, will never mimic a species that was completely decimated before herd statistics were ever taken (Hornaday 1887). The Lake Pepin historic herd may actually be closer to what studies about confined modern herds suggest.

In terms of both animal size and herd size, it has been suggested that herds subject to harsh climatic episodes or mixed forage are physically smaller and less numerous when compared to herds with access to extensive grasslands year-round (Sasso 2014; Widga 1997, 2006a). Prairie Peninsula herds were no doubt subject to these factors in prehistory to at least a small degree, as supported by Widga (2006a).

There are seasonal patterns to aggregation and to bison herd composition (Chapman and Feldhammer 1982; McDonald 1981; Nowak 1999; Van Zyll de Jong 1986). Adult females and calves of up to three years stay in herds year-round (Nowak 1999). Male bison often spend part of the year either solo or in bachelor herds of a small number of individuals. Adult males typically enter mixed herds only at certain times of the year. This means year-round herds usually only have females and young as permanent members. Analysis of the sex ratio of bison represented at the Late Prehistoric archaeological site of Big Bone Lick in Kentucky showed one male to three females (Widga 2006a). Mating has been noted as a summer through fall activity, while birthing occurs in the spring. Females take around three years to gain full maturity, while males usually take twice as long (Nowak 1999).

Also critical to modeling the needs of a local bison herd is an understanding of the size of their daily and annual range, and the degree to which long-range seasonal migrations are typical. Modern herds are often maintained by humans in bounded areas and sometimes supplied with fodder. Herd size is often managed via selective culling to keep it sustainable on the available land. Sources vary in their estimates of range. Nowak (1999) and McDonald (1981) describe daily herd movements of an average of three kilometers within a potential thirty-kilometer range per herd. Hornaday (1887:389), in reviewing historic accounts, notes that on the Great Plains along the Arkansas River, a general traveling from one fort to another in 1871 noted a single herd occupying over twenty-five miles of land.

To better model bison herds in environments relevant to prehistoric Wisconsin, I will now look more closely at recent observations of herds of bison that have been re-introduced in Wisconsin and the neighboring state of Illinois. These herds include the Sandhill State Wildlife Area in Wisconsin, and the Fermilab, Midewin National Tallgrass Prairie, and Nachusa Grasslands in Illinois.

The herd in the Sandhill State Wildlife Area is treated as an integral member of a reconstructed ecosystem, key to regaining higher numbers of rare butterflies and birds that need Wisconsin grasslands to persist in the state. Bison there are kept in a 260-acre enclosure and used to help maintain an oak savannah environment (Hess et al. 2014; W.DNR 2019). Originally introduced in 1946, the herd is currently maintained at about 15 individuals, with human intervention in the form of winter fodder, annual culling of the herd, and controlled breeding. This grassland, like others, supports the idea that bison foraging, wallowing, horning, and grazing all reduce woody vegetation, and that these activities are essential to maintaining an oak savanna or prairie ecosystem (Hess et al. 2014:332). It is worth noting that the W.DNR (2019) defines “oak openings-savannahs” as containing up to sixty-percent prairie ecosystem plants and grasses.

The herd in the Nachusa Grassland in Illinois is of special interest because the policy there is to have minimal intervention with the herd, and to let them rely exclusively on native vegetation for food (Blackburn 2018; Brockman 2017; Burke 2016). Also relevant is that the

Nature Conservancy bought the land to preserve and restore native prairie. The land has been described as a seasonally fired mosaic of sedge wetland, oak-savannah, deciduous forest, and tallgrass prairie (Blackburn 2018; Brockman 2017). Mosaic grassland environments were common in Wisconsin post-glaciation (Burke 2016; Gates et al. 2010; Larter and Gates 1991; Jackson et al. 2010; Middleton 2002). The Nachusa grassland is just outside the Illinois Driftless area, making it similar topographically to my Lake Winnebago study area. The grass species are similar to Wisconsin grassland species found in both my study areas (Jackson et al. 2010; USDA 2013).

At the Nachusa Grassland, around 100 bison have stabilized as a breeding population with access to around 1,480 acres. Roughly half that acreage is grassland, the remainder a mix of trees, wetlands, and water (Brockman 2017). The herd has been free-ranging since 2014. Based on Nachusa studies, the way a bison subsists in a mosaic habitat is more related to what can be foraged seasonally, taking whatever will be available in the way of C4 shortgrass or tallgrass prairie forage in the summer and fall, and balancing this out with other resources like C3 grasses, sedges, or woody-forage in the winter and early spring. Blackburn (2018) confirms via isotopic analysis that age and sex do not affect foraging habits in the Nachusa bison herd.

To summarize, to model the needs of a prehistoric bison herd in Wisconsin based on bison biology and behavior, the modern herd in the Nachusa Grassland suggests that a mixed herd of less than 100 individuals can do well in a mosaic habitat of 6 square kilometers (~1,480 acres). While it is hard to quantify just how many acres of grassland a herd living in a mixed habitat would need, the Nachusa herd has access to roughly 740 acres of prairie.

Environmental Reconstruction using GLO and GIS

This thesis uses a combination of historic GLO records and GIS mapping techniques to reconstruct prehistoric vegetation patterns relevant to the Oneota occupation (A.D. 1050-1700) of the La Crosse and Lake Winnebago localities. The original GLO data for these two study areas were collected from 1832-1866. In this section I will review the nature of GLO data and some of the issues involved in using these historic records to address diverse research questions, including its application by plant ecologists to model native vegetation patterns and by archaeologists to model prehistoric resource catchments. I will also review GIS scholarship pertinent to this thesis.

What is known in modern times as the state of Wisconsin was surveyed by order of the United States government in the mid-1800's. The federal government sought to gain funds by the sale of public lands, and the survey was seen as a necessary first step to creating a detailed record of those lands. The process started in 1785 in eastern Ohio. The General Land Office (GLO) implemented the Public Land Survey System (PLSS). The Board of Commissioners of Public Lands (BCPL) has since provided public access to digital copies of some of these original records, with this caution: "use this information (GLO maps) as a guide but realize that there may be records that do not fully match the standard." This refers to the fact that there is some diversity in the way individual surveyors in the field recorded the information they observed. Records may be inconsistent due to variation in surveyor skills and the timing of the survey during a span of years that saw rapid landscape changes (BCPL 2019; Bolliger and Mladenoff 2005; Bolliger et al. 2004; Cogbill et al. 2018; Manies and Mladenoff 2000; Mladenoff 2019; Saleh 2017). Even at a county level, every survey was not conducted in the same season or year, or by the same surveyor (BCPL 2019). Over the three decades of survey noted in Wisconsin specifically, surveyors changed and variations in standard survey procedures occurred.

Equally important are the diverse ways these data have been used by researchers since. Finley (1951) notes that reconstructions of GLO data occurred as early as the late 1800's, with many researchers disregarding the GLO surveyor boundaries and combining only certain elements of the surveyor reports in attempts to map particular aspects of the environment. These researchers sometimes incorporated theoretical models specific to the topic of interest. Some have showed that the simplest applications of the original data are the most reliable (Bolliger et al. 2004; Edwards IV 2010). Prell (1989:62), in her review of historic vegetation mapping, states that Finley (1951) and Curtis (1959) created the most useful vegetation manuscripts. The University of Wisconsin-Madison Ecology Lab has since attempted to create the most up-to-date geographic set (Bolliger and Mladenoff 2005; Bolliger et al. 2004; Cogbill et al. 2018; Manies and Mladenoff 2000; Mladenoff 2019).

The GLO implemented the PLSS system in Wisconsin; field data was gathered between the years 1832-1866. This system used a grid comprised of townships, ranges, and sections to produce geographically associated field notes and maps. Townships are six square mile units labeled with east or west ranges, consisting of thirty-six one square mile sections. The GLO field surveyor would walk each section line, using a compass for orientation and a metal chain to measure distances, recording the vegetation and other landscape features he observed. At the corner of each section he would record the species of one or more trees. The entire statewide survey started at an "initial point" ten-miles east of the Mississippi River on the border of

Wisconsin and Illinois (BCPL 2019). This point was intersected by a “baseline” and “principal meridian,” and in Wisconsin, the GLO used the “fourth principal meridian” as the datum at this initial point (BCPL 2019).

The GLO PLSS was under the direction of a “Surveyor General,” and these administrators oversaw large areas of survey at a multi-state level. “Deputy Surveyors” supervised the actual fieldwork in states like Wisconsin, and facilitated the PLSS “General Instructions,” “Special Instructions,” and “Contracts” (BCPL 2019). The workers from state to state under these deputy surveyors had varying levels of experience and were subject to slow moving procedural changes in Wisconsin, which affects the data quality they produced. Once the system and surveyors were established in a territory or state, notes and maps became the result of field work related to documenting land along section lines, with a noted degree of variability occurring in many places. Figure 2.11 shows an example of GLO notes in Wisconsin near Lake Winnebago.

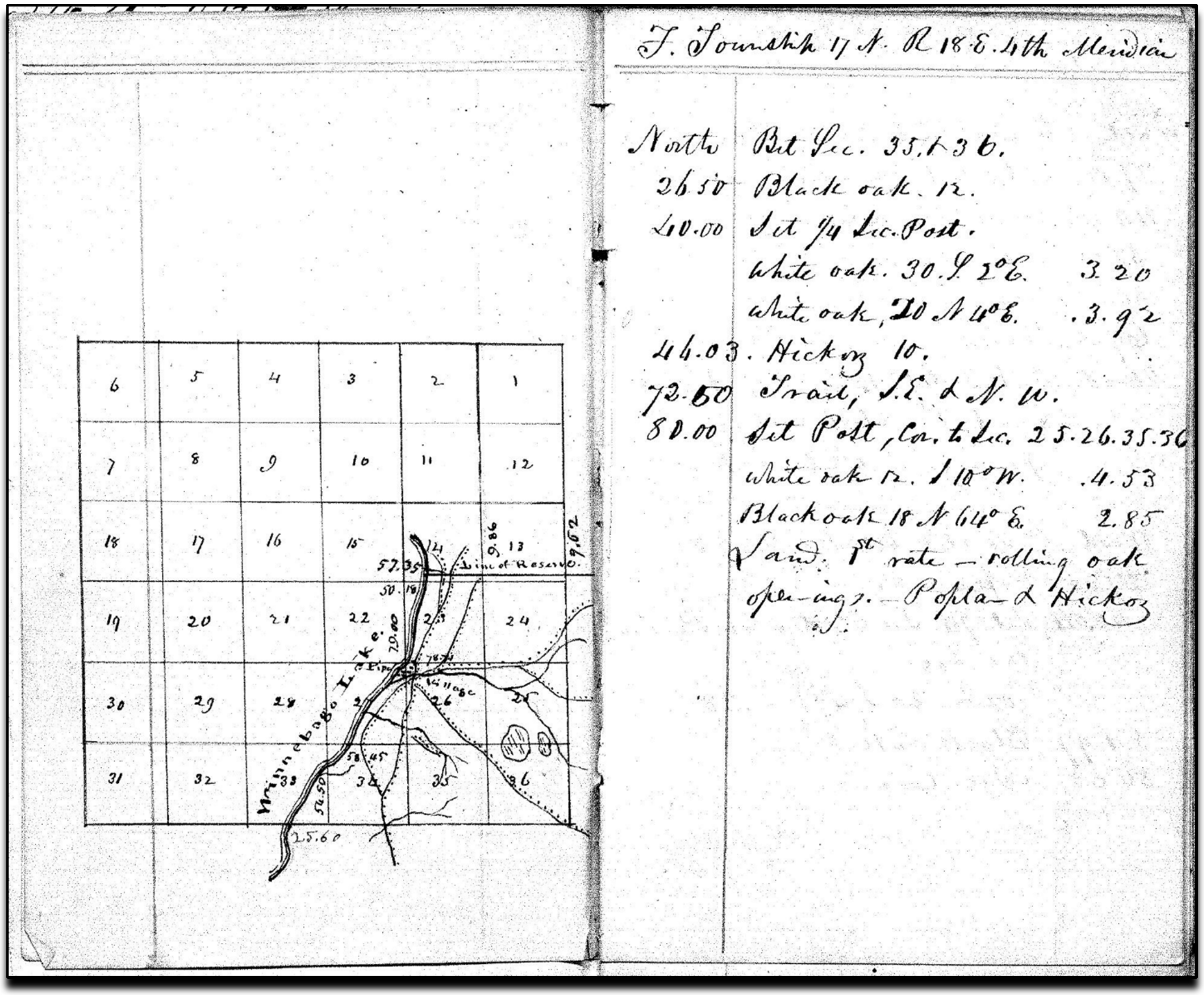


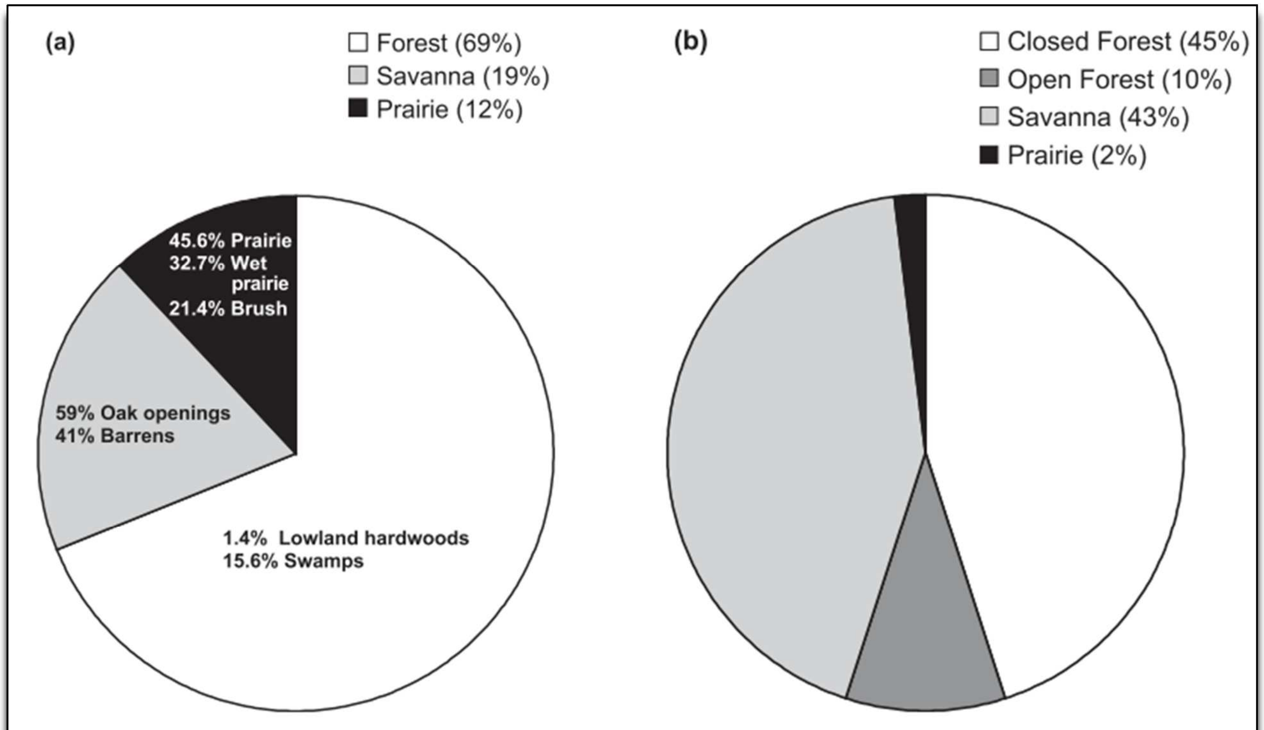
Figure 2.11: BCPL (2019) GLO notes and sketch map for T17N/R18E in Wisconsin.

These GLO images are in the BCPL's easily accessible digital archives, and these archives are open to the public. The BCPL essentially houses forestry-related information for the state of Wisconsin. The BCPL (2019) digital library offers a three-part warning in using its archive. First, GLO maps and notes are old, and some level of deterioration occurred of the original paper records; scanned copies make them widely accessible but cannot resolve such issues. Second, some surveyors wrote in cursive styles that are very difficult to decipher. Third, some terminology was abbreviated in keeping with conventions typical of the times of the original surveys and related to the surveying profession; the translations of these are not always obvious. The conclusion by the BCPL (2019) was that successful reading of the original records requires practice.

Previous to the advent and implementation of modern GIS, scholars tried to take GLO data and apply it to many scientific ventures. Beyond the GLO, Lea (1836) shows that maps were made of the "Wisconsin Territory" before the GLO's PLSS system was implemented, but nothing as systematic. GIS allows a user to recreate these GLO maps digitally, but in the past, some just analyzed the maps and notes or hand drew recreated versions of them (Jeske 1990).

The end goal of a study seems to greatly affect how the GLO is manipulated, even in the non-digital era without GIS. Finley (1951) and Prell (1989) have both commented on many of these studies. Finley (1951:257) believed that GLO data, because it was not collected by ecologists, did not actually represent real vegetation regimes; so, the maps he created of pre-settlement Wisconsin were weighted by soil types, drainage, topography, catastrophe, climatic evidence, and time-lag. Finley (1951) essentially took all of Wisconsin's townships, hand-coded them based on these factors, combined them with what the original GLO surveyor saw, and created a statewide map for the pre-European settlement vegetation of Wisconsin. This map, along with an update, were digitized by a student under the supervision of professor Ventura (1990) at the University of Wisconsin-Madison and is now available in digital format on the W.DNR GIS portal (Finley 1951, 1976; Ventura 1990, 2019; W.DNR 2019). Curtis (1959) updated Finley's (1951) vegetation information and others in "The Vegetation of Wisconsin." He provides data to create an essential encyclopedia on native Wisconsin vegetation past and present. The importance of these two ecologists amongst others is clear in modern publication (Baker and Mladenoff 1999; Bolliger et al. 2004; Bolliger and Mladenoff 2005; Cogbill et al. 2018; Edwards IV 2010; Jeske 1990; Liu et al. 2011; Host et al. 1996; Kay 1990; Meyer 2018; Mladenoff 2019; Manies and Mladenoff 2000; Mladenoff et al. 2008; Prell 1989; Shea et al. 2014; Stencil 2015; Wood 1976). This GLO effort has not just taken place in Wisconsin, and other ecologists and scientists have tried to quantify states like Illinois, showing how important inquiries on the topic are treated in science (Bourdo Jr. 1956; Hansen 1981; Jeske 1990; King 1978, 1981; Kilburn 1955, 1959; Moran 1978, 1980; Transeau 1935).

By 1996, scholars at UW-Madison's Ecology lab were taking ideas from Finley (1951) and Curtis (1959) and updating them in combination with GIS (Host et al. 1996:615). With GIS, one can take land cover information, historic or modern, and create ecosystem classifications designed to analyze evidence more precisely at a local level, and scholars like Finley (1951) or Curtis (1959) essentially did not have access to these techniques. Baker and Mladenoff (1999:334) show modeling from patches to tree levels in Wisconsin is possible, and Bolliger et al. (2004) show specifically that the GLO can be quantified by individual patch area and cover type density. When they took their analyses and compared them to Finley's (1951, 1976), Bolliger et al. (2004:136) found that most of pre-settlement Wisconsin was either a closed forest or a savanna (not quite a prairie, but very few trees). The trees that appeared on the savannas were largely comprised of white oak, bur oak, black oak, mixed oak, and jack pine. Figure 2.12 shows what happened at a state level when Bolliger et al. (2004) initially reconceived the original vegetation cover of the state with an objective classification schema that used tree counts, rather than Finley's (1951, 1976) subjective classification schema. Essentially, forests are not as dominant as was once conceived, and savanna may have been more prevalent in Wisconsin prehistory than previously thought.



Area coverage of the structural landscape features of (a) the subjective and (b) the objective landscape classification.

Figure 2.12: From Bolliger et al. (2004:135) showing A.) Finley's statewide averages versus B.) Bolliger et al.'s statewide averages.

Archaeologists, with and without a GIS, have also manipulated the GLO. Jeske (1990) shows that one does not need a GIS to successfully analyze the GLO, and in his Fermi Accelerator Lab study in northern Illinois, he compared archaeological sites to the GLO and quantified the patterns. Edwards IV (2010) shows that using simplified vegetation regimes proposed by Jeske (1990) and Bolliger et al. (2004) can be quite effective in converting the GLO details into more general patterns of relevance to human behavior. Edwards does this for Late Prehistoric Lake Koshkonong Oneota sites and their relation to their vegetative surroundings, and Saleh (2017) does this for La Crosse. Wisconsin archaeologists have also used Finley's (1951, 1976) conception of the GLO as well, due to its public and digital availability (Kay 1990; Stencil 2015). The theme in all of these studies is how best to use historic GLO data to model the environments relevant to historic and prehistoric archaeological sites.

This thesis, like others, uses a GIS to analyze GLO data as it provides an elegant way to create and analyze mapped data, often referred to as geospatial data (Ballas et al. 2018). It allows the researcher to associate many different types of data with specific points on the landscape. These data are stored in a relational database as "layers" that can be added to or taken out of any particular map to facilitate analysis of spatial associations. Of special interest to this thesis are the ways that a GIS can be used to create maps, to define catchment areas, to measure distances between points of interest, and to measure acreage of particular types of resources. GIS can also be used to model solutions to spatial problems; for example, models can simulate future climate change or least-cost paths of travel from point A to point B (Ballas et al. 2018; Howey 2011; Mladenoff 2019; Sherman et al. 2010; Supernant 2017; Wheatley and

Gillings 2002). Of special interest to this thesis is the use of weighted landscape modeling to evaluate the relative impacts of vegetation, terrain, and water.

There are some special issues when converting GLO mapped data into a GIS. For example, it is not unusual to experience slight township to township alignment issues based on modern projections and township lines. One of the reasons for this is that compass readings used for the original GLO were obtained on a 360-degree bearing compass, while most modern compasses use the azimuth (BCPL 2019). Most modern compasses and geographic coordinate systems can point to “true north,” or the azimuth, while historic surveyors did not have access to this. There is also the idea that simple surveyor error existed, and this cannot be reversed (BCPL 2019). A good way to solve some spatial issues in dealing with historic data is to georeference old maps; essentially, tie these maps to a known geographic reference point, such as a township corner, with a program like ArcMap (Ballas 2018:18; Esri 2019).

For many reasons, Wisconsin pre-settlement vegetation has appeared in many forms (Finley 1951; Prell 1989). The original GLO data has certain issues, but the multitude of applications that have followed also show some issues and variability. For example, Mladenoff (2019) and Finley (1951, 1976) never mapped historic waterways. In my thesis, I will compare the impact of some of these differences on the interpretation of the bison suitability of catchments in the La Crosse locality.

Catchment analysis has been approached in a number of ways related to archaeology (Arroyo 2009; Ballas et al. 2018; Ebert 2004; Edwards IV 2010; Greene 2008; Hunt 1992; Roper 1979; Tiffany 1982; Vita-Finzi and Higgs 1970; Wheatley 2004; Wheatley and Gillings 2002). It provides a way to look at the natural resources within a bounded area and evaluate their relative extent. This requires the definition of resource types and their mapping across space. Catchments are often mapped as circles radiating out from a center point, where the center point represents the starting point of the population using the resources. For example, an archaeologist might treat a residential site as the center point and map a radius to represent the distance of a one hour walk. Catchment size and shape are sometimes refined to accommodate realities of travel as these may be impacted by terrain or waterways, or by mode of travel.

Catchment analysis can be used to address diverse questions, including those related to human practices of farming, plant gathering, and hunting. For example, Edwards IV (2010:80,91) uses one-two kilometer catchments around Lake Koshkonong's Carcajou Point, Crescent Bay, Schmeling, and Twin Knolls sites to evaluate the agricultural potential within two catchment sizes, and what patterns were caught within these rings related to Oneota sites. In another example, Morgan (2008:255) shows catchments and least-cost paths can be used to estimate hunter-gatherer foraging limits and paths of travel to acorn caches. In the southern Sierra Nevada of California, Late Prehistoric period Western Mono groups had an estimated maximum foraging radius limit of 9.4 kilometers from their main habitation site, and three kilometers from their camp sites. Morgan (2008:256) laments the distance of hunting is not well-represented in his study, only the distance of gathering. In another study, Arroyo (2009:31) shows, using catchments and theory, that hunters in lowlands settings could potentially travel ~ten hours and have walked ~twenty kilometers in a straight line to hunt red deer and ibex. Hunting patterns do not necessarily follow straight lines and hunting time incorporates search, kill, processing, and return. The author states that if a Cantabrian prehistoric hunter travels 1.6 hours to kill a red deer, it will take a total of 7.5 hours to return to the home base if that red deer is fully processed at the kill site (Arroyo 2009:31). Therefore, a day's hunt must also consider dressing the animal, and this is important in considering hunting within vegetation and terrain regimes of a catchment.

Archaeologists have implemented weighted landscape models in their studies to combine multiple environmental factors and simulate their relative importance (Ebert 2004:331). Ebert (2004) states that archaeologists aim to experiment and generate data with simulations. Catchment analyses can be improved in archaeological studies with the implementation of cost surfaces that use vegetation, slope, natural barriers, and more (Ebert 2004:328). A cost surface is a weighted landscape that ranks zones, allowing a user to simulate scenarios with the set of ranks as levels of costs.

This thesis implements a cost surface to analyze land viability for bison. Sherman et al. (2010) show that with these surfaces, one can create pathways of travel from point A to point B with a GIS. With the implementation of GIS' in archaeological studies, if one is using catchments and landscapes, the idea is to balance the complexity and use. If a landscape is too simple, more can be said, but if it is too complex, the simulation can represent scenarios that are not necessarily valid. As Arroyo (2009) shows, catchments do not always have to be circles, as circles do not always model reality. This can also be said about vegetation. Enlarging circular catchments, creating more human-friendly catchments, creating cost surfaces that consider more than one landscape factor, and implementing mathematical simulations can all help the researcher achieve a level of balance in creating more realistic models. This thesis uses GIS to quantify and model landscape features relevant to bison, using a twenty-kilometer hunting distance catchment in relation to archaeological sites.

Vita-Finzi and Higgs (1970) frame one approach to catchment analysis, from the perspective of people making decisions about how far they will go for which resources: the closer to a site a given resource is located, the less energy needed to bring the resource back to the site. Roper (1979:121) follows with the idea that these catchments, usually centered around archaeological sites, are estimated, as no one really knows how far people actually traveled in prehistory. She states further that ten kilometers might be a safe maximum distance, and Arroyo (2009:31) echoed this sentiment over three decades later. If a resource is further away within a catchment, then there is a lesser likelihood of that resource appearing in the archaeological record based on travel costs and efficiency. The abundance of the resource can also play a role, which is why catchment analyses often model area or acreage. Hunt (1992:284) defines site catchment as a theory in itself, one which grew out of optimization theory. When applied to prehistoric people it assumes a specific travel distance to the resource as being an optimal "home-range" or catchment; thus, hunter-gatherers may be likely to collect subsistence items within a home-range of ten-square kilometers and horticulturalists may be likely to create gardens within a home-range of 1.5-square kilometers.

The use of principles of efficiency link site catchment analysis to optimal foraging and the culling of resources, such as large mammals, in many ways (Arroyo 2009; Edwards 2010; Jochim 1976, 1991; Keene 1981; Smith et al. 1983; Stevenson 1979; Tiffany 1982; Vita-Finzi and Higgs 1970). Optimal Foraging Theory (OFT) is derived from evolutionary theory and viewed as a product of natural selection; it argues that there is an evolutionary advantage for humans who make more efficient choices in their foraging strategies (Jochim 1991). Arroyo (2009) directly applies both site catchment and OFT to show what a day's hunt might have looked like in prehistoric Cantabria, Spain. Stephens and Krebs (1986) outline many concepts of OFT, showing that foraging economics, average-rate maximization, prey and patch models, the economics of choice, the economics of risk, and foraging or hunting constraints are all factored at varying degrees; their focus is on applications in biology and the foraging of non-human animals.

For the purposes of this thesis, hunting constraints, foraging constraints, and the economics of choice are all considered in defining the catchments and the implemented GIS. Foraging constraints are applied to bison, hunting constraints are applied to people, and archaeological sites are used to define the relevant size of the catchment. Therefore, along with GLO data and a GIS, site catchment theory and OFT are part of the modeling represented in this thesis.

Chapter 3: Methods

This thesis focuses on the application of GIS to the modeling of Oneota site catchments to evaluate those catchments for their ecological suitability for sustaining a local bison herd. This chapter discusses the methods used to: 1) develop criteria for evaluating bison herd viability, 2) translate GLO primary data into relevant vegetation categories, and 3) build maps and statistics using GIS. The GIS work involved making analytic decisions about coding and digitizing GLO notes and using ESRI's Model Builder software. The vegetation data was supplemented by elevation data to establish terrain, and the mapping of waterways, as both of these environmental attributes impact the travel and sustainability of herds of bison and their human hunters.

Criteria for Evaluating Bison Herd Sustainability:

The Nachusa Grasslands in Illinois provide a good source of data for modeling bison needs in a region ecologically similar to the study areas. At Nachusa a mixed herd of approximately 100 bison have had free ranging access to approximately 1,480 acres (equivalent to about six square kilometers) of mixed habitat since 2014. Brockman describes the vegetation as a mix of prairie, forest, savanna, and wetlands, with about half of it representing remnant or restored prairie (2017:8). There are two small spring-fed creeks and a scatter of ephemeral wetlands and depressions that hold water. These modern data allowed me to establish some minimal parameters for bison habitat in prehistoric southern Wisconsin: roughly 1,500 acres of mixed habitat for a breeding herd, including at least 50% or 750 acres of prairie and some access to wetlands.

GIS, and specifically catchment modeling, are used in this thesis to analyze local bison herd viability and Oneota options for hunting bison locally. Catchment modeling creates a buffer of a particular radius around a center point and maps the areal distribution of each or several resource zones within this buffer (Arroyo 2009; Edwards IV 2010; Hunt 1992; Roper 1979). For this study I created catchments with twenty-kilometer radii around known Oneota archaeological sites in two localities, La Crosse and Oshkosh. I chose a twenty-kilometer radius to better approximate the distance a hunter could travel roundtrip from a residential hub in a single day or two, in keeping with my intent to test a local bison hunting model. Although this buffer may be seen as a bit large, this is intended, as hunters sometimes set up smaller camps away from home bases (Morgan 2008). Since I worked with clusters of sites, I buffered every site individually with a measure of twenty-kilometers, and then merged those into a single large catchment for both study areas.

The Wisconsin Historical Society's Archaeological Site Index (WHS ASI) was used to create the site catchment "home bases" or center points (Arroyo 2009; Ebert 2004). It was made available by the University of Wisconsin-Milwaukee's Cultural Resource Management program (2018-2019). The geospatial data for the archaeological sites used in this study were derived from the state's site index shapefile. These were cross-referenced with Sasso's (2014) list of which sites had reported bison remains.

I then viewed these catchments from the perspective of bison to evaluate whether they could sustain a local herd. My Lake Winnebago study area represents approximately 2,275 square kilometers, and my La Crosse study area represents approximately 1,640 square kilometers, thus both catchments represent ample acreage when compared with the Nachusa Grassland's six square kilometers. In fact, the Lake Winnebago catchment represents a landscape equivalent in size to about 379 Nachusa grazing ranges, and the La Crosse catchment represents a size equivalent to about 273 Nachusa grazing ranges. The next question is whether the catchments provide sufficient prairie and adequate access to wetlands. I use GIS modeling tools to compare the quantitative mix of wetlands, oak openings, forest, prairie, and water in each of my study areas with data from Nachusa. The Nachusa Grassland is shown in Figure 3.1 as a way to view the landscape the bison herd there has access to year-round as well.

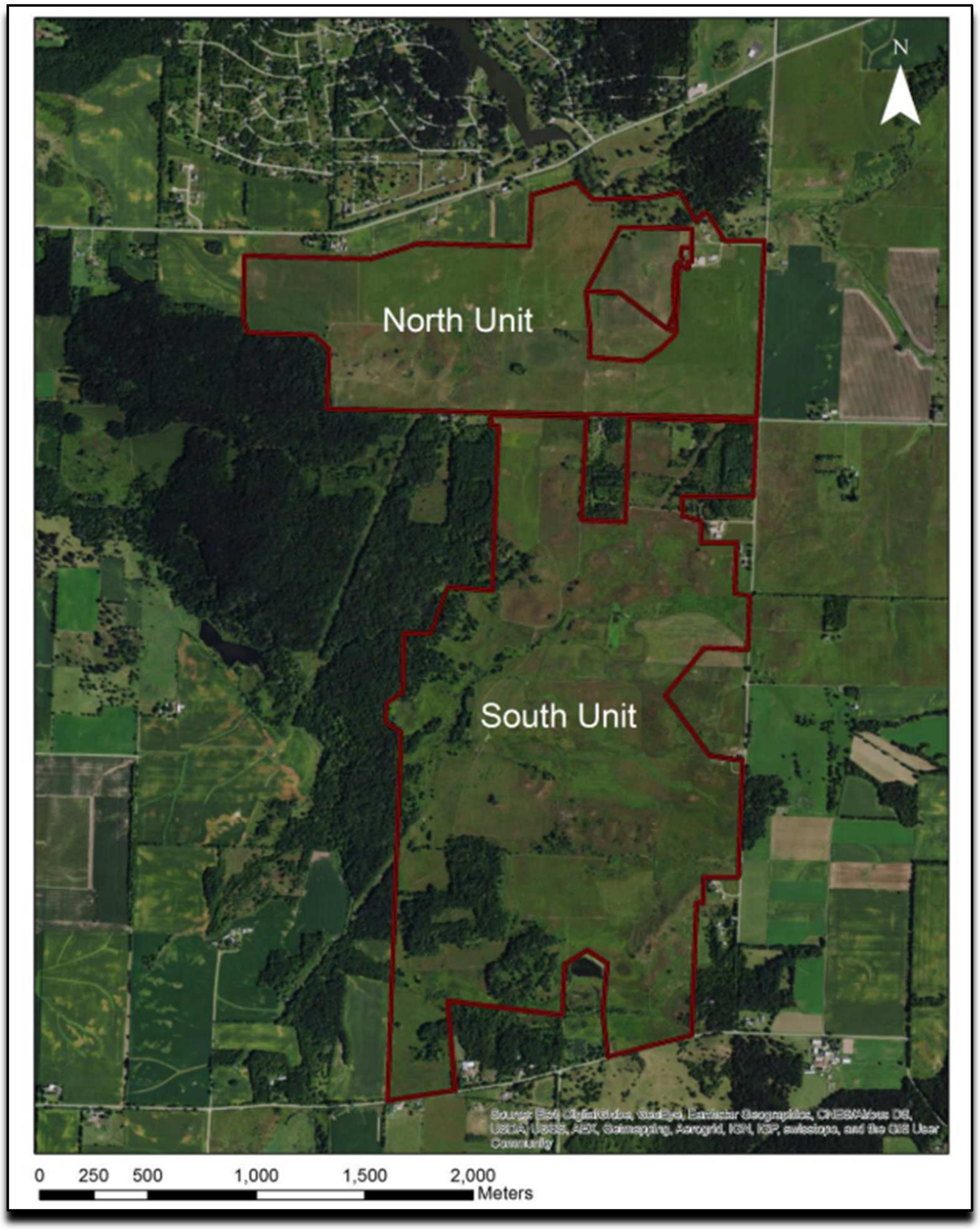


Figure 3.1: This thesis used data from the Nachusa Grassland in northern Illinois. This figure of Nachusa is from Brockman 2017:31, and the North Unit is noted as the pasture where bison are corralled or trapped.

A key issue for my catchment analysis was knowing how best to convert the vegetation details provided in the historic GLO notes into the four broad vegetation categories relevant to my comparison. Although Wisconsin ecologists have suggested and put into practice multiple ways to quantify GLO data, their research questions do not wholly match those of this thesis. Ecologists are often focused more on tree species and densities (Bolliger et al. 2004; Bolliger and Mladenoff 2005; Finley 1951; Host et al. 1996; Liu et al. 2011; Cogbill et al. 2018). Bison, however, are focused on grasses. In particular, they are looking for C4 grasses when they can find them, and C3 grasses, C3 sedges, or woody-forage when they cannot. My approach was to go back to the original GLO notes and code them with a focus on the presence, absence, and relative abundance of grasses and sedges.

To compare the La Crosse and Lake Winnebago localities, particularly as those related to the ability of the local catchment to sustain bison, I used both the Finley approach (Finley 1951, 1976) and the Mladenoff (2019) approach. The Finley (1951, 1976) approach transformed the GLO data into a map of the state of Wisconsin at a 1:500,000 scale, essentially summarizing vegetation patterns at the level of townships (a six mile square) and coding for many types of vegetation, with an emphasis on differentiating dominant tree species (Bolliger et al. 2004; Bolliger and Mladenoff 2005). This map was made into a coded shapefile by Ventura (1990, 2019) and a student matching Finley's hand-drawn data (1990). This shapefile did not contain waterways upon drawing; however, the W.DNR (2019) reports adding part of the 1:250,000 scale modern hydrology shapefile for the state of Wisconsin to the publicly available "pre-European settlement vegetation" shapefile in its metadata, mirrored in the digital data to this day. The Mladenoff (2019) approach transformed the GLO data into a map of the state of

Wisconsin, focusing on tree density at the level of sections (a one mile square) and quarter sections (a quarter mile square). This approach did not record wetlands or waterways, and because the dataset is currently private to the UW-Ecology lab, this study only obtained vegetation within the study area buffers.

In the case of the La Crosse locality I compared these two approaches with a third, which I derived from my own reading of the GLO (Saleh 2017 and this thesis) following and updating a style of coding and spatial scale suggested by Edwards IV (2010, 2017) and Nicholls (2017). My approach transformed the GLO data into coding for four types of general vegetation categories: Prairie, Oak Opening, Forest, and Wetlands. All of these categories were subject to slight naming differences in the original notes and maps. Waterways were mapped, and inundated bottoms that were mapped by GLO surveyors were mapped as wetlands as most were reported as inundated in the La Crosse surveyor notes with no reported prairie grasses. It also used GLO quarter section level plat maps to digitize a linear approximation of transitions or boundaries between those four vegetation types. My goal in applying this third approach was to highlight vegetation distinctions that would be both important to bison (e.g., the relative amount of grassland versus wetland available) and comparable to other archaeological approaches to catchments (Blackburn 2018; Edwards IV 2010; Jeske 1990). My goal in comparing the three approaches was to assess the impact of differences in spatial resolution, coding, and mapping of GLO data on the interpretation of vegetation patterns. These differences slightly tweak how one views the landscape versus bison viability.

Translating GLO Primary Data into Broader Categories:

The original GLO field notes and sketch maps provide the following types of data on vegetation observed in the early 1800s. Surveyors were not recording every tree in a section, just tree counts, soil rates, and ecological zone changes along section lines or meanders. Some surveyors noted when they entered forested regions, while others noted when they left forested regions. In terms of note taking and map making, detail was variable township to township. This variability is explored more thoroughly in Appendix A.

Prior to my thesis work I conducted a test of the impacts of mapping the GLO vegetation data at a finer spatial scale and with broader vegetation categories than those provided by the public sources (Saleh 2017). Using the original GLO notes I built a map of vegetation for one-mile site catchments near La Crosse, Wisconsin, working at the spatial scale of a quarter section (a quarter mile square) coding vegetation into general vegetation categories (Saleh 2017). This test demonstrated that these methods do change the vegetation reconstruction in significant ways.

The Jeske (1990:148) categories (oak barrens, oak-dominated mesic forest, prairie, and Aquatic/wetland) are still seen as working well with upper western Great Lakes archaeological vegetation reconstructions, as he was working with sites in northern Illinois' prairie peninsula area and using the historic GLO notes as a source of inference for prehistoric vegetation. Of note, Jeske (1990) notes that the categorical terms he uses are interchangeable in reconstructing general vegetation categories (for example, he treats oak openings, oak savannas, and oak barrens as the same general category). These four habitats are relevant to both humans and bison as they provide a simple contrast between forest, prairie grassland,

grassland with scattered trees, and wetlands. This thesis separates water (or aquatic) from wetland for modeling purposes. These transformation categories were used in this thesis for the twenty-kilometer La Crosse catchment in creating a custom thesis dataset.

Although this schema appears simple, certain complications in its execution are worth mentioning as they relate to the custom La Crosse area thesis dataset. These complications mainly pertain to the handling of timber of unspecified thickness and prairies or scattered timber areas that may in fact have been seasonally inundated and thus overlapped with the wetland designation. Some degree of flexibility was also needed to accommodate some of the idiosyncrasies of the language habits of GLO field workers. For example, the term “scattered timber” was judged to be equivalent to “oak openings/savannas” and translated as Oak Openings. “Timber”, as well as “oak mesic forest,” and specific mention of thick white and black oak densities were translated as Forest. “Prairie” was translated as Prairie, but it should be noted that that designation in the original notes may have been under-represented. Because the purpose of the original surveys was to define land for sale to future residents, and land full of good timber and first-rate soils had premium value, the PLSS note taking technique focused on tree types or counts and soil rates rather than prairie grasses (BCPL 2019). On the other hand, “prairies” in bottom lands were also translated as Prairie although these may have been inundated at some points of the year. “Aquatic/wetland” is split and expanded in this thesis because it is possible to obtain this data at an accurate level for both categories. For the purposes of this thesis, most river bottoms were combined with “wetlands” and “swamps” to create a Wetlands category to account for the dynamism of the Mississippi River and its linking waterways. When one views the GLO notes within the La Crosse study area it becomes clear that some bottoms were subject to inundation up to six feet at the times of their survey; yet, these bottoms are variably mapped as wetlands, swamps, wet, or dry by the original surveyors (BCPL 2019). “Waterways” are given their own category in this study. This was due to their importance for hunters and bison, as well as to weighted landscape modeling within catchments (Supernant 2017).

It is worth noting that prehistoric waterways are not routinely considered in the two other geospatial databases used in my comparison. For example, in the Mladenoff (2019) dataset, waterways and wetlands were omitted altogether; this decision was based on northern Wisconsin’s numerous small bodies of water (Mladenoff 2019). They also treated bottoms differently, as did Finley (1951, 1976). Bottoms are especially dynamic in the La Crosse region (Knox and Mickelson 1974). These classification choices are important to judging and adapting weight values for weighted landscapes.

The category “Non-Vegetative Features” was used in this study as a place holder for terrestrial areas that could not be coded for vegetation based on the original GLO notes; these were later removed from landscape statistical counts. Using this category uncovered a few interesting details in the La Crosse area as a byproduct. Initially intended to simply record features that were historic areas of disturbance, the collection of non-vegetative features uncovered what has been interpreted as a network of Native American trails reported by the GLO linking the La Crosse sites together across the region (La Crosse GLO Townships BCPL 2019). The areas mapped as historic roads may also have been a part of the prehistoric trail network, but this has not been established. While the non-vegetative feature category appears on some of the mapped results, it was not included in calculations of total percent contribution of water and vegetation. This category made weighted landscapes more accurate in that it removes a tiny percentage of land forage when combined with waterways.

Besides showing how this thesis coded GLO data, it also reviews how Finley (1951) and Mladenoff (2019) methods compare. Figure 2.10 shows how Finley (1951, 1976) and Mladenoff (2019) can be compared graphically, and Bolliger et al. (2004) essentially shows that Finley's set was subjectively collected. Finley's (1951, 1976) collection method included coding seventeen vegetation zones that he drew state wide. They are listed by order of importance per category (W.DNR 2019): 1) White spruce, balsam fir, tamarack, white cedar, white birch, aspen 2) Beech, hemlock, sugar maple, yellow birch, white pine, red pine 3) Hemlock, sugar maple, yellow birch, white pine, red pine 4) Sugar maple, yellow birch, white pine, red pine 5) White pine, red pine 6) Jack pine, scrub (hill's), oak forest and barrens 7) Aspen, white birch, pine 8) Beech, sugar maple, basswood, red oak, white oak, black oak 9) Sugar maple, basswood, red oak, white oak, black oak 10) Oak – white oak, black oak, bur oak 11) Oak openings – bur oak, white oak, black oak 12) Prairie 13) Brush 14) Swamp conifers – white cedar, black spruce, tamarack, hemlock 15) Lowland hardwoods – willow, soft maple, box elder, ash, elm, cottonwood, river birch 16) Marsh and sedge meadow, wet prairie, lowland shrubs and 17) Area with vegetation cover type not interpreted. These zones overlay the entire state of Wisconsin.

Mladenoff (2019) used an objective method to obtain a "density class" category that is seen as potentially more accurate than these zones (Bolliger et al. 2004). Although Mladenoff (2019) provides the first and second most dominant vegetation type per quarter section in the attribute information, their collection never goes past two species, unlike Finley's (1951, 1976). There is nothing wrong with this by any means, but these attributes do not do the best job of revealing prairies. For this reason, this thesis only considers Mladenoff's (2019) density classes. Mladenoff's (2019) collection technique essentially uses more of the GLO notes and tree counts rather than the drawn boundaries. This thesis tried to balance what both prominent scholars had to say. For example, it uses drawn boundaries like Finley rather than quarter section densities; but within the drawn boundaries, simple classes are used like Mladenoff. Table 3.1 shows how the UW-Ecology lab collects GLO data objectively into density classes (Bolliger et al. 2004). They use prairie, savanna, open forest, closed forest, and an open category that is said to be of an unknown density class. In fact, they suggest against using the category in quantitative studies, so this thesis follows their warning to an extent (Mladenoff 2019). They were used in the same way non-vegetative features were for this thesis or the "area with vegetation cover type not interpreted" category for Finley's (1951). After using and analyzing many GLO data sources, Table 3.1's is seen has high quality as it focuses on the most accurate part of the GLO survey, the actual written notes where specific tree counts, species, and soil rates can be found (BCPL 2019).

Table 3.1: From Mladenoff (2019) vegetation coding of GLO data based on tree density.

Vegetation density class	# trees/acre	# trees/hectare
Prairie (pra)	< 1	< 2.5
Savanna (sav)	1- 19	2.5 – 47
Open Forest (opf)	19 – 40	47 – 99
Closed Forest (clf)	> 40	> 99

GIS as a Mapping Technique:

GIS, as related to the social sciences, has been defined as a Geographic Information System, capable of quantitative spatial analyses (Ballas et al. 2018:3). These systems of information essentially allow a researcher to generate new knowledge related to the dataset they are manipulating within a geospatial database. A GIS can analyze anything from crime patterns to transportation patterns. GIS' need a coordinate system and a projection type to project data geospatially within a mapping program (Ballas et al. 2018; Wheatley 2004). A user needs to be highly critical of what data is put in their GIS, as bad data can lead to invalid results and conclusions.

Within a GIS, shapefiles and models can be related under the same coordinate system. Esri (2019) allows a user to implement a GIS from ArcCatalog in coordination with their ArcMap program. Within ArcMap (this thesis used ArcMap 10.5-.6), geoprocessing tools, toolbars, and geospatial files can be implemented in coordination with one another to create useable maps and tables (see Appendix B for Esri terms and adaptations). This thesis found that current Esri (2018-2019) software packages and tutorials offer some of the best options for using, creating, and learning about new geospatial data. This thesis uses many teachings in creating geospatial data, some from Esri, but others from colleagues. Every basic learned technique cannot be accounted for in this thesis, but it suggests that before anyone uses ArcMap or ArcCatalog, that they do some background research with any available accompanying training. This thesis implemented a GIS in order to obtain new knowledge on the distribution and exploitation of the prehistoric and historic bison.

To obtain new data on bison, the GIS used in this thesis related multiple geospatial files and functions. In the GIS, this thesis stored and related vectors and rasters including: vegetation layers, site catchment buffers, WHS archaeological site location information, FAUNMAP bison archaeological site location information, terrain elevation information, waterways, weighted landscapes, geoprocessing toolboxes, geoprocessing models, coded domains to draw new vegetation with, W.DNR (2019) locational data, and many different georeferenced images. Geospatial data was provided by Esri (2019), FAUNMAP 2019; the Board of Commissioners of Public Lands combined with the General Land Office (GLO) records (2019), the University of Wisconsin-Madison Ecology Laboratory (Mladenoff 2019), the University of Wisconsin-Milwaukee Cultural Resource Management (2019), the Wisconsin Department of Natural Resources (2019), and the Wisconsin Historical Society's Archaeological Site Index (2019).

This data was manipulated with a number of toolbars and geoprocessing tools available with Esri's ArcMap (2019) (see Appendix B). In terms of toolbars, Esri's (2019) editor, spatial analyst, and georeferencing toolbars were used the most frequently to produce datasets. In terms of geoprocessing tools, Esri's (2019) buffer, clip (raster and vector), merge, polygon to raster, reclassify, slope, and weighted overlay were used the most frequently. Figure 3.2 shows how geoprocessing tools were linked together in Esri's (2019) Model Builder program. This geoprocessing model can be used to continuously simulate landscapes with input data.

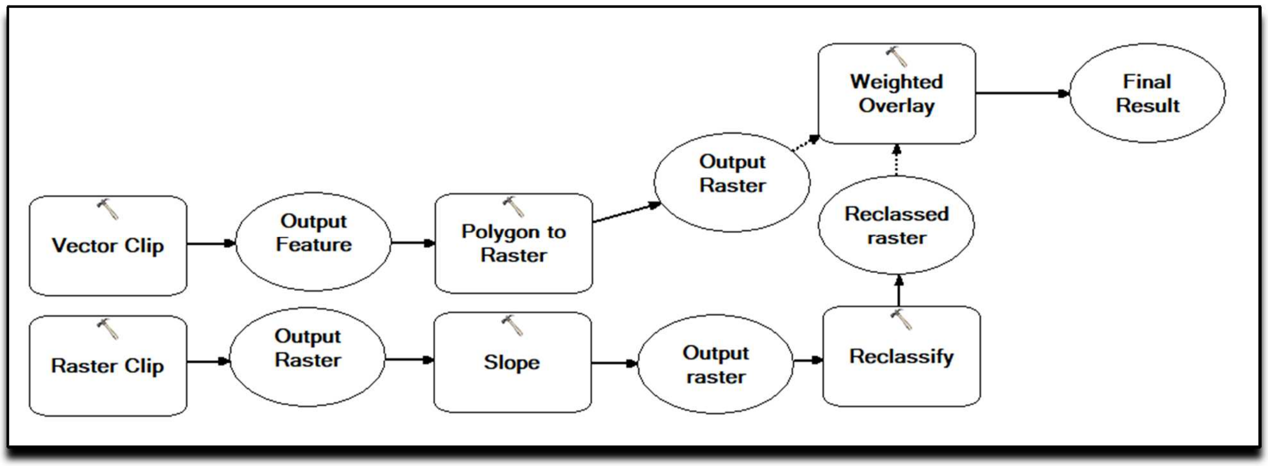


Figure 3.2: This thesis produces weighted landscapes. Esri (2019) Model Builder helped, linking tools to make a geoprocessing model. This model specifically can overlay vector data (like vegetation) onto a manipulated terrain dataset to make a coded raster. This model is versatile; for example, it could be adapted to least-cost path modeling (LCP) to generate future results. It is suggested that much practice goes into using models such as these, and Esri software in general. Preparing oneself for the time it could take to achieve results using GIS is key.

This model can handle many inputs, including the custom thesis data. A critical step in building a GIS is the process of georeferencing the data. The main technique in creating custom La Crosse area data was simply to use Esri's georeference toolbar in coordination with a historic map. After this, with the editor tool bar, it was easy to digitize sections of townships based on original maps and notes to create quarter square-mile feature-level accuracy. Although time-consuming, the quarter-section approach to the original GLO records is worth the effort if a researcher wants accuracy, precision, and categories that address their research questions. To georeference in ArcMap, one simply loads in an unreferenced raster image, and ties it to geospatial data like townships. It is suggested by this thesis's collection of historic maps that one "rectifies" georeferenced images into their GIS to save finalized images. To contain the data that was created from this process of georeferencing at a township level, buffers from all the archaeological sites were merged at twenty-kilometers, and everything was clipped and analyzed within these site catchments. These site catchment buffers were the bounds of the model in Figure 3.2, and the vegetation layer starts by getting clipped within this buffer with "vector clip."

Although this thesis is described as mostly implementing a version of the GLO reconstruction categories developed by Edwards IV (2010) and Jeske (1990), just reading the notes and maps revealed how region-specific interpretation is needed for relaying historic GLO vegetation information. Appendix A explores township by township in Trempealeau, La Crosse, and Vernon counties, Wisconsin and provides a general summary of what this thesis saw from the original surveyors, and how that relates to the custom data that I collected. Figures 3.3, 3.4, and 3.5 provide a zoom-in of a georeferenced GLO plat map. This thesis reproduced these digitally with the editor toolbar continuously until the La Crosse study area catchment was covered.

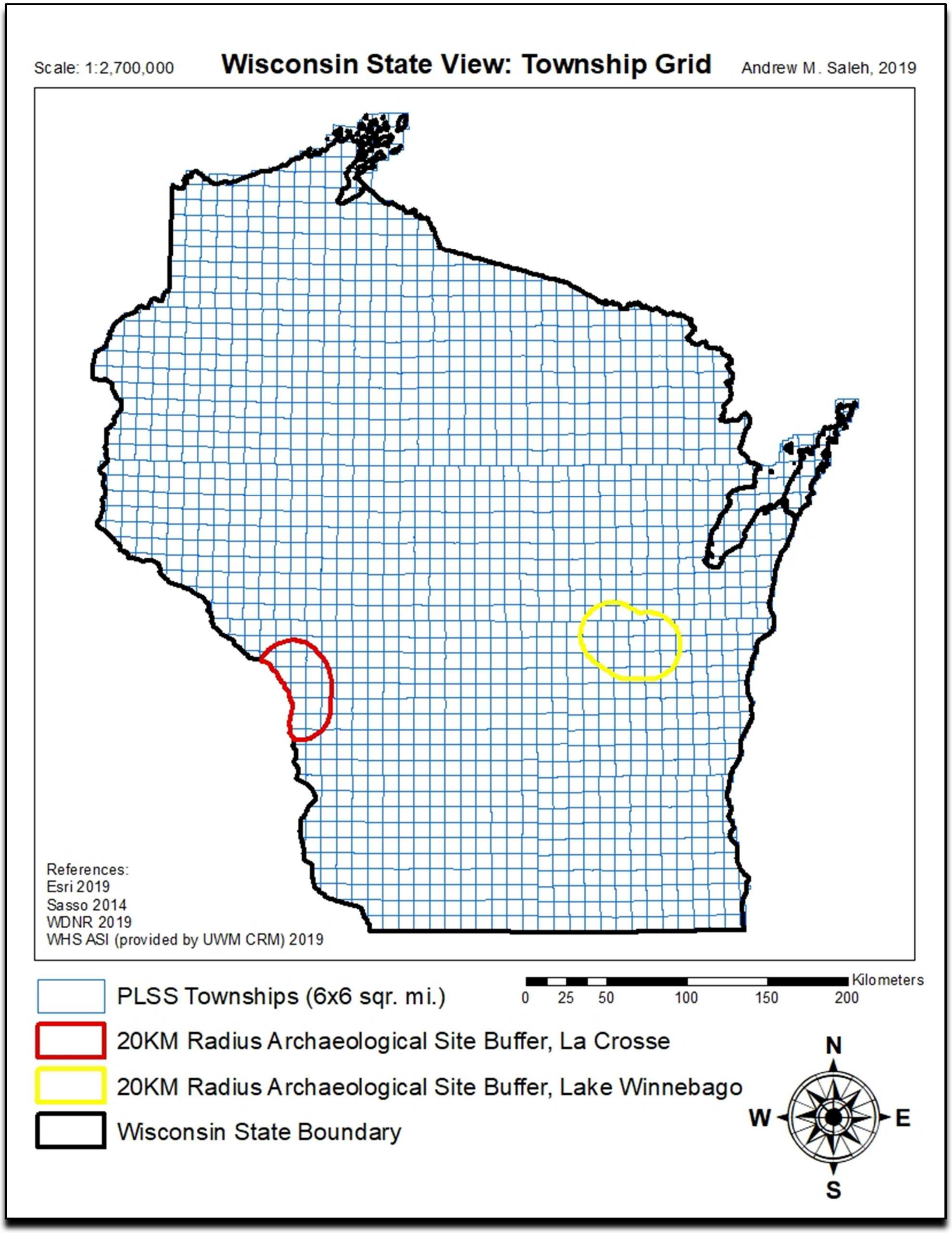


Figure 3.3: Wisconsin DNR (2019) township grid and thesis site catchments.

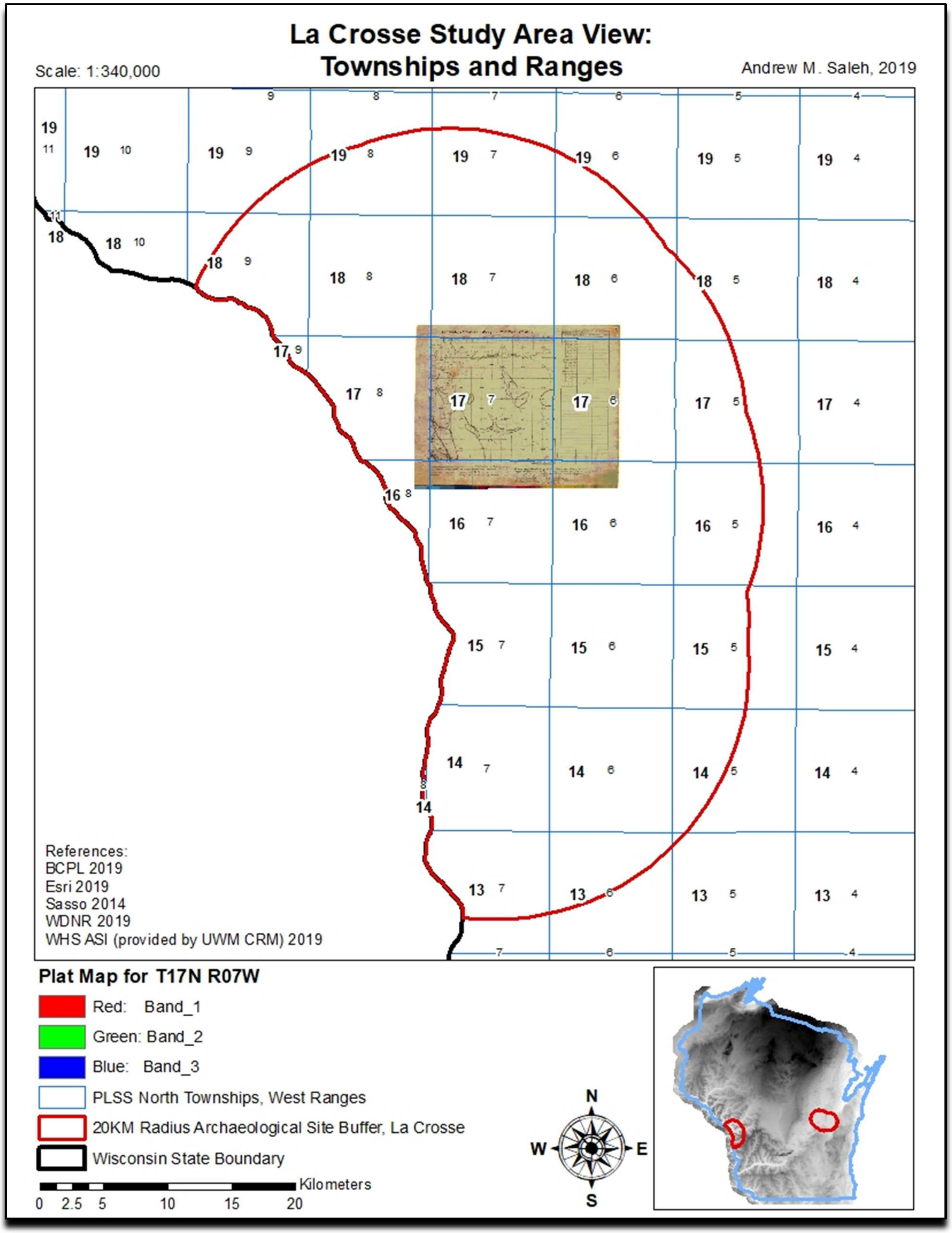


Figure 3.4: Wisconsin township/range grid, La Crosse site catchment, and a GLO plat map from La Crosse county.

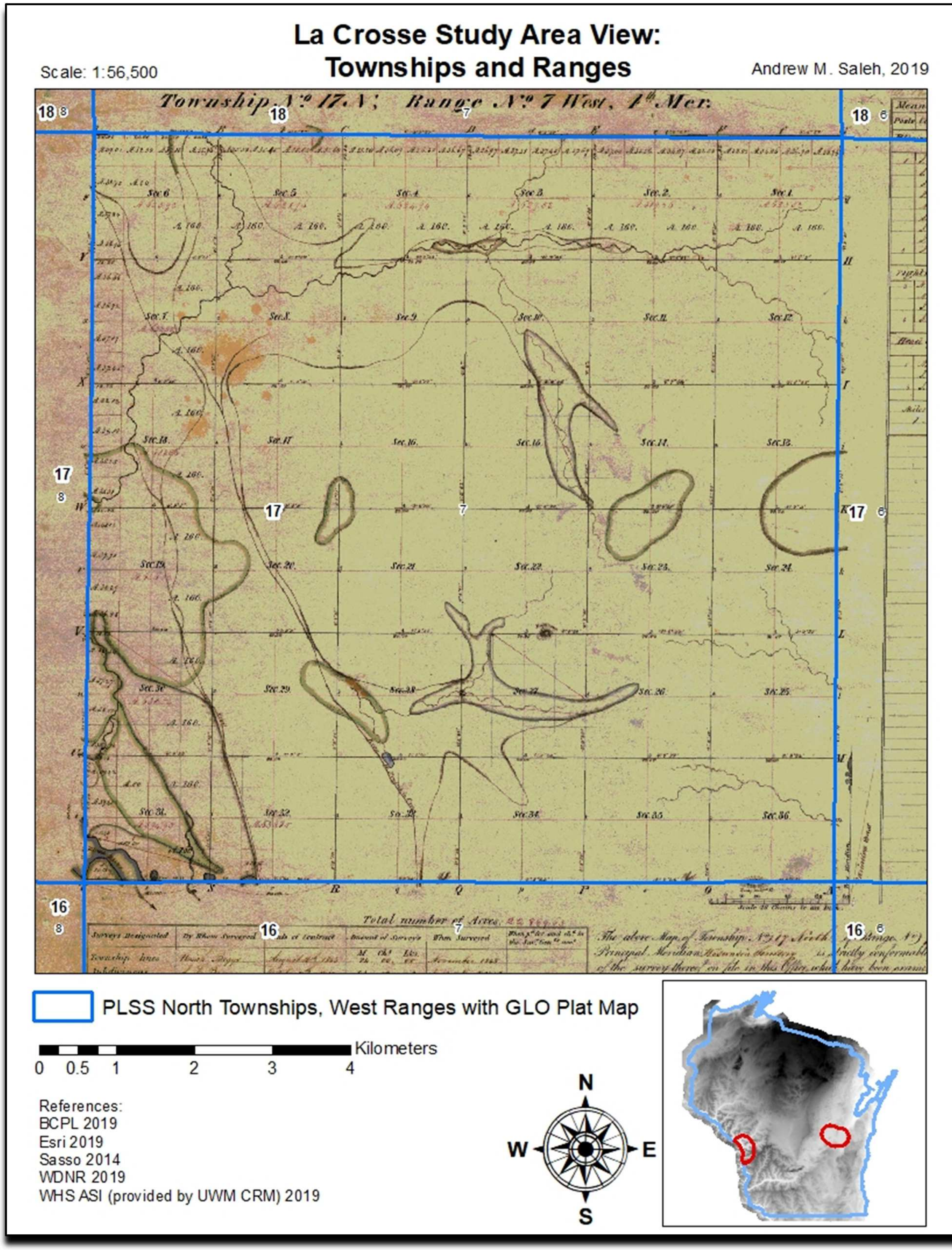


Figure 3.5: Detailed view of a sample GLO plat map from La Crosse county (T17N/R07W).

All of the vegetation datasets used in this thesis were in some way, shape, or form derived in this fashion originally. This makes the vegetation layers useable in Figure 3.2's model like the custom thesis dataset. At the base of all GLO reconstructions, a map is referenced to a township and considered in coordination with a note set. Any additions after this are based on user input. Considering all three of these datasets as raw statistics was a goal of this thesis. The acreage and square kilometers are considered in Chapter 4. Viewing and manipulating the raw statistics is useful, but this thesis also simulated these statistics.

To simulate statistics and show their results, weighted landscapes were generated from the weighted overlay tool at the end of the model in Figure 3.2. This thesis combined modern terrain, historic or modern water, and historic vegetation within this tool. These dataset inputs were weighted with percentages or ranks. After much tinkering, and with bison as the focus, vegetation was weighted at 75 percent, and terrain was weighted at 25 percent.

Terrain was derived from a Digital Elevation Model (DEM) provided by the W.DNR with ten-meter accuracy (2019). Archaeological and geographic suggestions on how to manipulate DEM to slope in least-cost path studies were referenced to consider reclassified slope percentage rankings in relation to bison landscape viability; these were also considered in weighting and ranking individual vegetation regimes in this thesis (Cook and Nolan 2010:143; Howey 2011:2526; Kay 1990:408; Sherman et al. 2010:289; Supernant 2017:69; Webster et al. 2016:17). Figure 3.6 shows how a weighted overlay can be generated with Figure 3.2. For this thesis, this method was used many times to simulate results, whether tests or final. Esri (2019) suggests making a database to pump rough draft landscapes into, and this thesis echoes this sentiment, as it takes many attempts to find the solution that seems to best suit the problem.

A ranking system of “1” (best) through “4” (worst) was used after considering Kay’s (1990:408) hunting weighting system that used Finley vegetation (1951, 1976). Data from Finley (1951, 1976), Mladenoff (2019), and this thesis are ranked by like vegetation regimes with the same numbers. Areas within the site catchment that were not quantified are set to “restricted” in weighted overlays as to not affect *land* modeling. Slope and vegetation were both used with the same ranking system in order to create succinct final result landscapes. Figure 3.5 shows the order of the method in one example, and Appendix C shows the final weighted overlay tables related to this thesis’s Chapter 4 results. These Figure 3.5 images more specifically show an example of how overall landscape weight percentage and vegetation code to weighted rank conversions relate. Overall, GIS as a mapping technique in association with Esri products is all of the above and more. That is, a blend of raw data, geoprocessing tools, toolbars of various sorts, Model Builder, and a formatting system that exports useable information.

VALUE

Reclassification

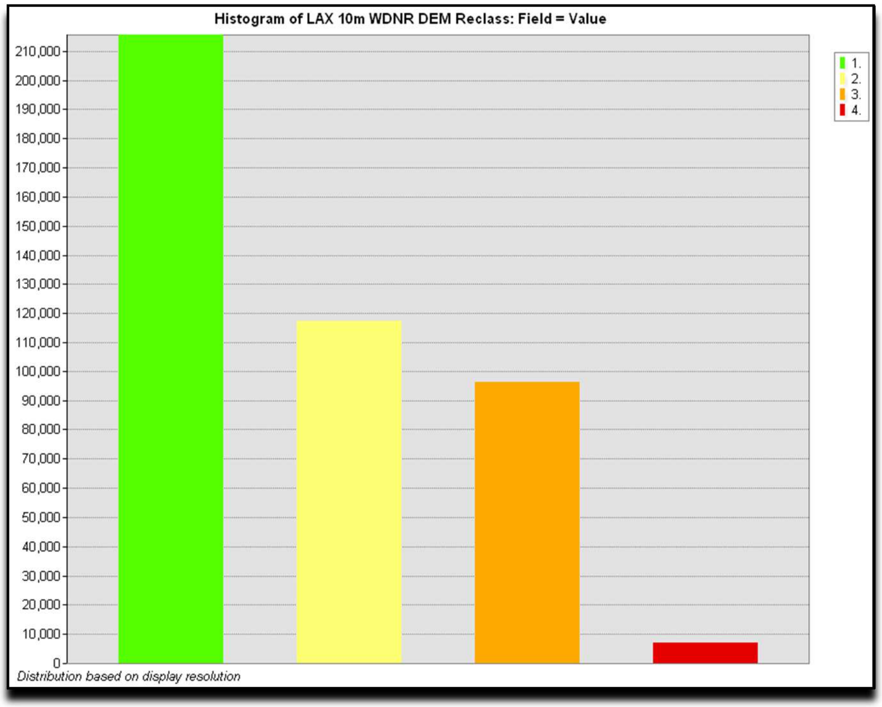
Old values	New values
0 - 20.908337	1
20.908337 - 41.816673	2
41.816673 - 62.72501	3
62.72501 - 83.633347	4
NoData	NoData

Weighted overlay table

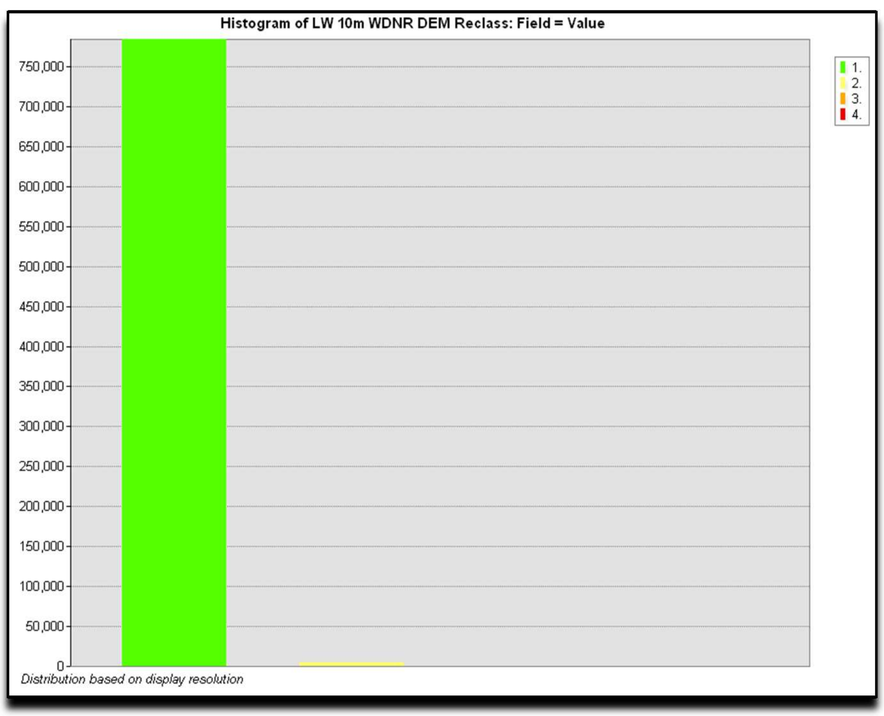
% Influence	Field	Scale Value
25	Value	
	1	1
	2	2
	3	3
	4	4
	NODATA	NODATA
75	denclass	
	sav	2
	clf	4
	opf	3
	ope	Restricted
	pra	1
	NODATA	NODATA

Figure 3.6: This example comes from the Lake Winnebago catchment Mladenoff (2019) analysis. This helps illustrate how terrain can be combined with landscape in Figure 3.2's "reclassify" and "weighted overlay" steps. The reclassification shows the "old values" which come from the slope step in Figure 3.1. Slope ("old values") is converted and ranked with the "1" (best) to "4" (worst) classification schema. This ranked slope is given a final 25% thesis value in the weighted overlay tool. Vegetation uses the same ranking classification but shows the final 75% thesis value. This creates a weighted landscape where one can evaluate the percentage of each classification within a site catchment by looking at histograms of pixel counts generated by Esri's Spatial Analyst toolbar.

Slope percentage was derived the same way for every weighted landscape in this thesis to keep everything succinct. The values from Supernant (2017:69) show that slope above twenty-five percent becomes less favorable for movement, and over fifty-percent becomes far less favorable. At the same time, bison are noted near mountainous environment edges historically, so this thesis recognizes that travel above this slope percentage is not impossible, just not as energetically efficient. The maximum slope percentage for this thesis was derived from the steepest part of the two site catchments. With this maximum, this thesis was able to implement matching slope percentages which could be reclassified into ranks that could match to vegetation (see Figure 3.4). Figure 3.7 shows histograms produced by the spatial analyst toolbar. Esri (2019) allows a user to use this toolbar as a way to produce graphs of raster pixels within a site catchment. These pixels show how much of each rank occurs in a study area. Figure 3.7 shows how the final slope method affects each site catchment. This can be related to Chapter 4's bison viability results, and also shows that the La Crosse catchment has more terrain penalties than the Lake Winnebago catchment. The results for this thesis come from a degree of all the listed methods.



Value	Count
1	14146790
2	7685950
3	6323686
4	456460



Value	Count
1	31615987
2	213353
3	15594
4	41

Figure 3.7: La Crosse (LAX) and Lake Winnebago (LW) catchment slope value histograms. The "value" and "count" columns relate to the bar graphs. These relay how many pixel counts comprise each slope value. Figure 3.4 shows how these slope values were derived. The La Crosse site catchment shows more terrain penalties.

Chapter 4: Results

The results will be presented in the following way. First, the summary acreage values for the two study areas will be compared to Nachusa data. Table 4.1 presents these data and the estimated number of herds and individual bison that the two study areas could support based on acreage alone. This establishes the more-than-adequate amount of range space in both study areas catchments. Second, the two study areas are compared in terms of vegetation types and their spatial distributions and acreage. The Lake Winnebago study area is presented first, with base maps showing archaeological site locations, the catchment boundary, modern waterways and terrain. These are followed by vegetation reconstructions, comparing Finley's reconstructions with those of Mladenoff. These results are presented as maps and as tables of acreage per vegetation type. The implications of these results for bison suitability are discussed. Parallel data are then presented for the La Crosse study area. Third, the interpretive outcomes of three different translations of GLO data for the La Crosse catchment are compared; the objective here is to evaluate how coding and spatial scale impact environmental reconstructions. Fourth, the two study areas are compared using a weighted landscapes approach to quantify the relative importance of vegetation, terrain, and water in a single GIS model; this is implemented using Esri Model Builder software as describe in Chapter 3. Multiple scenarios and their statistics are considered.

Table 4.1: Study area catchment statistics compared to Blackburn's (2018) reported Nachusa bison herd statistics. These statistics are inflated, so the goal of this thesis was to refine and consider their significance.

Thesis Study Areas	Acres	Square Kilometers	Potential Bison Herds	Potential Individual Bison
La Crosse 20 km Radius Site Catchment Buffer	405,485.78	1,640.94	273	23,247
Lake Winnebago 20 km Radius Site Catchment Buffer	562,168.38	2,275.01	379	32,229
Nachusa's Accessible Grassland (Bison as of 2018 free ranging year-round)	1,482.63	6.00	1	85

The Lake Winnebago Site Catchment:

Figure 4.1 shows the locations of the five Lake Winnebago archaeological sites that had bison remains; in all cases the remains were scapula fragments (Dirst 1985; Peske 1966, 1971; Sasso 2014). The base map is from ESRI and indicates modern features such as roads and counties; the greyscale shading depicts waterways and lakes in darkest grey, modern urban developments in a middle tone, and the rest of the landscape in the lightest grey. Four major bodies of water fall within the catchment: Lake Winnebago, Lake Butte des Morts, Lake Winneconne, and Lake Poygan. All four lakes are relatively shallow; the water system has been dammed in modern times and may have represented more extensive wetland and less water acreage in prehistoric times (W.DNR 2019). Figure 4.2 illustrates the general terrain, and Figure 3.4 shows how data such as these can be manipulated into slope. It also shows that this region in particular does not have much variation in terrain or slope percentage.

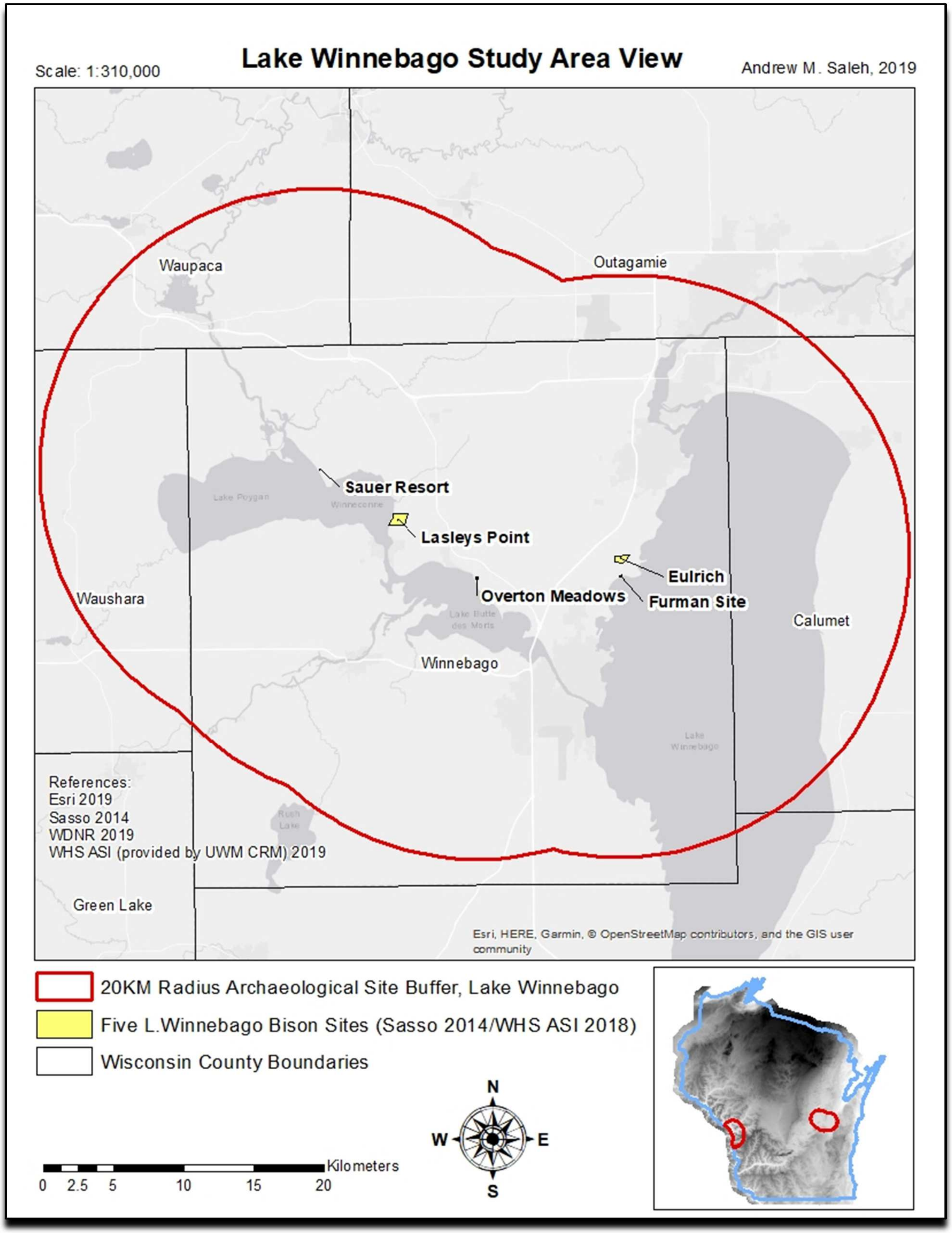


Figure 4.1: Lake Winnebago archaeological sites and combined catchment.

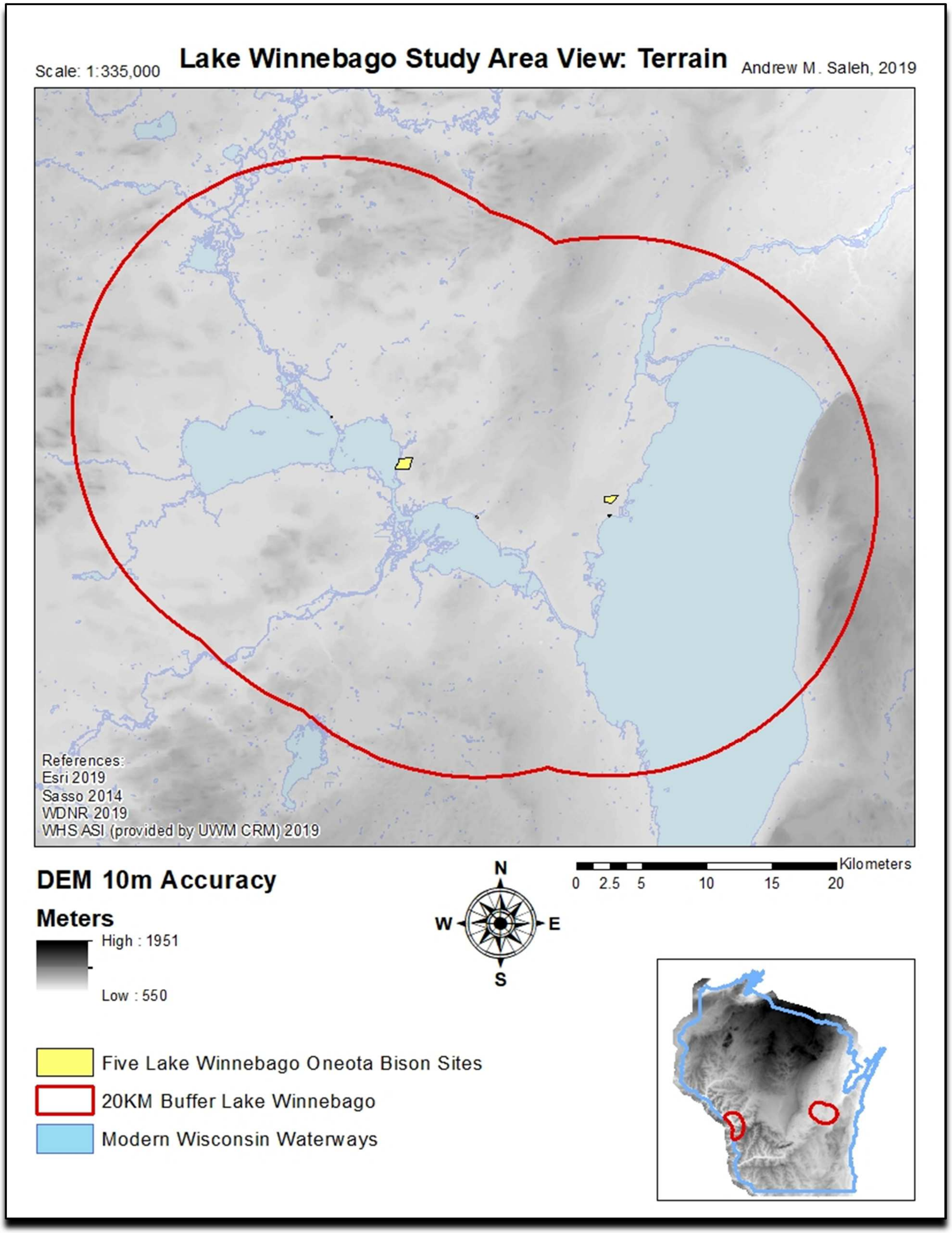


Figure 4.2: Lake Winnebago modern terrain and water with archaeological sites and their combined catchment.

In order to evaluate the catchment in terms of forage suitable for bison, vegetation data was added to the GIS. This was done using two sets of GLO codings, the first developed by Finley (1951, 976) and the second by Mladenoff. Table 4.2 shows the acreage calculated using Finley's vegetation codes, and how these twelve codes were adapted to the four broader vegetation types used in this thesis. Figure 4.3 shows the distribution of praire, oak openings, wetlands, and forest. This adaptation allows more direct comparison with the vegetation available to the Nachusa Grassland bison herd.

The Nachusa Grassland is noted as having 1,482.63 acres of forage area for free-ranging bison. Although the pockets of prairies are not connected in Figure 4.3, many are seen as having multiple kilometers of space. In the Lake Winnebago site catchment, according to Finley (1951, 1976), prairie makes up 4,467.27 acres alone. That is to say at 18.08 square kilometers, prairie alone has enough raw space to provide enough land for three Nachusa herds. Oak openings are also important, and as shown in the background of Chapter 2, bison can not only survive in these habitats in modern Wisconsin and Illinois, but can actually help them thrive (Blackburn 2018; Brockman 2017; Burke 2016; Gates et al. 2010; Hess et al. 2014). Oak openings make up 99,527.80 acres within the Lake Winnebago site catchment. That is to say at 402.77 squared kilometers, and 67 Nachusa herds could hypothetically subsist in this vegetation zone alone. If prairie and oak openings are combined, 70 Nachusa herds could find forage in these grass-friendly patches; this represents almost 6,000 individual bison. Wetlands provide additional resources for bison in the form of C3 sedges and access to drinking water. In summary, the Lake Winnebago catchment seems quite capabale of supporting a Late Prehistoric period bison herd year-round.

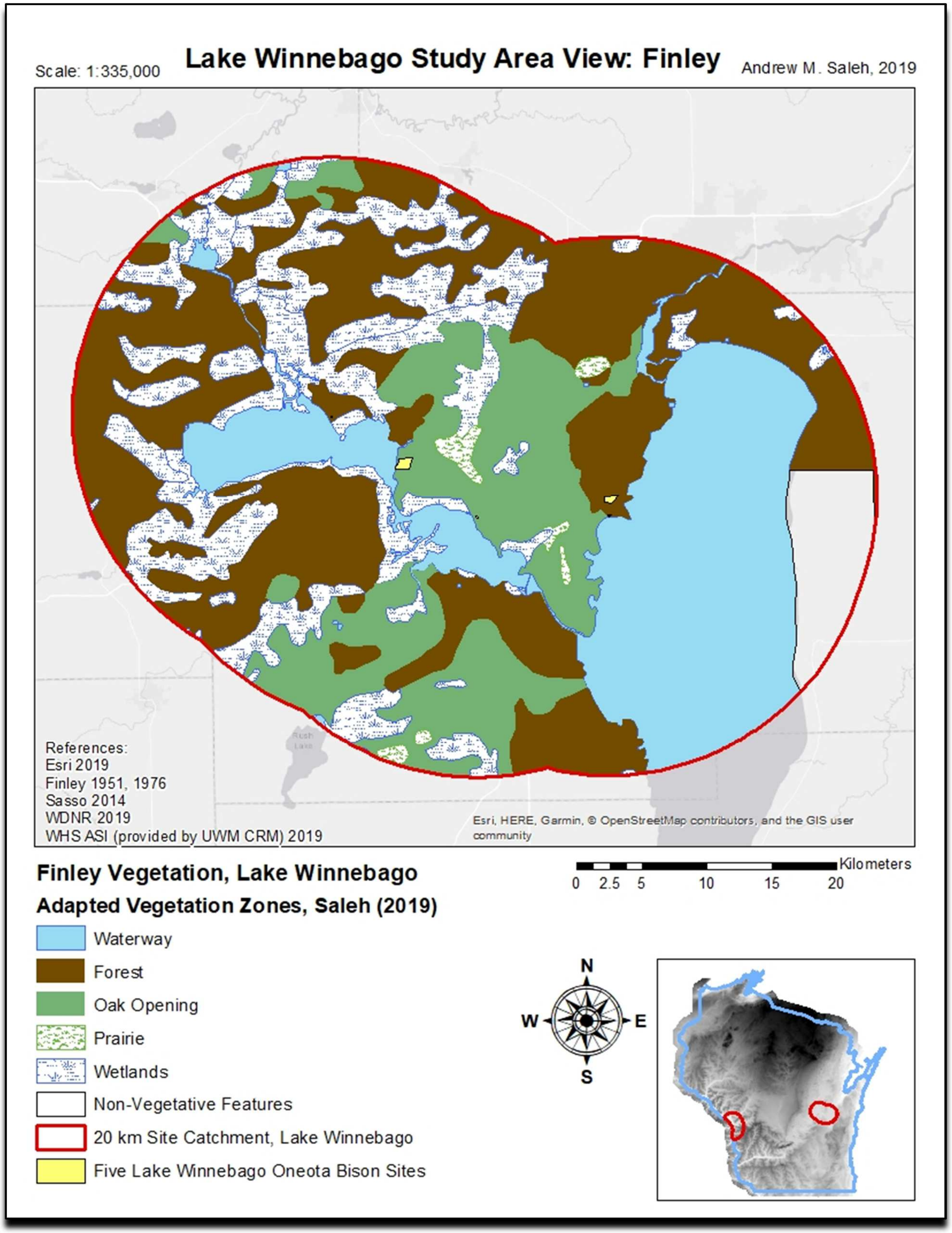


Figure 4.3: Lake Winnebago vegetation based on Finley's translation of the GLO adapted to the thesis schema.

Table 4.2: Shows Finley's (1951, 1976) individual categories and statistics, and how these were converted into the general zones (defined in Chapter 3). This table is related to Figure 4.3. Categorical adaptations are based what is the most accurate geospatially and environmentally, as well as bison forage needs (outlined in Chapter 2). Removing areas that cannot be grazed helps view the landscape more simply.

Finley's Vegetation Types	Acres	Adapted	Final Acres	Final Acres %
Water	132,110.93	Waterway	Removed	Removed
White Pine, Red Pine	4,806.97	Forest	202,134.54	49.50%
Jack Pine, Scrub (Hill's), Oak Forest and Barrens	2,476.94			
Aspen, White Birch, Pine	3,820.81			
Beech, Sugar Maple, Basswood, Red Oak, White Oak, Black Oak	7,909.61			
Sugar Maple, Basswood, Red Oak, White Oak, Black Oak	129,258.48			
Oak – White Oak, Black Oak, Bur Oak	53,861.73			
Oak Openings – Bur Oak, White Oak, Black Oak	99,527.80	Oak Opening	99,527.80	24.37%
Prairie	4,467.27	Prairie	4,467.27	1.10%
Swamp Conifers – White Cedar, Black Spruce, Tamarack, Hemlock	38,659.63	Wetlands	102,222.02	25.03%
Lowland Hardwoods – Willow, Soft Maple, Box Elder, Ash, Elm, Cottonwood, River Birch	7,112.02			
Marsh and Sedge Meadow, Wet Prairie, Lowland Shrubs	56,450.37			
Stockbridge-Munsee Reservation Land/Unmapped Vegetation (labeled "Null Data" (W.DNR 2019))	20,184.89	Non-Vegetative Features	Removed	Removed
Grand Total:	**560,647.45**	**-**	**408,351.63**	**100%**

How does Mladenoff's vegetation reconstruction for the Lake Winnebago catchment compare to Finley's? Mladenoff (2019) data is presented in Table 4.3 and Figure 4.4. Because waterways and wetlands were not mapped by Mladenoff, these are not quantified. As detailed in Chapter 3, Mladenoff reconstruction is based on densities of trees; a by-product of this approach is that wetlands are not recorded as such. While the two reconstructions produce similar estimates for acreage of forests, they differ markedly in the acreage identified as prairie and oak opening or savanna, with Mladenoff suggesting more grasslands of both kinds. There are 36,197.20 acres or 146.48 square kilometers of prairie, and 168,873.73 acres or 683.41 square kilometers of oak openings, available to forage. These differences in GLO coding impact the estimates of how many bison herds this catchment could sustain.

Table 4.3: Mladenoff's (2019) GLO vegetation density classes adapted for this thesis.

Mladenoff's Vegetation Types	Acres	Adapted	Final Acres	Final Acres %
Closed Forest	157,969.85	Forest	216,701.88	51.38%
Open Forest	58,732.03			
Open	138,874.64	Non-Vegetative Features	Removed	Removed
Prairie	36,197.20	Prairie	36,197.20	8.58%
Savanna	168,873.73	Oak Opening	168,873.73	40.04%
Grand Total:	**560,647.45**	**-**	**421,772.81**	**100%**

Roughly 24 Nachusa herds could subsist in the prairie alone, another 113 herds could fit in oak opening densities, and 138 herds in both densities or patches combined. This represents almost 12,000 individual bison. Thus both the Finley and the Mladenoff vegetation reconstructions support the viability of local bison herds in the Lake Winnebago locality.

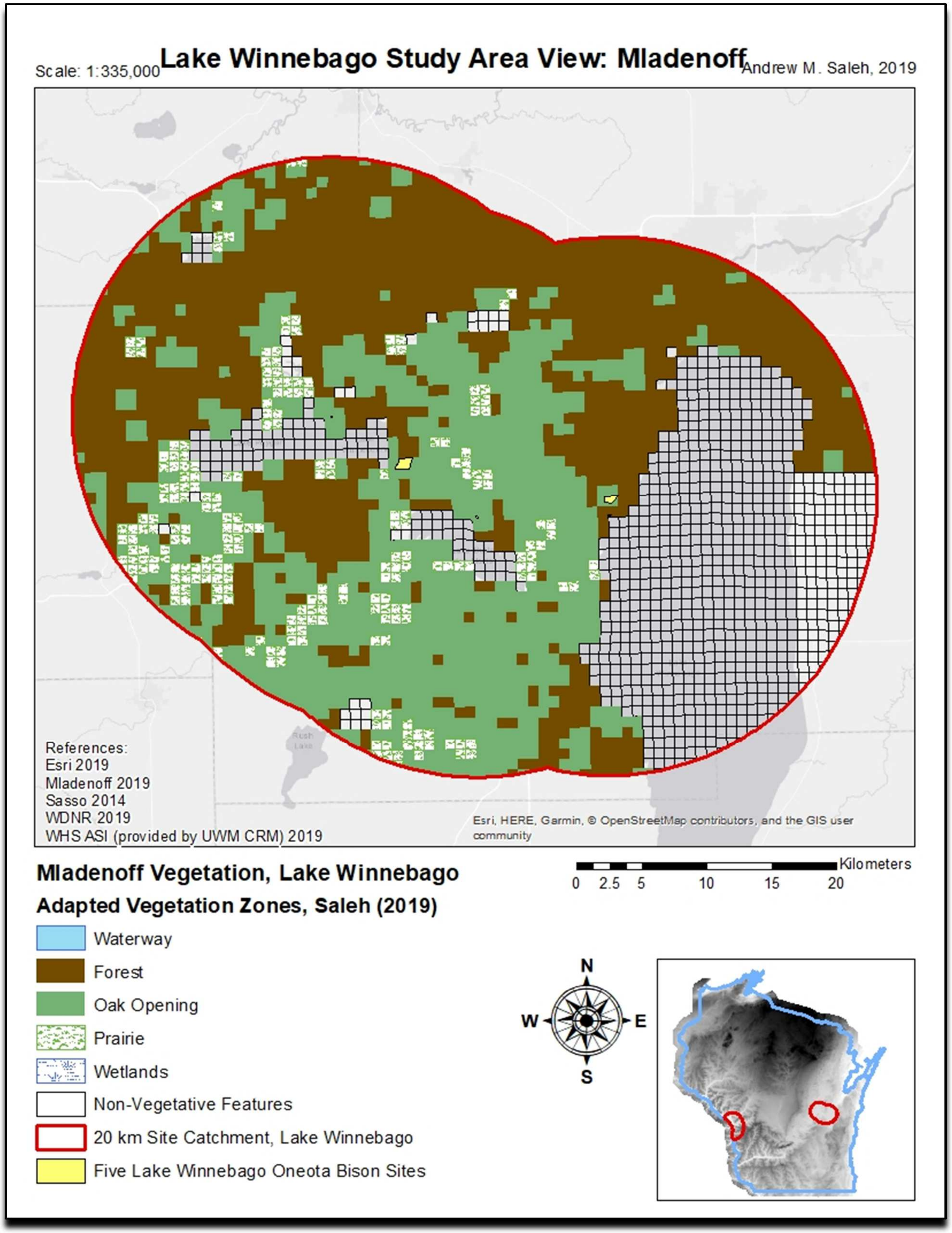


Figure 4.4: Lake Winnebago vegetation based on Mladenoff's translation of the GLO adapted to the thesis schema.

The La Crosse Site Catchment:

Figure 4.5a shows the locations of the sixteen La Crosse archaeological sites that had bison remains; Figure 4.5b provides a zoomed-in view to allow legible labeling of the individual sites. This region has the most reported bison remains in Oneota contexts in Wisconsin (Sasso 1993, 2014). This is also the catchment where I created my own translation of the GLO, coding the original notes directly into four broad vegetation types chosen for their relevance to research questions about bison and archaeological catchments. This allows me to make a 3-way comparison of the coding methods. Three major rivers fall within this catchment: the Black, La Crosse, and Mississippi Rivers. Figure 4.6 illustrates the general terrain, and Figure 3.4 shows how data such as these can be manipulated into slope. These figures also show that this region has much more variation in terrain or slope percentage than Lake Winnebago's site catchment.

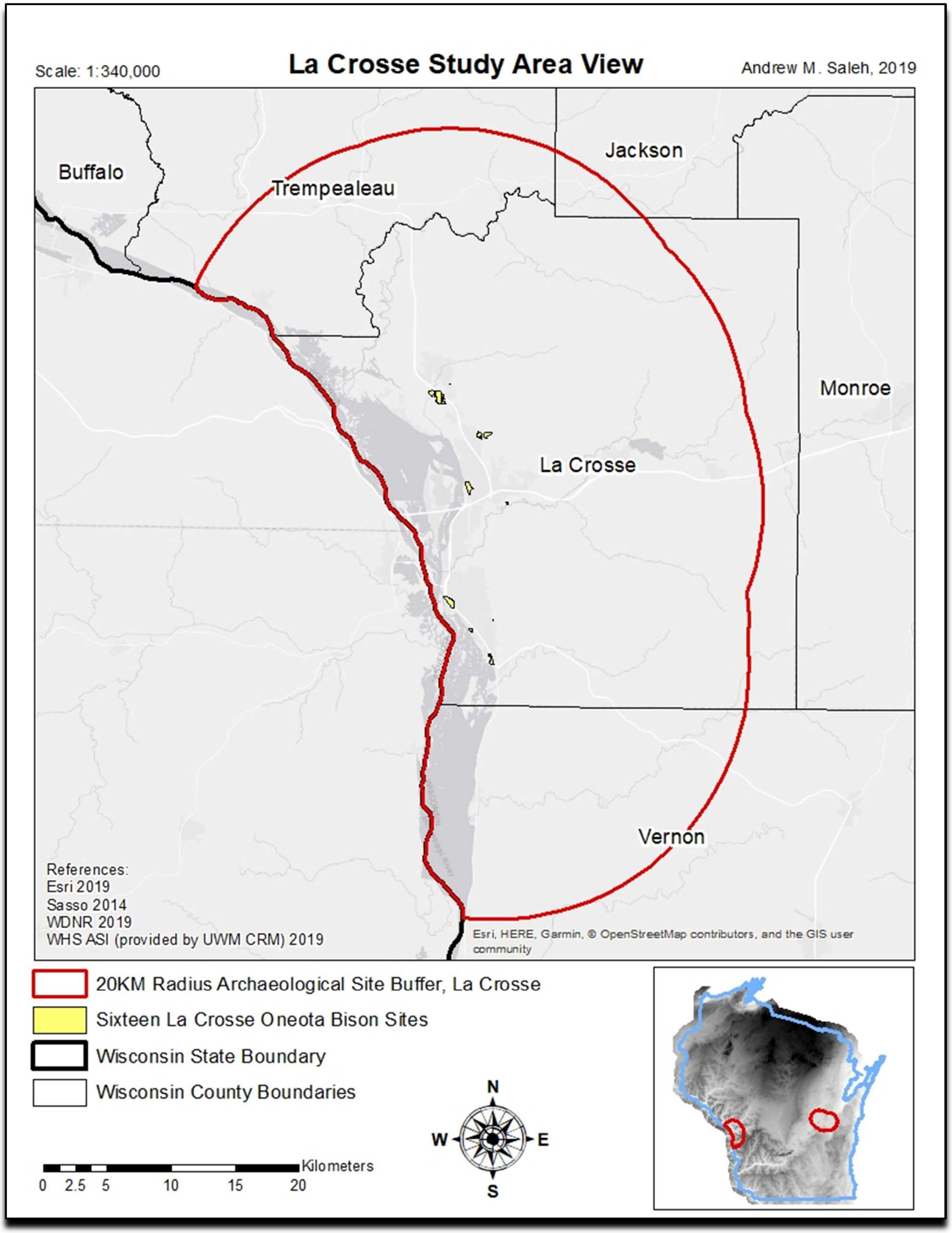


Figure 4.5a: La Crosse site catchment and archaeological sites.

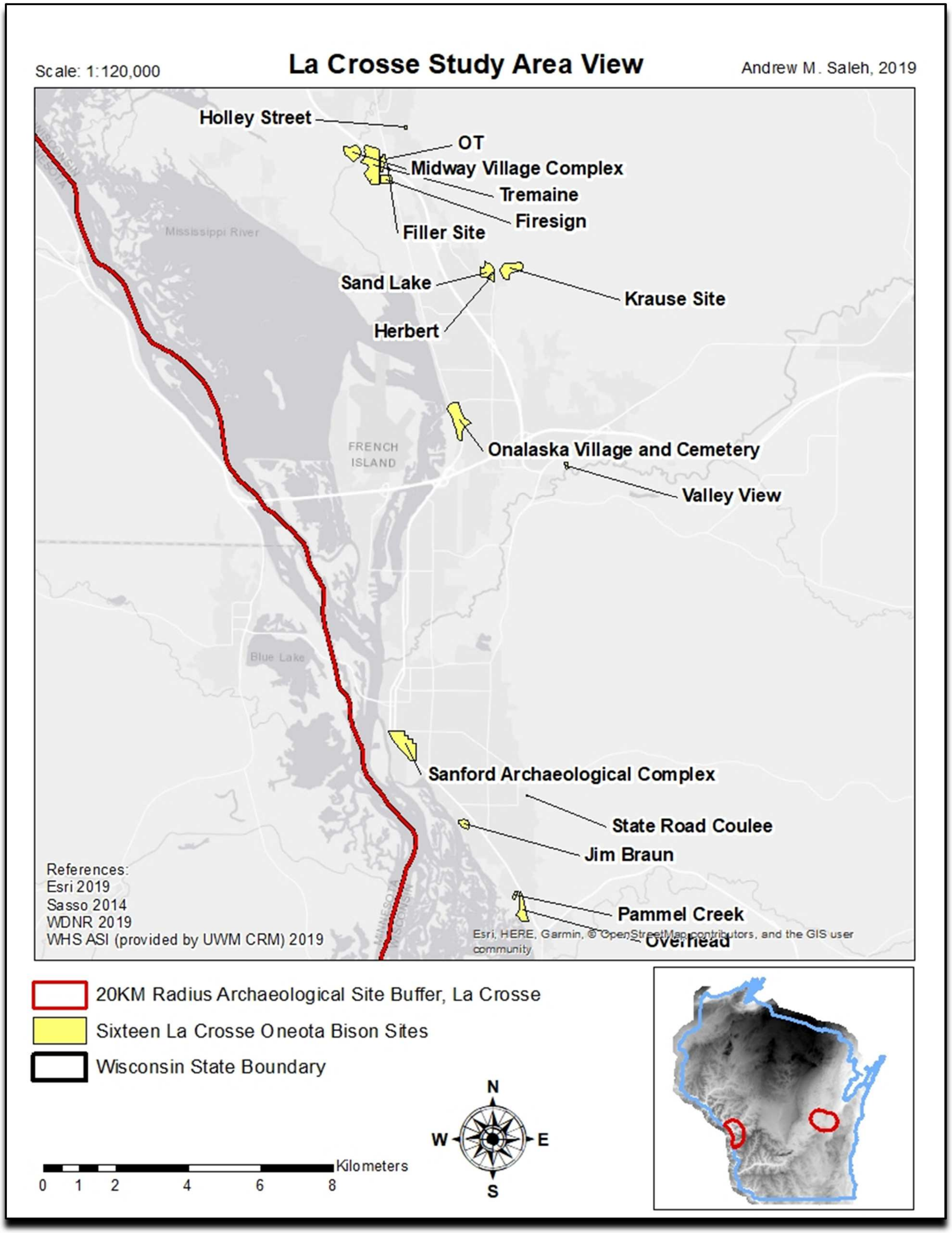


Figure 4.5b: La Crosse site catchment and archaeological sites. Zoom-in.

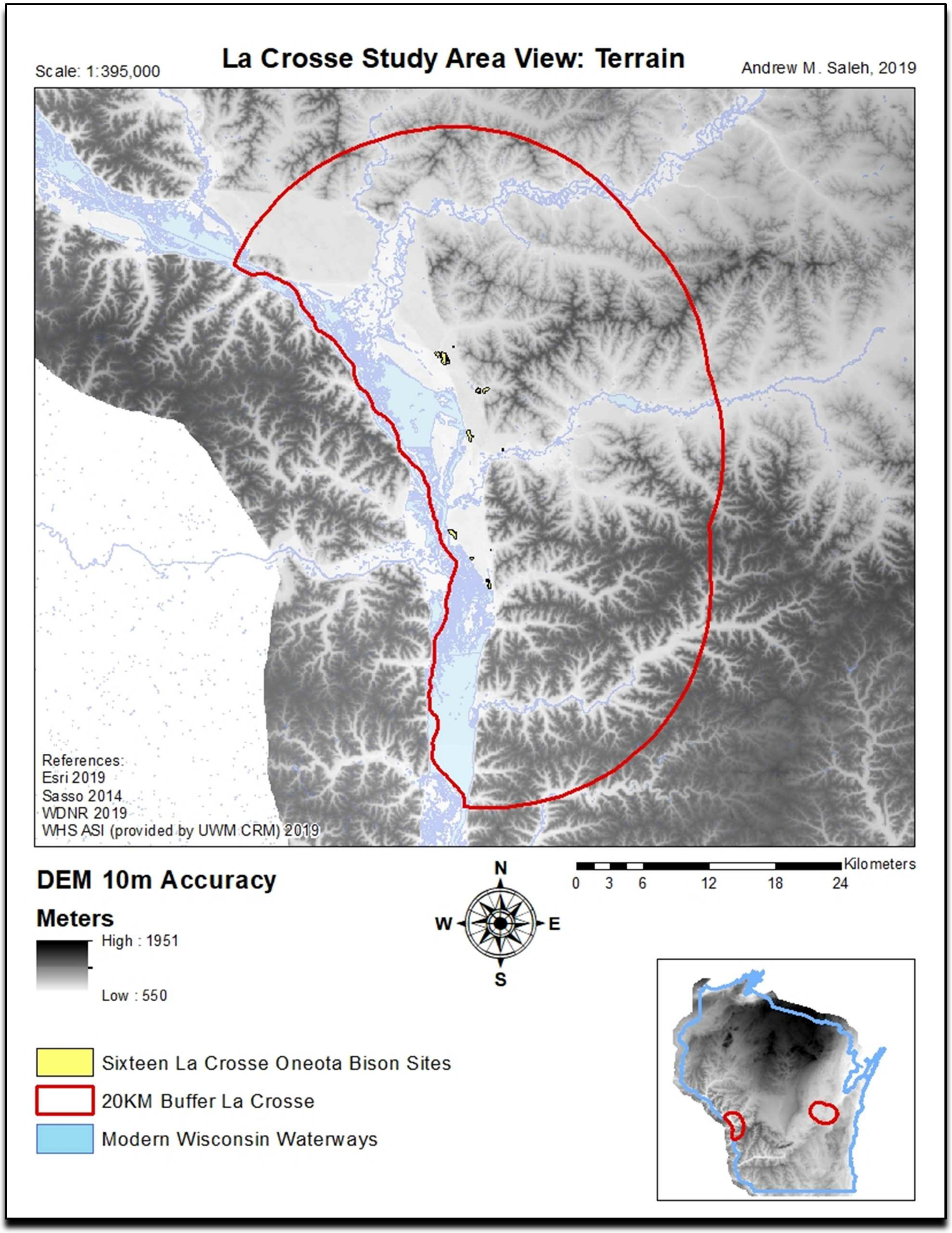


Figure 4.6: La Crosse modern terrain and water with archaeological sites and their combined catchment.

Figures 4.5 and 4.6 illustrate general terrain, water, and archaeological site distributions within the La Crosse catchment. Vegetation was added using Finley's coding of the GLO. Table 4.4 shows how Finley's (1951, 976) codes, detailed in Chapter 3, were collapsed into broader zones for this catchment. These zone adaptations allow more direct comparison with the zones used to describe the Nachusa Grassland. Figure 4.7 maps their distribution. Finley's data shows a mix of prairie, oak openings, forest, and wetlands.

Table 4.4: Shows Finley's (1951, 1976) individual categories and statistics, and how these were converted into the general zones (defined in Chapter 3). Brush was combined with oak openings. Lowland hardwods were grouped with wetlands based on GLO notes. This table is associated with Figure 4.7.

Finley's Vegetation Types	Acres	Adapted	Final Acres	Final Acres %
Water	25,669.41	Waterway	Removed	Removed
Sugar Maple, Basswood, Red Oak, White Oak, Black Oak	524.16	Forest	170,363.69	45.12%
Oak – White Oak, Black Oak, Bur Oak	169,839.53			
Oak Openings – Bur Oak, White Oak, Black Oak	105,035.65	Oak Opening	119,830.68	31.74%
Brush	14,795.03			
Prairie	42,058.60	Prairie	42,058.60	11.14%
Swamp Conifers – White Cedar, Black Spruce, Tamarack, Hemlock	1,629.07	Wetlands	45,323.44	12.00%
Lowland Hardwoods – Willow, Soft Maple, Box Elder, Ash, Elm, Cottonwood, River Birch	28,890.43			
Marsh and Sedge Meadow, Wet Prairie, Lowland Shrubs	14,803.94			
Grand Total:	**403,245.83**	**-**	**377,576.42**	**100%**

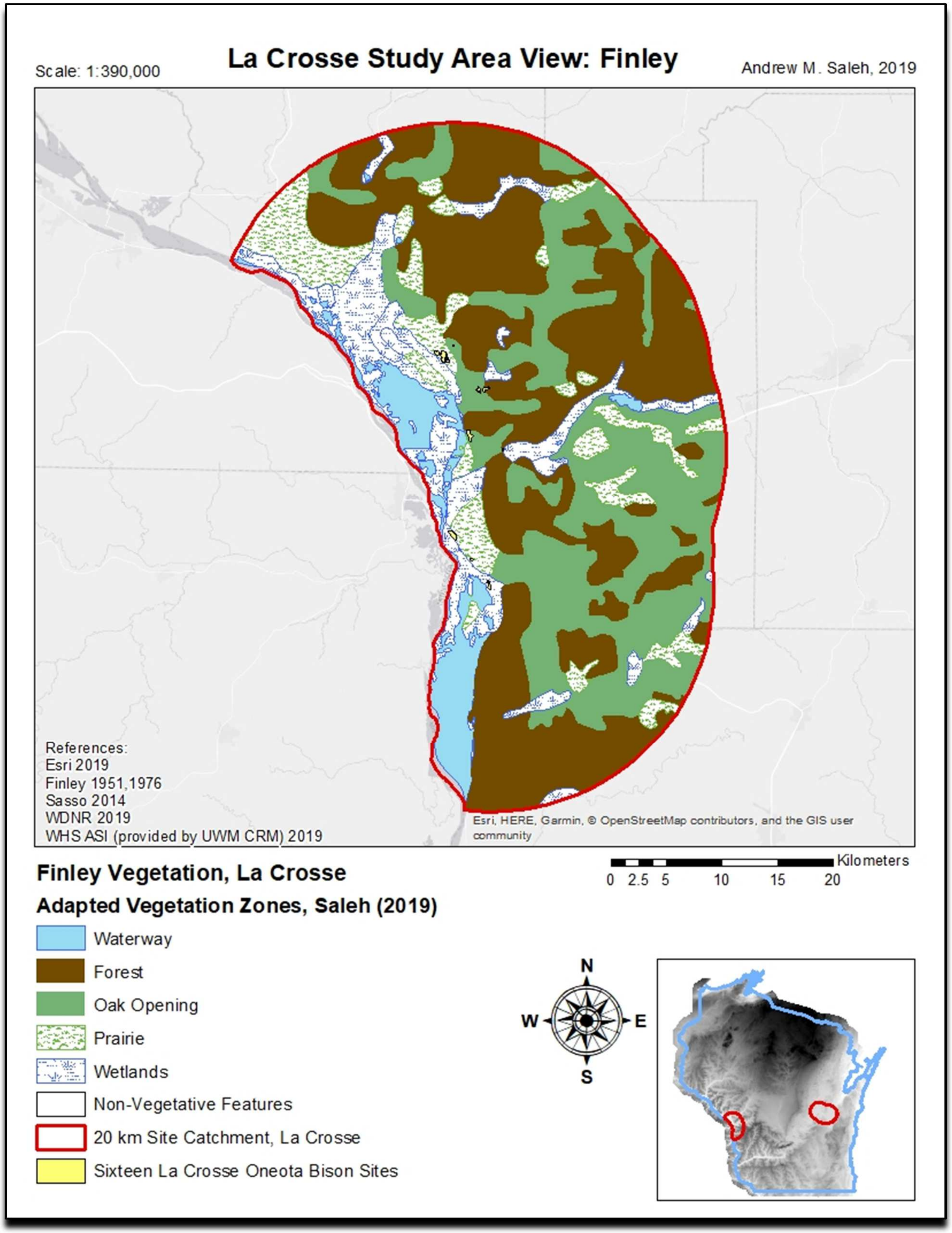


Figure 4.7: La Crosse vegetation based on Finley's translation of the GLO adapted to the thesis schema.

Although all the prairie lands are not connected, their acreage represents many kilometers of space. Some patches of prairie are quite large, such as the one at the northern boundary of the catchment. In the La Crosse site catchment, according to Finley (1951, 1976) as a raw statistic, prairie makes up 42,058.60 acres. This is equivalent to 170.21 square kilometers. There would enough room for 28 Nachusa herds even if they foraged only on the C4 grasses represented by the prairies of this catchment. Oak openings are also important, and again, grazing bison can help maintain the openness of this zone (Blackburn 2018; Brockman 2017; Burke 2016; Gates et al. 2010; Hess et al. 2014). Oak openings make up 119,830.68 acres or 484.94 square kilometers. Another 80 Nachusa herds could forage in this vegetation zone. If prairie and oak opening acreage is combined, some 109 Nachusa herds could be accommodated, or roughly 9,000 individual bison. Prairie is 11.14% of the total recorded land area and oak opening is 31.74% of the total recorded land area. Wetland C3 sedges, as shown in Table 4.4, were also available. Wetlands provide both food and access to water.The vegetation mosaic in the La Crosse site catchment seems quite capabale of supporting Late Prehistoric period bison year-round.

Mlandenoff (2019) provides a second approach to coding the GLO for the La Crosse catchment. Table 4.5 provides the acreage for his vegetation codes and shows how they are collapsed into the four broad zones described for Nachusa. Figure 4.8 maps this distribution. Because waterways and wetlands were not mapped by Mladenoff, these are not quantified. The most striking difference between Mladenoff and Finley's reconstructions are the relative abundance of forest and oak openings. Mladenoff's attention to tree densities results in a much higher acreage of oak openings and a lower acreage of forest.

Table 4.5: Mladenoff's (2019) GLO vegetation density classes adapted for this thesis.

Mladenoff's Vegetation Types	Acres	Adapted	Final Acres	Final Acres %
Closed Forest	22,289.54	Forest	58,703.16	14.91%
Open Forest	36,413.62			
Open	11,510.41	Non-Vegetative Features	Removed	Removed
Prairie	34,660.16	Prairie	34,660.16	8.80%
Savanna	300,407.45	Oak Opening	300,407.45	76.29%
Grand Total:	**405,281.18**	**-**	**393,770.77**	**100%**

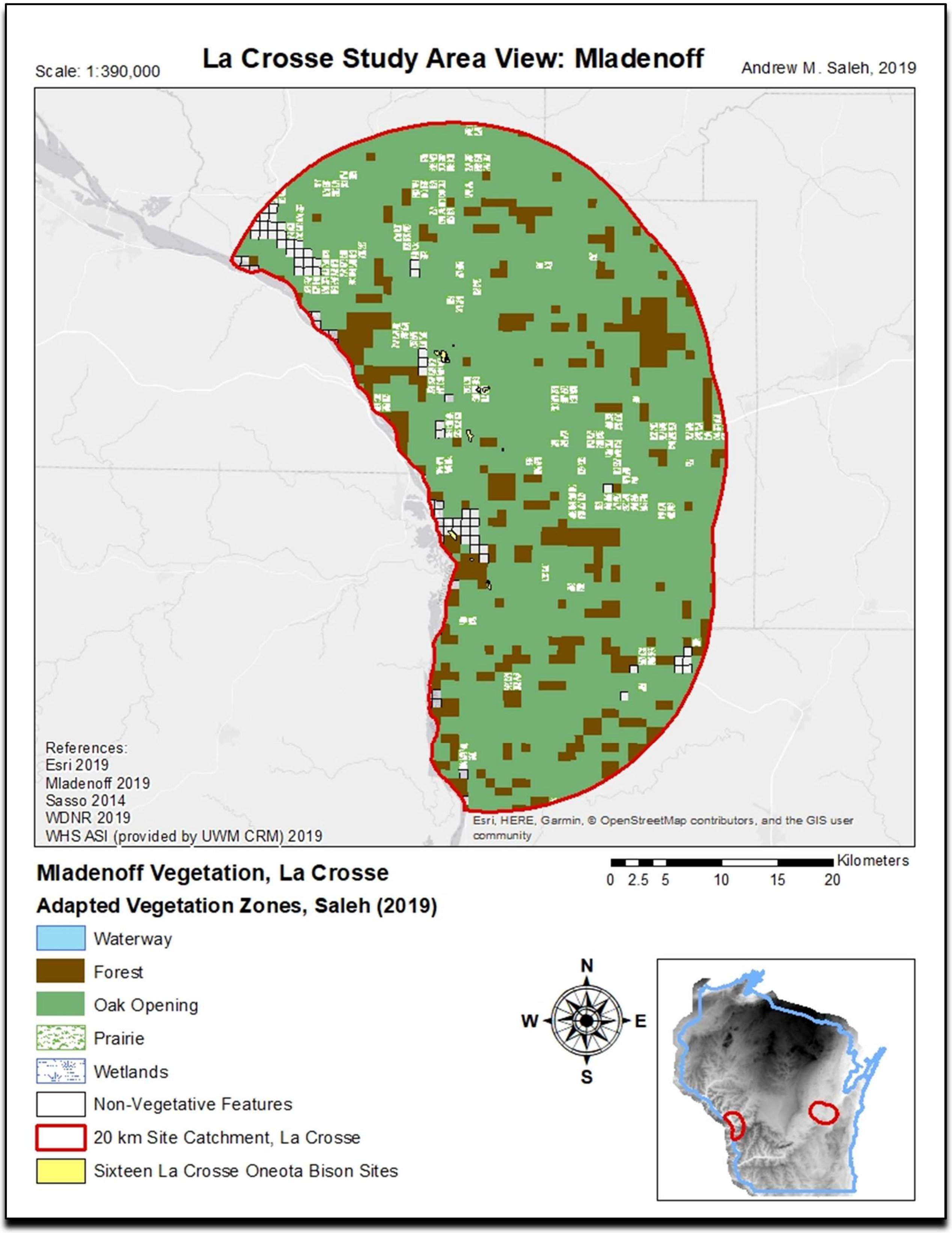


Figure 4.8: La Crosse vegetation based on Mladenoff's translation of the GLO adapted to the thesis schema.

Mladenoff's reconstruction for the La Crosse locality includes 34,660.16 acres of prairie and 300,407.45 acres of oak opening. This is equivalent to 140.26 square kilometers of prairie and 1,215.71 square kilometers of oak opening. This landscape could accommodate 23 Nachusa herds in the prairies and an astounding 202 herds in oak openings, for a total of 226 herds when those resource areas are combined. That represents some 19,000 individual bison.

In both the Finley and Mladenoff reconstructions, the La Crosse locality had ample forage to sustain bison. Multiple healthy herds could subsist in all of these datasets. One could even create "local" site buffers of one-kilometer around each Oneota site based on the assumption that bison would not graze near human home bases, and the result would still be the same. Historic accounts and vegetation both provide a compelling case for bison in prehistoric Wisconsin.

I will now add a third approach to vegetation reconstruction from GLO records, one that was designed with bison in mind. It codes vegetation with attention to prairie and oak opening components and thus C4 grazing potential, and with attention to wetlands, since they are a source for the C3 sedges that are seasonally important to bison. It also distinguishes wetlands from waterways; the Mississippi, La Crosse, and Black River watersheds significantly impact this catchment when hand drawn. It codes at the spatial scale of quarter section and GLO feature level. I applied this approach to the GLO records for the La Crosse area with the goal of assessing its impact on the calculation of habitats suitable for bison when compared with the approaches of Finley and Mladenoff. This added a third reconstruction (Figure 4.9), but also allowed me to explore the potential of tackling the GLO at a large regional scale. Table 4.6 shows the related statistics. Visually, my reconstruction (Figure 4.9) looks more like Mladenoff's

(Figure 4.8) than Finley's (Figure 4.7) in terms of the abundance of oak openings. Mine differs from Mladenoff's in that my forests are clustered in the south, where his appear as small scatters throughout the catchment (Appendix A explores why these forests appear). Mine stands out among the three for having the largest acreage of prairie. Other significant differences with the Saleh dataset is the merging of inundated bottoms with wetlands, the accuracy of the historic waterways, and the attention to small pockets of non-vegetative data. The Saleh data set is the only one where historic waterways are mapped.

Table 4.6: Saleh's (2019) GLO vegetation types. Jeske (1990) and Edwards IV (2010) greatly contributed to these thesis-wide categorical choices. The removal of non-grazeable land aids in quantifying bison forage.

Saleh's Vegetation Types	Acres	Final Acres	Final Acres %
Waterway	14,715.16	Removed	Removed
Forest	41,839.35	41,839.35	10.74%
Oak Opening	193,488.72	193,488.72	49.68%
Prairie	77,784.50	77,784.50	19.97%
Wetlands	76,375.29	76,375.29	19.61%
Non-Vegetative Features	1,155.12	Removed	Removed
Grand Total:	**405,358.13**	**389,487.85**	**100%**

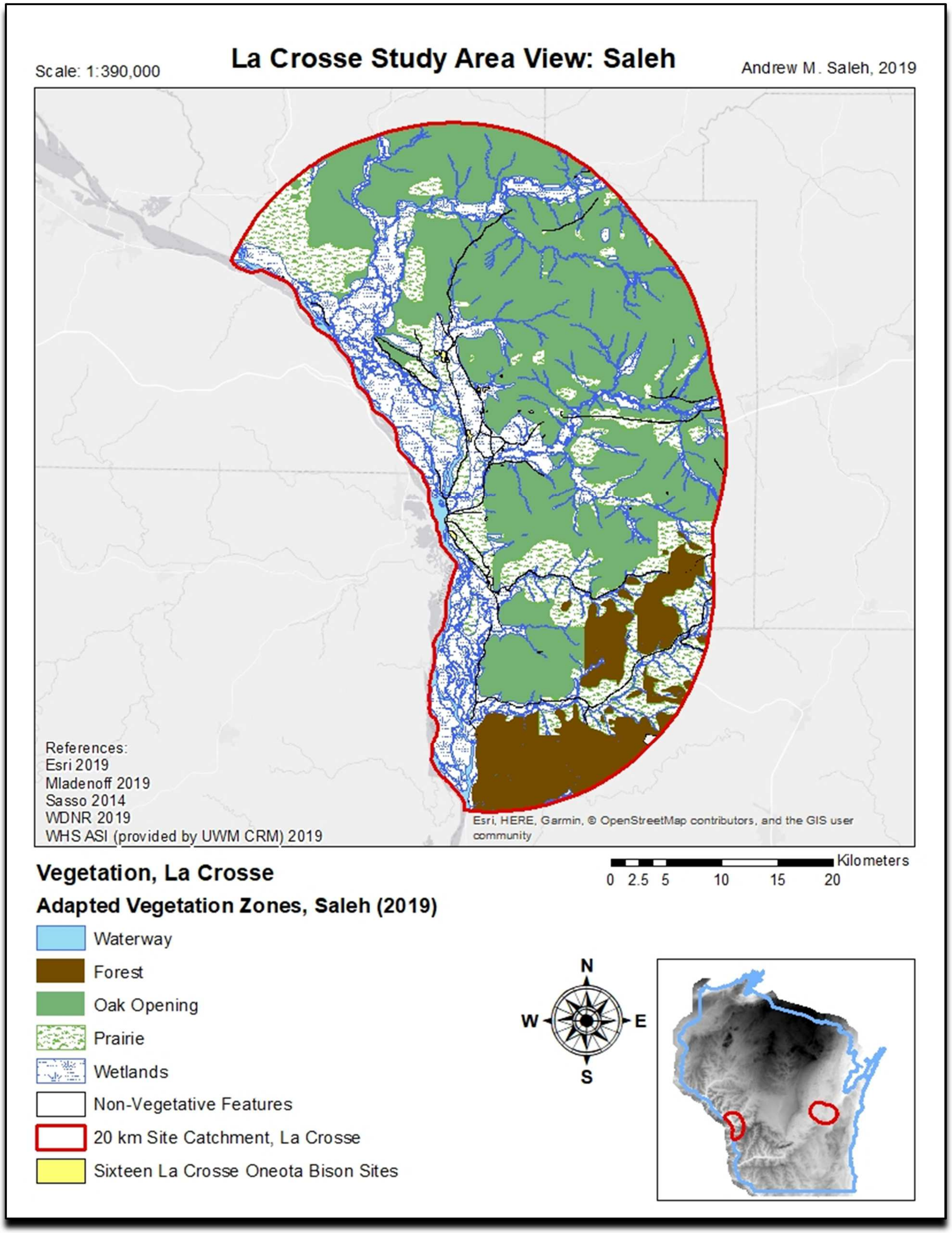


Figure 4.9: La Crosse vegetation based on Saleh's translation of the GLO with the thesis schema.

In terms of foraging lands suitable for bison, this reconstruction estimates 77,784.50 acres of prairie and 193,488.72 acres of oak opening were available. This is equivalent to 314.78 square kilometers of prairie and 783.02 square kilometers of oak opening. This represents enough prairie for 52 Nachusa herds, enough oak openings for another 130 herds, and a combined acreage sufficient for 182 herds. This represents roughly 15,000 individual bison in the La Crosse site catchment.

Thus all three approaches (Finley, Mlandenoff, and Saleh) confirm that both catchments were likely more than adequate to sustain a local Wisconsin bison herd in prehistoric Oneota times. It also confirms that this would have been possible within local hunting ranges.

One of the objectives of this thesis was to evaluate how coding of the original GLO notes impacts the results. One way to look at this is to compare how each approach ranked four broad categories of vegetation land comparatively: forest, prairie, oak opening, and wetlands. Table 4.7 shows how these translations compare in their approach to the La Crosse locality catchment. All three were derived from the same original GLO notes. While it is not surprising that exact acreages differ in all cases, it is perhaps surprising that when viewed more simply as a rank ordering of most abundant to least abundant vegetation, there is almost no agreement in the rankings. Some of this can be attributed to the lack of a fourth category for Mlandenoff, since he did not code wetlands. The only shared ranking is the ranking of oak openings as the most abundant type by Mlandenoff and Saleh. Both of these approaches made it a point to distinguish between trees that occurred scattered in grasslands versus trees in forests. Both also translated the GLO more directly, and translated at the spatial scale of section and quarter section.

Interestingly, because I took the approach of setting a particular acreage threshold for my evaluation of the needs of a bison herd, the interpretations of bison sustainability was the same for all three translations of the GLO. The different values of vegetation acreage did not have an impact once the threshold was met. The variations did lead to some large differences in estimates of exactly how many herds or how many bison could be sustained, but my research question was sufficiently answered as long as even one herd could find adequate forage.

Table 4.7: La Crosse catchment vegetation reconstruction comparison.

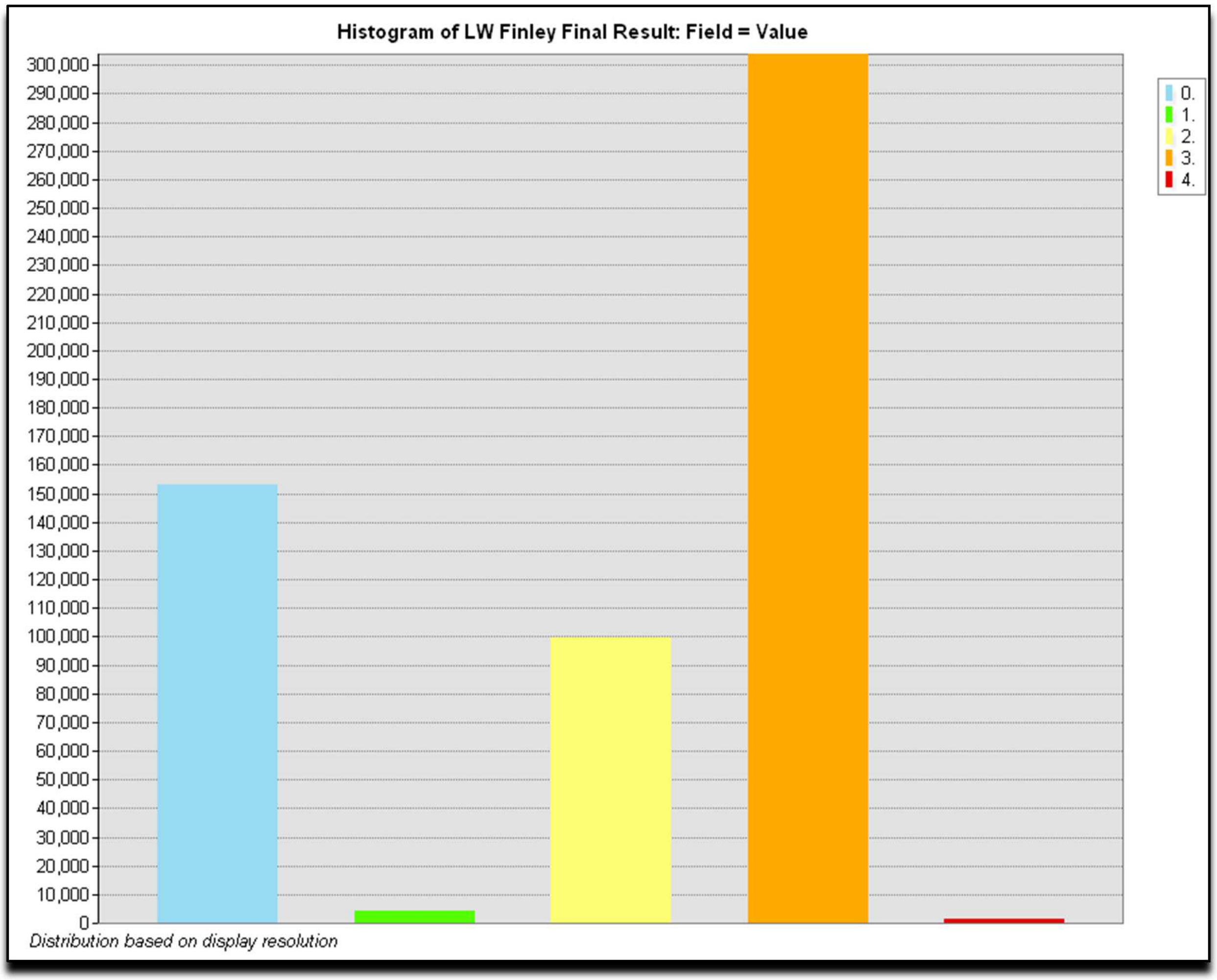
Vegetation Type	Finley Acreage Total and % (rank)		Mlandenoff Acreage Total and % (rank)		Saleh Acreage Total and % (rank)	
Forest	170,363.69 (1)	45.12%	58,703.16 (2)	14.91%	41,839.35 (4)	10.74%
Oak Opening	119,830.68 (2)	31.74%	300,407.45 (1)	76.29%	193,488.72 (1)	49.68%
Prairie	42,058.60 (4)	11.14%	34,660.16 (3)	8.80%	77,784.50 (2)	19.97%
Wetlands	45,323.44 (3)	12.00%	Not Coded	Not Coded	76,375.29 (3)	19.61%
Grand Total:	**377,576.41**	**100%**	**393,770.77**	**100%**	**389,487.85**	**100%**

Using GIS Modeling to Combine Vegetation and Terrain:

While forage is critical to modeling bison habitat, other environmental variables also play a role. One of the goals of this thesis was to incorporate terrain and water into modeling bison land viability. Terrain in particular is considered to impact bison access to forage. Modern studies show a preference for bison to aggregate in open grasslands, especially in the summer (Brockman 2017). Rugged terrain, on the other hand requires more energy to negotiate and may, in extreme cases, prevent access or require the bison to travel around an obstacle. Large bodies of water may also become obstacles to movement.

As described in the methods, I set terrain as 25 percent influence, and vegetation as 75 percent influence to create viability ratings with Esri's (2019) weighted overlay tool (see Figures 3.1 and 3.3). Terrain was converted to a percentage slope and ranked on a scale where 1 is the best (slope = 0 (min.) - 20.91%) and 4 is the worst (slope 62.73 - 83.63% (max.)) (see Figure 3.3). Vegetation was also ranked related to bison, which is described in Chapter 3. Prairie (1), oak opening (2), wetlands (3), and forest (4). Restricted values (0) represent an absence of grazeable land. These are presented both as histograms and maps; the histograms quantify the pixels or numbers of spatial units in the archaeological site catchments that fall into each of the ranked categories. The X axis in the histograms are color coded, and the Y values are scaled from the real pixel "counts." The landscape below the viability coloration is an adaption of the W.DNR (2019) terrain data provided to help visualize terrain relief. Appendix C provides the final result modeling weights, and Chapter 3 provides more in-depth method descriptions. All five vegetation scenarios from Lake Winnebago and La Crosse are presented as bison viability scenarios below.

Figure 4.10: Shows the resulting histogram using Finley's vegetation data for the Lake Winnebago area and the corresponding bison viability map. The combination of vegetation and terrain suggests that very little of the catchment was ideal for bison (rank 1) and a modest amount was adequate (rank 2). A rank 3 majority is directly related to the amount of woody forage in the catchment.



Value	Count
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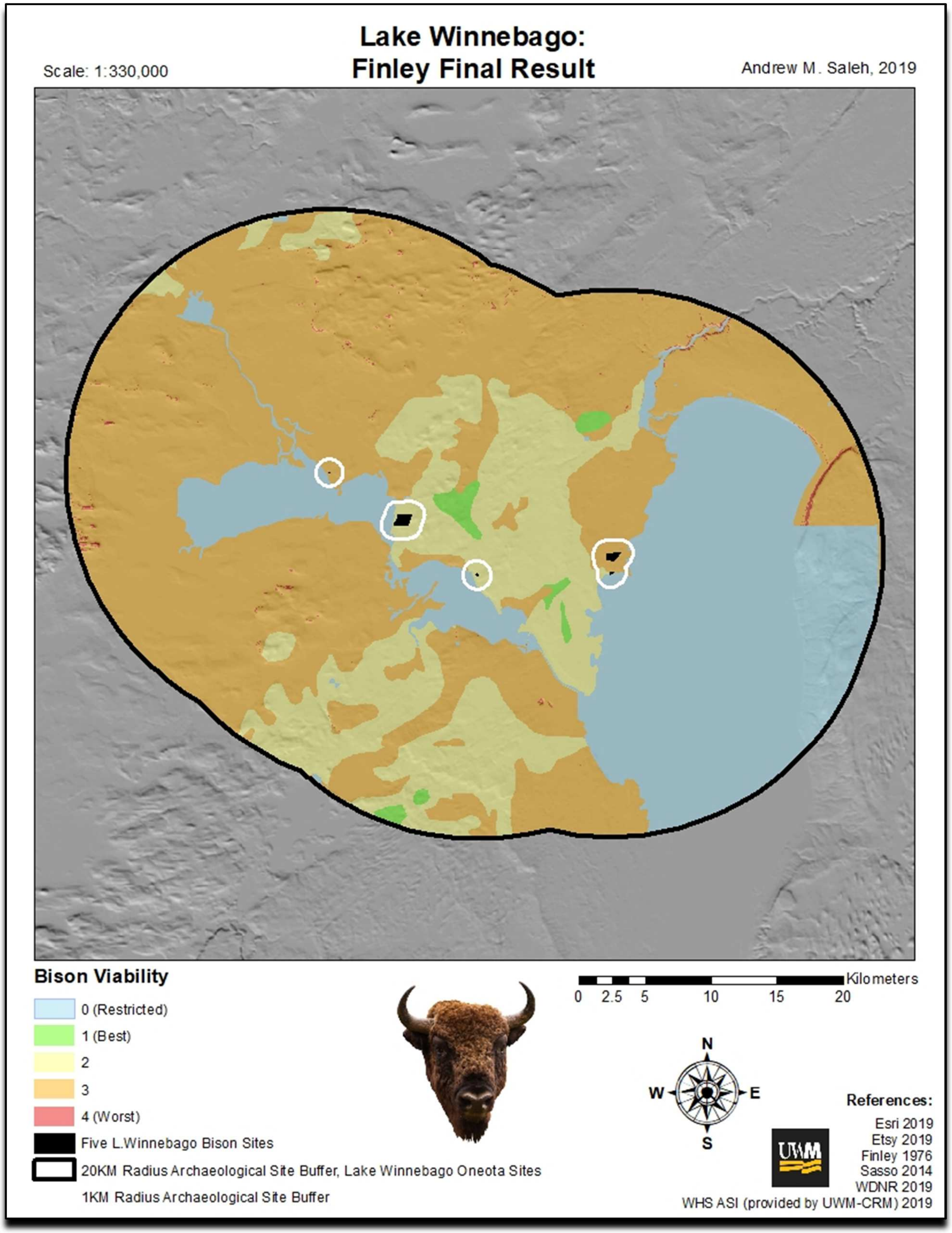
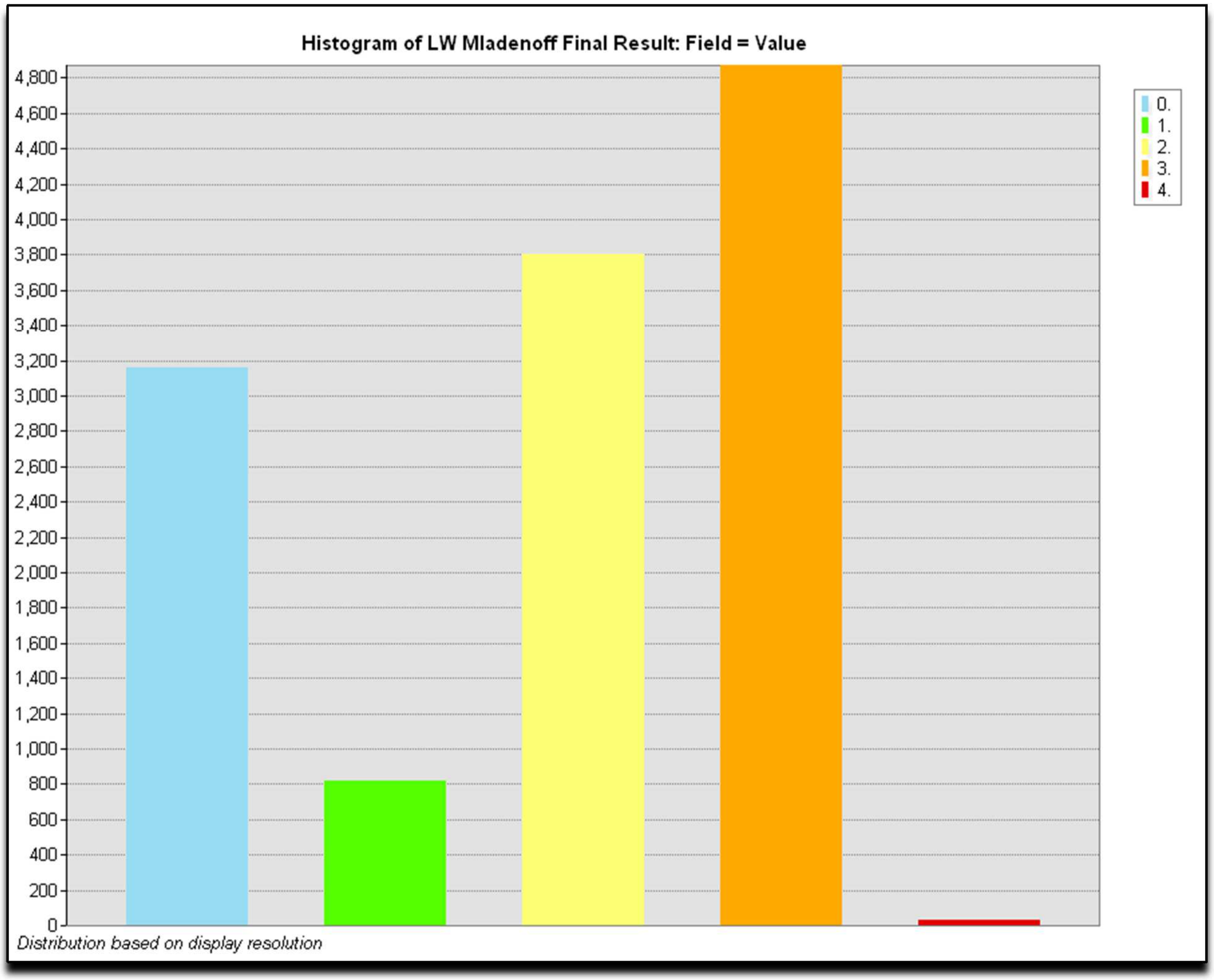
2	4028828
3	12255064
4	65693



Lake Winnebago:
Finley Final Result
Scale: 1:330,000
Andrew M. Saleh, 2019
Bison Viability
0 (Restricted)
1 (Best)
2
3
4 (Worst)
Five L.Winnebago Bison Sites
20KM Radius Archaeological Site Buffer, Lake Winnebago Oneota Sites
1KM Radius Archaeological Site Buffer
Kilometers
0 2.5 5 10 15 20
N
W
E
S
References:
Esri 2019
Etsy 2019
Finley 1976
Sasso 2014
WDNR 2019
WHS ASI (provided by UWM-CRM) 2019

Figure 4.11: Shows the same catchment using Mladenoff's vegetation data with the associated histogram and map. Comparing these with Finley's data we see that Mlandenoff's data increases the relative amount of rank 1 and rank 2 habitats (Figure 4.10 compared to Figure 4.11). The rank 3 maximum is noted to be driven, again, by a high percentage of woody forage available in this catchment.



Value	Count
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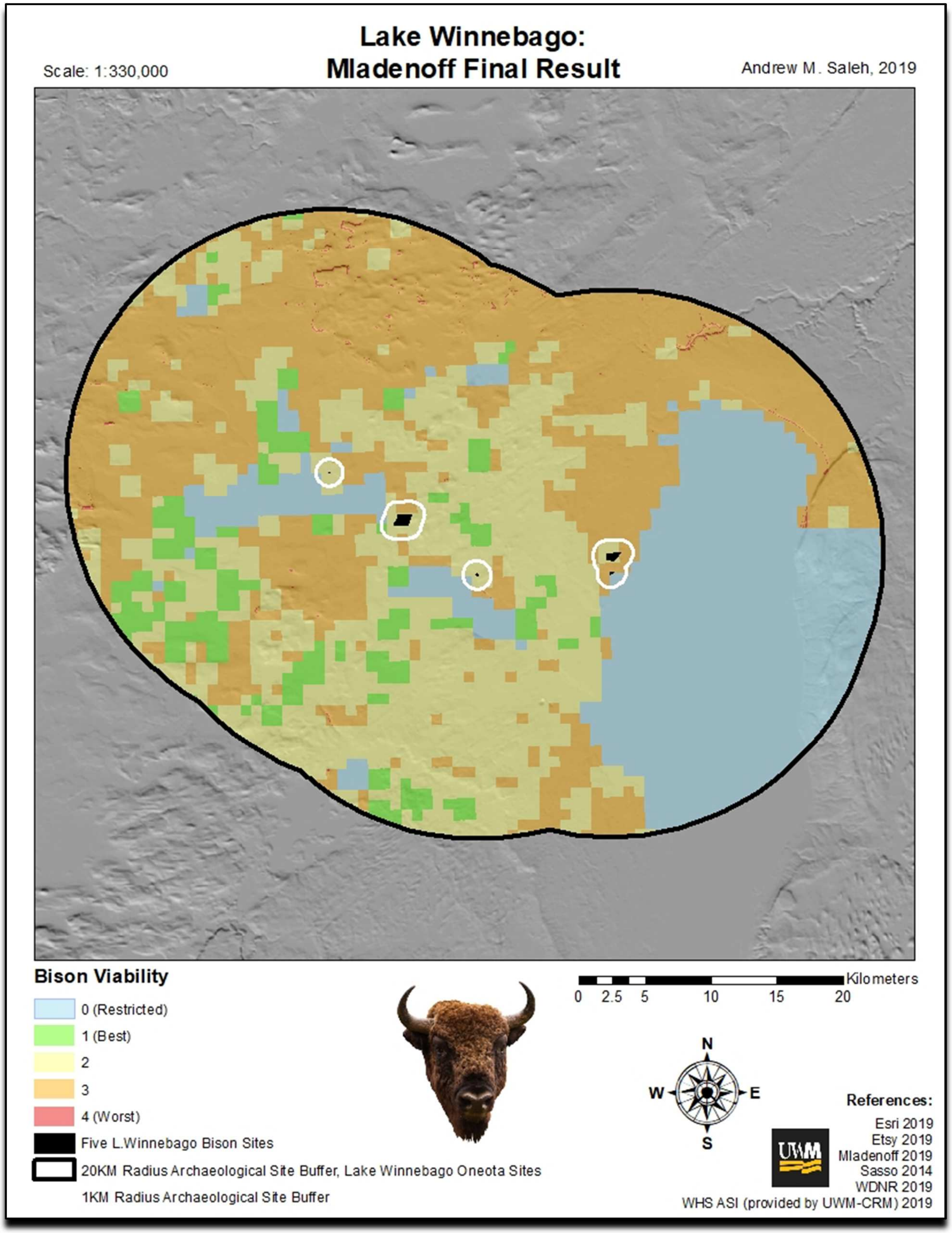
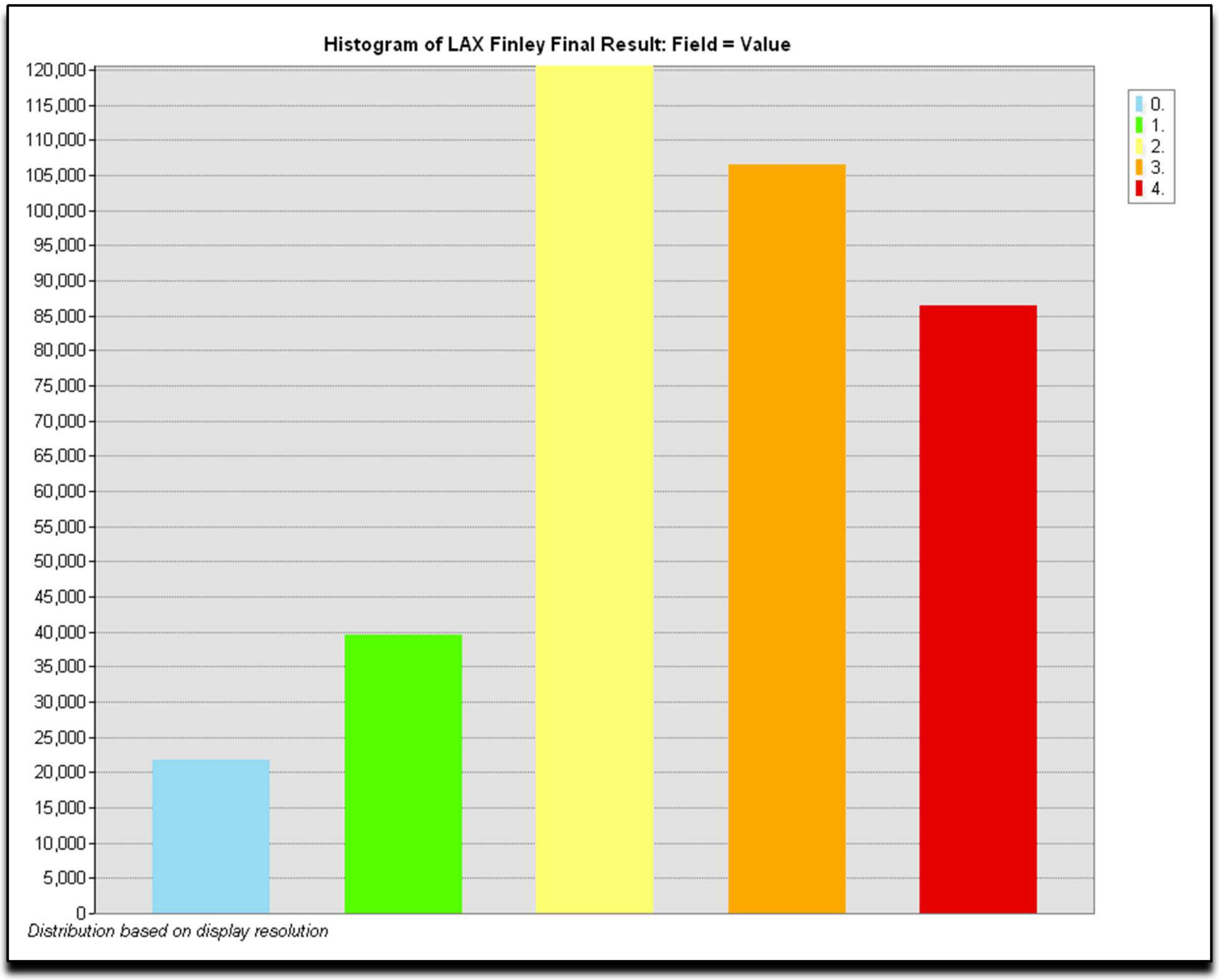
1	1465014
2	6836316
3	8724680
4	47490



Lake Winnebago:
Mladenoff Final Result
Scale: 1:330,000
Andrew M. Saleh, 2019
Bison Viability
0 (Restricted)
1 (Best)
2
3
4 (Worst)
Five L.Winnebago Bison Sites
20KM Radius Archaeological Site Buffer, Lake Winnebago Oneota Sites
1KM Radius Archaeological Site Buffer
0 2.5 5 10 15 20
Kilometers
N
W
E
S
References:
Esri 2019
Etsy 2019
Mladenoff 2019
Sasso 2014
WDNR 2019
WHS ASI (provided by UWM-CRM) 2019

Figure 4.12: Shows the resulting histogram using Finley's vegetation data for the La Crosse area with the corresponding map. The combination of vegetation and terrain suggest that a modest amount of the catchment was ideal for bison (rank 1) and a large amount was adequate (rank 2). Although rank 2 is the maximum, rank 4 is the point of statistical significance. If Finley's data holds true, much of the La Crosse region constitutes the poorest bison foraging habitats. The lowlands near the Mississippi River seem much more suited to ranks 1 and 2, and therefore also seem much more suited to year-round bison herds.



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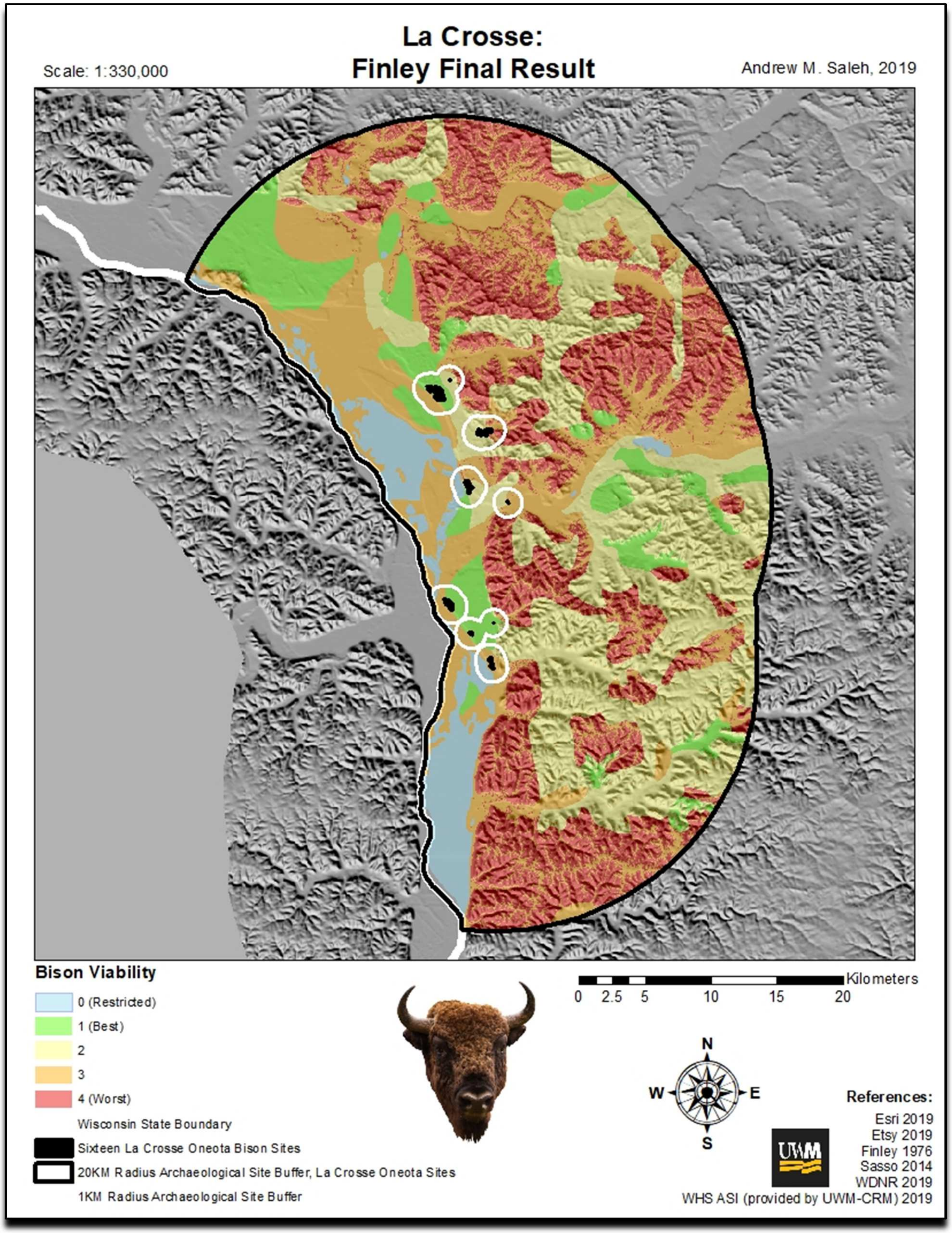
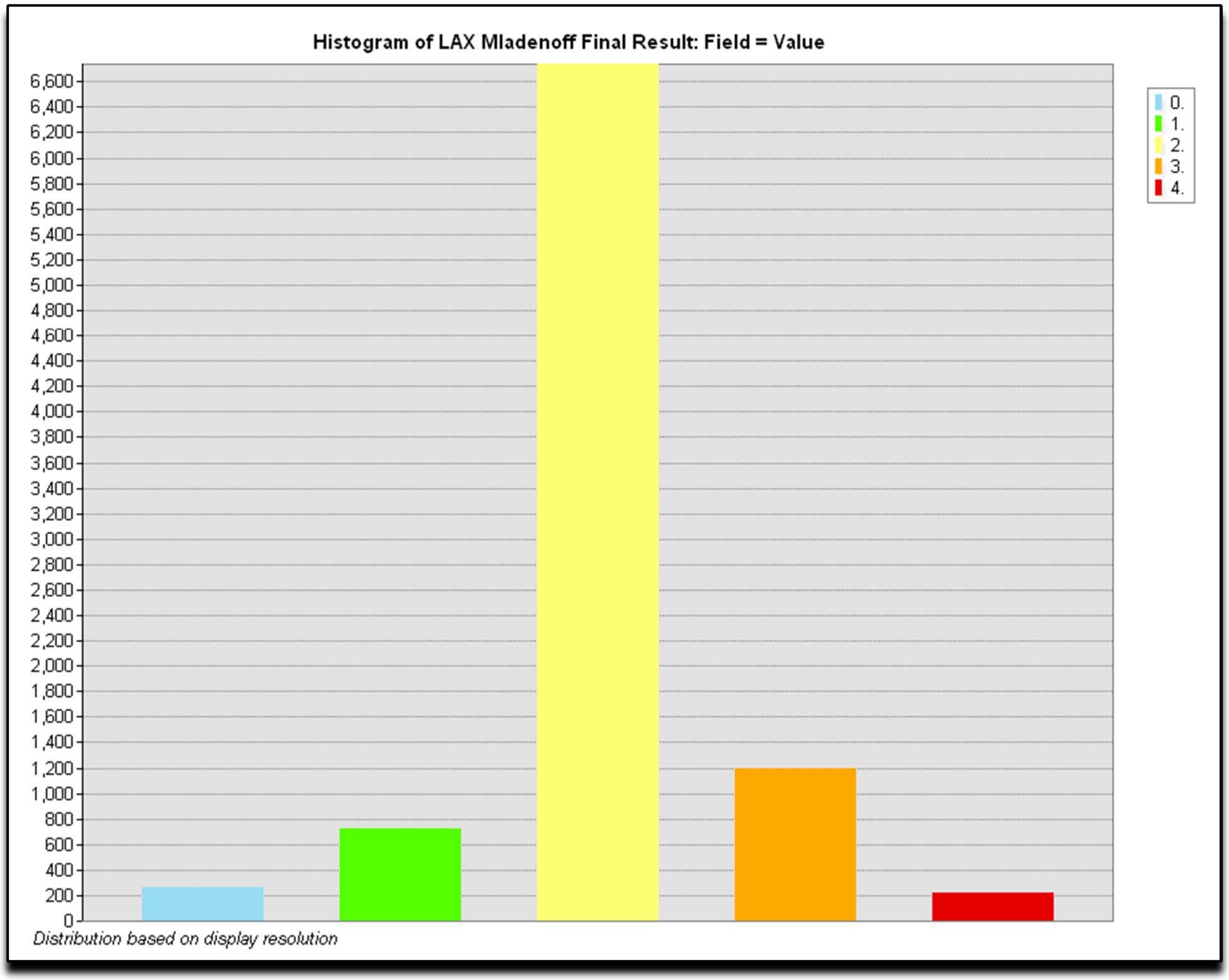
3	4581584
4	4226406



La Crosse:
Finley Final Result
Scale: 1:330,000
Andrew M. Saleh, 2019
Bison Viability
0 (Restricted)
1 (Best)
2
3
4 (Worst)
Wisconsin State Boundary
Sixteen La Crosse Oneota Bison Sites
20KM Radius Archaeological Site Buffer, La Crosse Oneota Sites
1KM Radius Archaeological Site Buffer
0 2.5 5 10 15 20 Kilometers
N
W
E
S
References:
Esri 2019
Etsy 2019
Finley 1976
Sasso 2014
WDNR 2019
WHS ASI (provided by UWM-CRM) 2019

Figure 4.13: Shows the same La Crosse catchment data using Mladenoff's vegetation. This figure presents the corresponding histogram and map. Comparing these with Finley's data we see that while Mlandenoff's data, like Finley's, shows high relative abundance of rank 2 habitats, it decreases the amount of rank 1, rank 3 and rank 4 habitats, resulting in an overall increase in the amount of the catchment adequate for bison. Unlike the Lake Winnebago catchment, using Mladenoff vegetation and Finley vegetation in the La Crosse catchments weighted landscape modeling produced much different viability results.



Value	Count
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2	12143440
3	2145601
4	402136

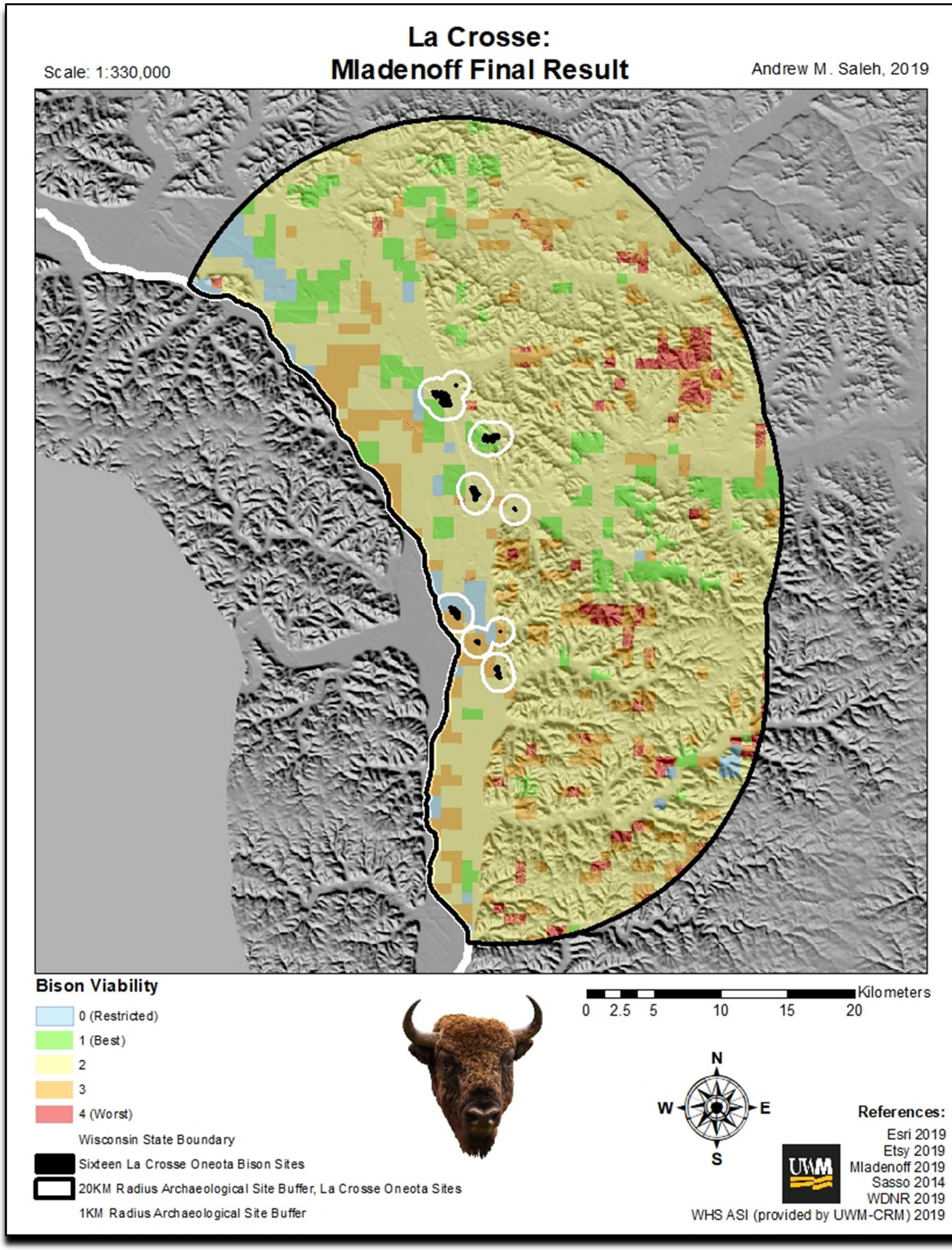
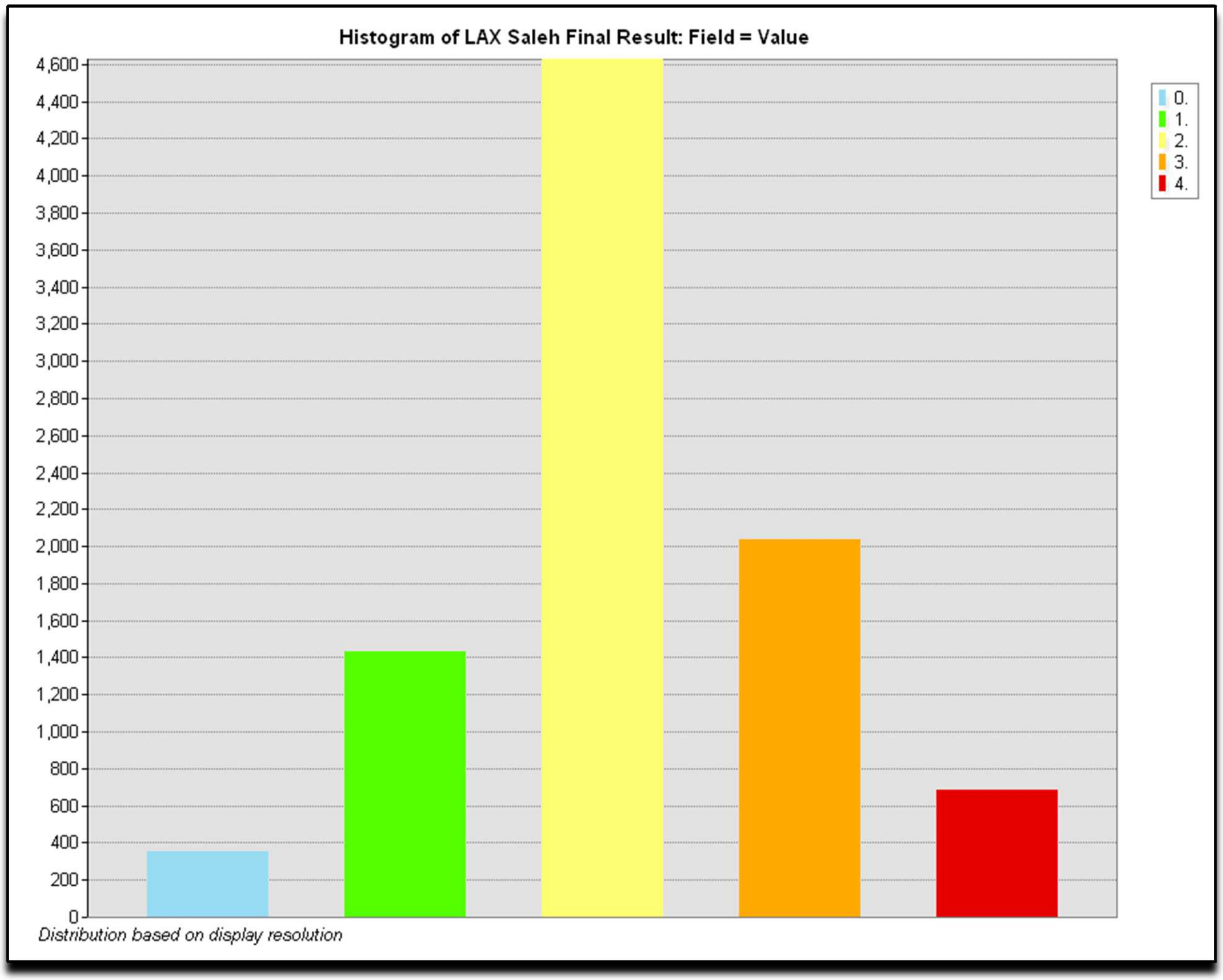
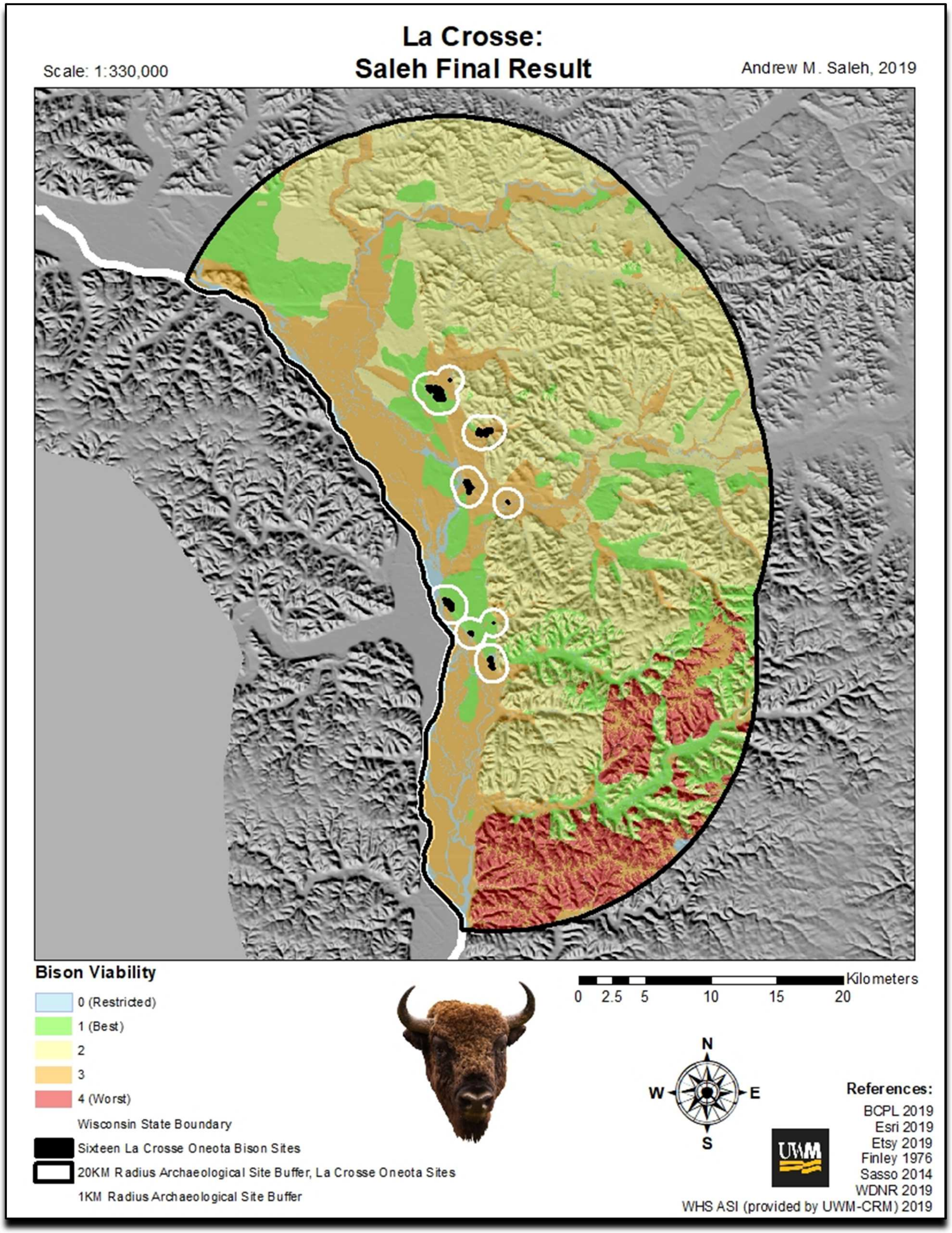

La Crosse:
Mladenoff Final Result
Scale: 1:330,000
Andrew M. Saleh, 2019
Bison Viability
0 (Restricted)
1 (Best)
2
3
4 (Worst)
Wisconsin State Boundary
Sixteen La Crosse Oneota Bison Sites
20KM Radius Archaeological Site Buffer, La Crosse Oneota Sites
1KM Radius Archaeological Site Buffer
Kilometers
0 2.5 5 10 15 20
N
W
E
S
References:
Esri 2019
Etsy 2019
Mladenoff 2019
Sasso 2014
WDNR 2019
WHS ASI (provided by UWM-CRM) 2019

Figure 4.14: Shows the La Crosse site catchment using Saleh vegetation data with the corresponding histogram. Unlike Finley (1951), the Saleh data did not incorporate additional factors such as barometric readings or soils. Unlike Mladenoff (2019), the Saleh data did not rely heavily on section by section tree counts either. Instead, the Saleh data made more direct use of the original surveyor maps and notes equally, without adding additional factors or numerical thresholds. The accuracy of prairies may be highest in this data set, as its categorical definition followed the original maps of the surveyors in coding them. The results in comparing the three datasets are quite similar from the rank 2 perspective. The Saleh histogram and map show a high amount of good (2) to best (1) bison viability visually and statistically. These figures continue to support the general idea that overall, as seen in all versions of the La Crosse area vegetation reconstructions, the rank 2 viability rank was quite prominent. It must be noted that accurate GLO non-vegetative features, waterways, wetlands, and inundated bottoms increases the power of landscape modeling.



Value	Count
0	643775
1	2561203
2	8321864
3	3656273
4	1228811



La Crosse:
Saleh Final Result
Scale: 1:330,000
Andrew M. Saleh, 2019
Bison Viability
0 (Restricted)
1 (Best)
2
3
4 (Worst)
Wisconsin State Boundary
Sixteen La Crosse Oneota Bison Sites
20KM Radius Archaeological Site Buffer, La Crosse Oneota Sites
1KM Radius Archaeological Site Buffer
Kilometers
0 2.5 5 10 15 20
N
W
E
S
UWM
References:
BCPL 2019
Esri 2019
Etsy 2019
Finley 1976
Sasso 2014
WDNR 2019
WHS ASI (provided by UWM-CRM) 2019

What did this exploration of the use of weighted modeling to combine the variables of terrain, vegetation, and water add to our evaluation of the two catchments as viable bison environments? Overall, it shows that the Lake Winnebago site catchment averages a majority rank of “3,” and the La Crosse site catchment averages a majority rank of “2.” In terms of bison viability, the simulation of terrain and vegetation into weighted landscapes helps show the La Crosse catchment is more favorable than the Lake Winnebago catchment. Although La Crosse bison viability is shown to be higher from a majority rank perspective, it must also be noted that there was a higher percentage of “4” (worst) values than Lake Winnebago in all simulations.

When the background of both catchments is considered, the local bison herd viability suggested by terrain and Finley, Mladenoff, and Saleh vegetation values mirror the bison remains frequency and representation. When these results are compared to other regional studies, like Nelson et al.’s (2007) combined GLO and pollen suggestions, they are shown to be less general and more refined geographically. The historic accounts of bison in southern Wisconsin are shown to be aided by the results of all three reconstruction approaches.

Terrain is noted to have impacted the La Crosse catchment more so than the Lake Winnebago catchment, and was a check and balance system versus vegetation. The percentage of slope influence was tested at different realistic percentages, and the simulation suggestions still showed the same general viability patterns. Although terrain’s impact was not extreme, creating a weighted landscape allowed for the easy quantification of site catchment patterns related to grazing on viable land.

Chapter 5: Summary and Discussion

The goal of this thesis was to explore the potential for local bison herds to have existed in prehistory within reasonable hunting range of Oneota villages in two localities in Wisconsin. The main conclusion is that multiple herds could have hypothetically existed within a local hunting range of archaeological sites in both thesis catchments that have produced bison remains. This thesis used GLO records from the mid-1800s to reconstruct vegetation patterns within twenty-kilometer La Crosse and Lake Winnebago area catchments. It compared three different approaches to coding the GLO, the Finley (1951, 1976), Mladenoff (2019), and Saleh (2019) reconstructions. Different GLO reconstructions led to different statistics and choosing how to categorize the reconstructions into ecological zones also affected comparisons. This thesis also added a consideration of the impact of terrain and water, first by simple visual inspection, and then with weighted landscapes built with a geoprocessing model constructed in Esri's (2019) Model Builder. It used the habitat parameters of a modern herd at the Nachusa Grasslands in Illinois to evaluate the suitability of the reconstructed environments for bison. The Nachusa herd is a breeding herd, with males and females, adults and young; it consists of approximately 85 individuals. This herd forages for itself year-round on approximately six-square kilometers of mixed habitat including prairie, forest, and wetlands.

All vegetation, waterway, and terrain considerations in this thesis show both catchments would be viable to bison herds in all scenarios. The percentage of the best bison landscape varies in its clustering and relation to the archaeological sites considered in this thesis. La Crosse is seen as a more viable landscape than Lake Winnebago, and this is supported by remain counts, remain utility considerations, and landscape viability quantifications. Other background information also supports the results in some ways; for example, bison site number frequency per catchment generally matches grazing land viability ratings. Beyond these general notions, more nuanced conclusions can be made; for example, viability combined with remain frequency may continue to favor trade as a more likely source of Lake Winnebago remains despite the statistics showing herds could exist within the catchment.

Using the Nachusa Grassland Bison Herd as a Model for Bison Needs:

At the most basic level, the most useful pieces of *local* information provided by this thesis are the quantified historic landscape patterns and the evaluation of the ecological suitability of the two Oneota site catchments. This makes the consideration of the model based on the Nachusa herd itself highly important. The herd is useful in that it is a free-range Midwestern herd in a reconstructed grassland with supporting scientific data such as isotopic results. Although the Nachusa Grassland herd is considered a quality case choice for this thesis, it is useful to evaluate alternative ideas about herd size.

Nowak (1999), in his review of bison species using Banfield (1974) and Lott (1974), suggests a healthy herd in an ideal environment could have around 57 individuals, mostly consisting of females, with a home-range of around 30 square kilometers in the warm season, potentially increasing to 100 square kilometers in the cold of winter. This represents fewer bison in more space than is true for the approximately 85 individuals over six-square kilometers at Nachusa. If we apply Nowak's (1999) statistics in the La Crosse catchment to a warm season range they show 55 Nowak herds compared to 273 Nachusa herds, based on acreage alone, without consideration of vegetation, waterway, or terrain. Nowak does not include data about percentage of prairie in his estimate.

We can also compare Nachusa with a modern Great Plains wildlife refuge. The National Bison Range in Montana is one of these refuges. It is a place where bison freely range over a larger landscape than Nachusa Grassland and have for over 100 years. Here, 75 square kilometers of a rolling plains landscape are available to 350-500 bison (Visit Montana 2019). The National Bison Range thus has 18-24 individuals per six-square kilometers, far fewer than the 85 bison at Nachusa. Not only that, but with up to 75 percent of the Montana refuge covered in prairie grasses of high C4 value, the amount of available prairie forage is higher in the National Bison Range compared to the estimated 50 percent at the Nachusa Grassland. Thus there is a lower density of bison grazing on a higher density of prairie land in Montana. Another way to view these data is to consider simply the amount of prairie land. Of the 75 square kilometers of National Bison Range land, 56 square kilometers is described as prairie. As an example, the Saleh GLO reconstruction shows 314.78 square kilometers of prairie available in the La Crosse catchment. That is to say enough prairie land for five or six times the number of bison in the Montana herd.

This comparison of the Nachusa model with two alternatives indicates that while both Oneota localities would remain viable for bison, the estimated numbers of bison would be less than those based only on the Nachusa herd. It is also worth noting that while the Nachusa model does not include natural predators, the herd is culled annually by people. A more sophisticated simulation might incorporate natural predators and might vary the role of human predators to better model the ecological dynamics of prehistoric hunting. Another issue that could be incorporated in future modeling would be seasonal migrations of herds.

Although these considerations make it clear that Nachusa is not perfect, combined with the GLO, the grassland's data is useful in showing the potential of what could have existed in the two thesis catchments in late prehistory. The isotopic information from the Nachusa bison herd is especially useful, as are the similarities of its mosaic Midwestern environment to parts of southern Wisconsin. Nachusa shows at the very least that multiple herds could exist within these catchments at the same time within clustered prairies or oak openings, as well as within the clustered good ("2") to best ("1") viability areas. Even if we applied other metric's such as Nowak's, the results relating to local herds would still show multiple herds could exist within the thesis catchments within range of human hunters. Overall, Nachusa's data are most useful in this regard. The role of winters, climate changes, intentional human burns to maintain grasslands, and the role of bison grazing in maintaining prairies or oak openings needs to be understood further in its relation to bison east of the Mississippi River, and using Nachusa as a scientific aid would be highly useful in this regard as well (Blackburn 2018).

Using GLO Notes and Maps to Model Prehistoric Vegetation:

This thesis begins to shed light on what the historic vegetation within twenty-kilometer site catchments of Lake Winnebago and La Crosse Oneota archaeological sites with bison remains looks like. These models use vegetation from approximately a decade after historic bison went extinct east of the Mississippi River (Hornaday 1887). Although quality state-wide general depictions of vegetation have provided us with atlas-style ecological information throughout the decades, a more precise version of what the GLO surveyors recorded can be produced with a GIS (Curtis 1959; Finley 1951, 1976; Mladenoff 2019; Prell 1989; Tanner and Pinther 1987; Ventura 1990, 2019; W.DNR 2019).

Although the GLO historic vegetation data can be useful, a quality reconstruction is needed. First, deciding how to quantify and match coding or spatial scales to a research question is imperative. If one wants to reconstruct their own GLO GIS data, it is highly recommended that the user practices not only using GIS software, but also interpreting GLO data; overall, expect to spend a lot of hours whether reconstructing or modeling. Further, there is a lack of what may be conceived as full-blown predator simulation, as it is an enclosed grassland, although the Nachusa herds are culled by humans. In terms of the thesis catchments and the Nachusa Grassland, although close, each environment slightly varies. For example, La Crosse is the only case used in this thesis' results from the Driftless Area. In terms of migration, bison at Nachusa Grassland cannot simulate this practice seasonally.

All of the GLO datasets used in this thesis have their own strengths. At the same time, they show different statistics. Although general patterns hold true across the datasets, the results show clear differences. One important difference is the choice of whether to reconstruct GLO waterways. This is a labor-intensive process but makes the dataset the most accurate. It is thought that a combination of the Mladenoff method, which recorded GLO tree density, and the method used in this thesis' reconstruction of the custom La Crosse layer, which reconstructed GLO waterways, is warranted in archaeological studies. Essentially, if GLO boundaries are not clear on plat or sketch maps, count how many trees there are within a quarter-section, and review the known surrounding zones. This way, instead of relying only on quarter-section densities, one can draw known boundaries first, and use densities as a back-up when plat and sketch maps fail the user. This allows wetland and waterway construction. In many places, coding the GLO runs into boundary issues statewide, and a combination of techniques may lessen this.

Another way to look at GLO-based environmental reconstructions is to evaluate whether they are more objective, meaning they rely directly on the original data, or more subjective, meaning they rely on additional types of environmental data and/or incorporate theoretical models about which sets of environmental variables are expected to co-occur and extrapolate from that to map likely vegetation zones. Both Mladenoff and this thesis use a more objective approach, relying more closely on what a surveyor observed. Finley, on the other hand, used a more subjective approach, combining GLO observations with ecological theory about which plants, soils, temperatures, and moisture should exist together.

Another issue in building environmental reconstructions from GLO data is spatial scale. Given the way the original data was recorded, one can choose to record details at the section or quarter-section scale, or at the township scale, and one can choose whether to read all the detailed notes or to rely on the plat and sketch maps that were created from those notes. Some studies may not require the finest possible scale. For example, at a state or national level, recording every waterway or wetland may not necessarily aid a vegetation study (Bolliger et al. 2004; Mladenoff 2019).

Aside from data quality and spatial scale decisions, using a GIS and organizing geoprocessing tools into a geoprocessing model with Esri's (2019) Model Builder is suggested by this thesis to be a productive way to apply geospatial data to reconstruct archaeological landscapes. At its core, a GIS relates and quantifies data and in archaeological studies, this can help clarify many aspects of a site or region. A GIS relies on quality data to produce quality maps and tables.

Using GIS to Analyze Catchments:

In terms of the data, the multiple GIS scenarios and simulations were meant to provide a critique for each other, but this does not make them perfect. It is recognized that taking a modern bison herd from a reconstructed grassland and applying it to historic vegetation and prehistoric site catchments makes certain assumptions and simplifications. One of these was the application of a twenty-kilometer catchment for clustered archaeological sites. Many of the sites used in this thesis have been shown to be home base style sites, but not all of them (Arzigian et al. 1989; Boszhardt 1989; Bullock 1942; Dirst 1985; Kreisa 1986; Peske 1966, 1971; Sasso 1993; Savage 1978; Sterner 2018; Theler and Boszhardt 2006; WHS ASI 2019). Twenty-kilometer catchments were chosen as appropriate for the combined analysis of local human hunting from clustered human sites and bison foraging or movement.

It is interesting to consider the impacts of using smaller catchments for a bison hunting model. Hypothetically, if twenty-kilometer catchments were reduced to ten-kilometer catchments, the viability estimates might actually increase. To highlight this notion, as an exercise, consider the land viability in the Lake Winnebago catchment results (Figures 4.10 and 4.11), and imagine reducing the size to ten-kilometers. Due to the clustering of better viability zones in the center and south of the catchment, the viability of the landscape would increase in terms of its potential to host local bison herds. In the La Crosse catchments, the Finley and Saleh statistics would change, and comparatively, the Finley dataset might show an even greater difference in viability versus the Mladenoff and Saleh hypothetical ten-kilometer results (Figures 4.12, 4.13, and 4.14). The time needed to repeatedly construct, process, and discuss all the weighting and catchment sizing potentials is seen as substantial, but in the future, the production of alternative results would help to create more refined suggestions on the Wisconsin bison topic.

This thesis still finds it useful to reconstruct and use historic GLO vegetation data. These maps, along with pollen samples, soils, the geologic record, or tree rings, are the best information sets in trying to decipher the prehistoric environment of the western Great Lakes (Finley 1951; Jeske 1990; Nelson et al. 2007; Palmer 1965). At the very least, they can show us patterns of potential. As this thesis notes, this land potential can be applied to a variety of research questions. At the same time, when we combine this data with other, more modern data, it becomes temporally skewed. For example, the terrain data and the vegetation data in this thesis were created over 100 years apart. As long as we recognize these issues, these data can still be useful.

The use of site catchment analysis to answer local hunting potential and bison land viability is seen as useful, but with caveats. Human lifeways do not sit within perfect circles. Further, Arroyo (2009) shows that there is no single rule about the distance that a hunter will travel in a day. Although many studies suggest using a ten-kilometer home base site catchment, this study enlarged this to twenty-kilometers to account for the unknown large-scale landscape relationship between prehistoric hunters and prehistoric bison subsisting over the same upper

Great Lakes landscape (Ebert 2004; Roper 1979; Wheatley 2004). Arroyo (2009) shows a hunter in a lowland setting could potentially travel over ten-kilometers in a straight line in much less time than a day. Schorger (1937) shows that historic Winnebago hunters may have traveled even further than twenty-kilometers to bison hunt in Wisconsin. Catchment size or shape is an important decision. The catchments used in this thesis are thought to cover more than enough land to answer its core question: could a local bison hunting hypothesis be supported within Oneota site catchments by historic accounts of vegetation, bison biological needs, and GIS modeling?

Revisiting Archaeological Models for Bison Acquisition in Wisconsin:

The research from this thesis adds a way to look at what prehistoric archaeological sites and historic landscapes can say compared to what we know about modern bison and terrain. More specifically, it adds a new line of evidence to show that local hunting near both La Crosse and Lake Winnebago Oneota sites could hypothetically exist and demonstrates multiple healthy bison herds could have potentially been available to late prehistoric Wisconsin residents.

Questions remain surrounding the topic though. For example, if herds could live in Wisconsin and herds did live east of the Mississippi River, why the lack of bison bone in archaeological sites? Some sites seem to have scapula only, while others show scapula and low utility meat elements, or low and high utility meat elements mixed together. Some sites in other states like Illinois and Kentucky (Lonza-Caterpillar and Big Bone Lick) show hunting and processing evidence, but nothing to this degree has been found in Wisconsin. These suggestions and more highlight another question, why does the patterning or amount of evidence of bison elements per site vary not only in Wisconsin, but east of the Mississippi in general? These are not new questions, and they continue in their validity.

More nuanced conundrums still exist as well. Using local and non-local analogic reasoning is tough for the Oneota in Wisconsin as “communal” bison hunting existed in Wisconsin history, but has little prehistoric evidence. It may be useful not to quantify or prescribe the style of hunt people were embarking on to groups before we have the unequivocal prehistoric evidence for hunt types and distances. Even the historic periods have problems. If we use Kay (1990) as an example, historic Winnebago hunting ranges covered much of southern Wisconsin year-round. Is the whole range local? Is every hunt within their land communal? Is local and non-local defined by modern state-boundaries? Does one trade on every hunt with another village? If an Oneota village hunts with another village from within the Lake Winnebago catchment versus another village from the La Crosse catchment, are both hunts communal? Is one of those a communal non-local hunt, while the other is a local-communal hunt? It was not the goal of this thesis to answer these questions, but they are important to how we conceive prehistory in southern Wisconsin in general.

The current debates about evidence for bison in the historic and prehistoric periods in Wisconsin warrant studies such as this one. The current lines of evidence suggest trade, non-local “communal” hunting, or local hunting may be the reasons we find bison remains in Oneota contexts at the Lake Winnebago and La Crosse localities. This thesis presents the idea of comparing distributions of high tool-utility scapula remains versus the remaining high and low meat-utility bones of a bison. Based solely on the remains, Lake Winnebago is said to more likely fit a trade or non-local model, while La Crosse potentially shows all three patterns. Although other parts of the animal could be used as tools, that is shown as rare in Wisconsin.

This thesis provides background evidence that all three modes of bison acquisition were potentially happening, and further contends that based on the remains patterning, this may have been the case at Lake Koshkonong and the Upper Mississippi Western Wisconsin locality as well. There are interesting parallels to this complexity of bison element site types in Illinois, as reported by Martin (2014).

Related to the two thesis site catchments, bones, historic accounts, rock art, lithics, effigy mounds, and accounts outside of Wisconsin all provide archaeological evidence in their own ways. Relying exclusively on any one skews an understanding of the topic. When we add refined GLO reconstructions as a new piece of the archaeological evidence, the viability of local bison herds around Oneota archaeological sites is seen as good. When we consider Widga's (2006a) Big Bone Lick information on Late Prehistoric Prairie Peninsula bison diets, as well the archaeological data from other western Great Lakes contexts, the Wisconsin archaeological record does not quite match the volume of remains one might expect when considering how easily bison could have hypothetically lived in places like southern Wisconsin.

Future Research Directions:

As questions still remain regarding this thesis' topic, other research options are possible for future lines of inquiry on bison in Wisconsin. These include revisiting faunal collections for missed bison bone, more use of protein residue studies, more use of isotopic studies where possible, and the introduction of strontium analysis on multiple bison specimens.

Lake Koshkonong seems ideal for applying isotopic studies to try to understand if bison were hunted locally. Non-scapula low utility meat remains have been reported and this suggests local hunting. Could strontium analysis confirm whether these bison were drinking local water (Saleh 2017)? This locality is also the southernmost in Wisconsin, so geographically speaking, it is also ideal, having best access to the northern boundaries of the Prairie Peninsula.

In the case of La Crosse, relating this conversation to Minnesota and Iowa is also seen as needing much more attention. The western side of the Mississippi River is argued as local to La Crosse Oneota, so tying the region together in terms of archaeological bone counts and site locations would be an ideal start. Sasso (1993) suggests the La Crosse Oneota locality can be conceived at around 650 square kilometers, with much of the locality located in Iowa and Minnesota. If this is the case, although time intensive, it could be useful to combine GLO notes and maps from all three states. A quick review of the I.DNR (2019), M.DNR (2019), and W.DNR (2019) pre-European settlement shapefiles and their metadata shows this task would have its issues in terms of connecting surveys, though it would still be possible. All of this data is publicly available too, and this would lead to quick manipulation by a skilled user. However, the accuracy or precision of the data would come into question. For example, Finley's subjective technique was not applied on the other public datasets. The GLO collection methods may warrant custom reconstruction, and it would take hundreds of hours to do this for the whole locality. Shea et al. (2014) have reconstructed the Driftless Area using methods similar to the Bolliger et al. (2004) and the Mladenoff (2019) data used in this thesis. Finding Driftless Minnesota and Iowa La Crosse Oneota sites with bison remains to combine with the Driftless Wisconsin sites would be useful as a comparative to this study. Shea et al. (2014) suggest over

70 percent of the Driftless Area in all states was Savannah (converted to Oak Opening in this thesis), which would be interesting to quantify compared to remain and site distribution.

A new more subjective-style GIS dataset similar to the one developed by Finley (1951) could conceivably be attempted within the study areas too. Soil rates and types could be quantified and updated per quarter section. This data is available at the bottom of most GLO survey note pages (BCPL 2019). For climate, the Palmer Draught Severity Index, could be considered and weighted into GLO vegetation data (Palmer 1965). Bison in the archaeological record are noted as being affected by climate stress, and this could strengthen the conclusions within the thesis study area catchments (Widga 1997).

In terms of GIS in Wisconsin, I think quantifying and mapping extinct bison and historic bison sites would also be useful. These would allow easier visualization of the temporal patterns of known bison remains. Ideally, these would be linked to climatic reconstructions and the changing extent of the Prairie Peninsula and grassland or savanna in general.

In terms of creating a better model for viable environments for bison, extracting actual modern grassland geospatial information to pull land cover from places like the Nachusa Grassland in Illinois and the National Bison Range in Montana would be ideal, as these could then be quantified in relation to GLO reconstructions within archaeological site catchments. Other aspects of the dynamic nature of bison ecology could also be integrated into modeling, including predation rates by human hunters and non-human predators, and seasonal and climatic migration impacts on herd health and location. Based on the time it took to model and reconstruct in this thesis, this may take hundreds of hours.

Further considering anatomical utility of bison could prove useful. For example, what could applying a comparative general utility model (Hudson 1993:142) to the remains reported by Sasso (2014) suggest if implemented? Ribs are well documented as being quite common compared to other elements at full-occupation sites on the plains, and these are currently identified as recovered from archaeological sites within the La Crosse study area catchment in low numbers (Bamforth 2007:206; Sasso 2014). Ribs and femurs are noted as having the highest food utility when considering bison specifically, yet these elements are relatively rare in Wisconsin archaeological sites. If low food utility elements are found as often or more often than high food utility elements, what human behaviors were bringing them into the sites? And what is the best way to model the very abundant high tool utility scapulae, which appear to occur both alone and in combination with other elements? Is their story more complicated than simply representing either the source or the destination of a valuable trade item? These questions and more could be explored further when considering the aspects of the general utility of individual elements. For example, how much meat, marrow, or tool use can one gain from a particular bison element, and what does this say about the element's appearance at an archaeological site and site-type?

Finally, what if there was a way to apply a potential human population statistic as a part of the catchment weighting? This might include human population density estimates. Theler and Boszhardt (2006) suggest human populations in the La Crosse area would have been large enough to affect how local bison herds occupied the landscape with an applicable metric. Other authors have suggested that the risks of inter-group violence affected Oneota subsistence and settlement systems (Edwards IV 2017; Koziarski 2012; Sterner 2018).

This thesis can echo what others have suggested: Wisconsin essentially needs an Oneota bison kill site within a certain proximity of a home base, or a seasonal camp near a home base, to tie most of this together and confirm it (McQuin 2010; Sasso 1993, 2014). Historic accounts prove these animals have subsisted in Wisconsin, with areas as far east as Lake Winnebago near modern Wild Rice Lakes described in the 1800s as "great buffalo ranges" (Schorger 1937:47). The faunal record may also benefit from a more comprehensive review of the collections themselves. As an example, Sasso (2014) alludes to the fact that Hall's (1962) Carcajou Point (at the Lake Koshkonong Oneota locality) faunal collection has yet to be reanalyzed and is reported to contain up to 7.5 percent bison or elk remains. Reviewing large mammal remains for identifications that may have been missed or left uncounted from some sites outside of the La Crosse area generally seems warranted. At any rate, the lid on the bison in Wisconsin "can of worms" has been opened slightly further with this thesis, and it hopes to inspire future research directions.

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Appendix A:

La Crosse Custom Data Collection GLO Township by Township General Summation

Due to the fact that the GLO notes can have some variance, a township by township commentary is provided below for the La Crosse study area in terms of my vegetation coding. This provides a deeper understanding of the procedure of going from the details of primary data – the GLO notes – to my digitization of the maps into four basic categories of plant coverage. This translation process was based on extensive reading and deciphering of plat maps, sketch maps, and surveyor notes from the PLSS GLO provided by the BCPL (2019) in what are now the modern counties of Trempealeau, La Crosse, and Vernon in Wisconsin.

The northern most township of the study area was T19N. This township was defined by the range T19N/R09W-T19N/R06W. Due to the fact that the twenty-kilometer study area buffer ended within T19N, no township had all thirty-six sections included in the analysis. The major waterway that is mapped within T19N is the Black River. Excellent, fair, or poor was an easy way to classify descriptively what I viewed. These descriptions relate to the quality of the collected GLO data, and is considered throughout Appendix A. These are judgement statements, and not highly systematic. The overall sketch map and field notes translation into the four plat maps that were drawn from T19N was considered fair, with no major errors. This was measured against the rest of the study area's notes and maps. Compared to the rest of the La Crosse study area, the plat maps matched fairly, but vegetation geographic boundaries in the notes were not necessarily always mapped. Further, the sketch maps created by the original surveyors lacked key word language. The only time this presented an issue was in deciphering

“Oak Barrens,” “Oak Openings,” “Scattering Timber,” or any other term relating to regions outside of bottoms or prairies. Defining where this “scattered timber” may thicken into a “timber” forest was hard in this region, and the soil was generally noted as second to third rate on a one to three scale (BCPL 2019). Bottoms were wet and swampy in T19N, and as will be clearly noted with the rest of the study area, I noted these as blanket wetland vegetation areas due to reported inundation, their proximities to waterways, and the dynamism of the Driftless area Mississippi River valley (Knox and Mickelson 1974).

Some prairies entered bottoms, and were possibly wet at the time of the survey. White, black, and burr oak were highly dominant in terms of tree cover for T19N in all ranges. The dominant vegetation classification within T19N was “scattered timber,” as is shown in the results section. Some noted undergrowth included prickly ash, ash, vines, and oak. Some bluffs were noted, and the conceived “null data” in the results included a historic road to Black River Falls, Wisconsin, and the “Douglass” saw mill.

In descending order, the next township analyzed within the twenty-kilometer study area was T18N. The ranges considered within this township included T18N/R09W-T18N/R05W. Most of the sections were used, except for in T18N/R05W, where the study area catchment buffer just captured data within this T18N range. T18N/R09W along the Mississippi River actually captures the western bank of the river, which is variable in Wisconsin GLO notes (BCPL 2019; Meyer 2018). As usual, nothing was made of the Minnesota side vegetation or elevation besides where the Mississippi is located geographically. Besides the Mississippi, the Black River is the main waterway within T18N. Roads to Black River Falls and “Prairie La Cross” (now known as La Crosse) Wisconsin are a part of the “null data” digitization result within T18N, as well as a

Mississippi River boat landing, and river houses within the Mississippi River bottom. The location of these houses means, at some point, whether seasonally or not, bottoms could also be quite dry within the study area. Overall though, inundation up to six feet was noted within some bottoms. Some wetlands were present, but due to the fact that most bottoms were wet too, T18N could be considered especially dynamic in terms of vegetation. Overall, the theme is the same. Oak openings, barrens, or scatterings are associated with any mentions of the dominant black and white oak timber on sketch or plat map notes in every range except for T18N/R08W. Although timber may have thickened in this region, overall, there is no indication of this geographically. In general, the only study area thick timber that is noted and sketched does not appear until T14N. T18N/R09W has an especially large prairie section that continues out of the study area. In general, the further east the surveyors went, the less open the land seemed. T18N/R06W clearly states how scattered the white, black, burr, or jack oak was, and in these regions, the W.DNR (2019) notes that up to sixty percent of the vegetation within these openings would indeed have been prairie grass. When I aligned T18N custom data with the precise quarter section UW-Madison dataset (Mladenoff 2019), this was also apparent from the density classification, as this can be seen by the “savannah” category in the results below. T18N supports a landscape that is generally dynamic, with valleys and flat areas intermingled within ever-changing flooding zones. Oak seems to be the dominant tree type, with others appearing here and there. Willow was documented from time to time, for example.

The next township of the study area was T17N. The ranges considered within this township included T17N/R09W-T17N/R05W. All sections were used with the exception of some within T17N/R05W. T17N/R08W’s notes provide a perfect example of surveyor disconnect.

Bottoms from T18N/R08N and T17N/R07W are no doubt in T17N/R08W, especially considering it graces the Mississippi River; yet, they appear incomplete in surveyor notes, and the bottom area was altogether missing from the plat and sketch maps (BCPL 2019). For the purposes of my study, this area is conceived as part of the dynamic Mississippi river bottom, which constitutes the giant western wetland and bottom combined vegetation regime that runs the length of the custom dataset within this thesis in the results below. Further, the township notes “timber” and a “timber grove,” as does T18N/R08W, yet was surrounded by maps and notes noting scattering timber with known geography. This “scattered timber” to “timber” thickening may have occurred within T17-18N then, but the overall presence of scattered timber cannot be denied either based on the GLO notes (BCPL 2019). Overall, the soils were mostly second to third rate and sandy. Mississippi River bluffs were noted as far east as T17N/R07W. Native trails, historic Euro-American trails, and giant rock outcrops made up most of the null data, as well as the missing Minnesota data. The Black and “La Cross” or La Crosse Rivers are within T17N in the twenty-kilometer study area buffer. Again, willow was found in a bottom. Although other minor species such as aspen, maple, birch, cottonwood, and willow exist in T17N and others, overall, black and white oak seem to be the dominant tree species. The general picture was that of an oak savannah that becomes hillier and more open as one hits the Mississippi River bottom (BCPL 2019; Mladenoff 2019). Of importance to this study, many sites with bison remains from the Classical La Crosse Oneota phase (AD.1300-1650) are located in T17N/R07W. These sites are not only tied together temporally and geographically via space and artifacts, but also, via a fairly extensive trail network that was discovered as a biproduct of this thesis.

Whether by river or trail, the whole study area is essentially connected with a path. The results support this further.

The next township within the study area catchment was T16N. The ranges considered within this township included T16N/R08W-T16N/R05W. All sections were used with the exception of some within T16N/R05W. T16N marks a study area boundary of GLO note differential at its southern boundary. Essentially, the plats, sketches, and notes do not properly align with T15N, where things are somewhat inaccurate and poor in general. The first study area “tree grove” that was able to be mapped as “timber” appeared in T16N/R06W. These became ever present in T15N. The main waterway within this region besides the Mississippi River was the La Crosse River. Oak scatterings, prairies, and bottoms were clearly distinguished in T16N. An extensive road network, and the north half of “Prairie La Cross” the historic town appear as “null data” within the results section, as well as large rock structures. Two study area archaeological sites appear in T16N/R07W. T16N/R06W notes that some of the bottoms were filled in with water during the survey, which supports the collection technique of considering bottoms as dynamic wetland areas or dynamic wet prairies subject to inundation. Within the GLO section line notes of sections 7-8, one can find “scattering” within T16N/R05W (BCPL 2019). Continuously, this study’s data collection consistently found this type of vocabulary, but this range represents the last range where this was absolutely clear-cut. Notes and maps made sense in terms of just viewing one township, and were considered fair. Further, if it was the right season, surveyor, or year, many townships could successfully align with little survey error. Starting with T15N/R05W, a prime example of where townships do not align becomes readily apparent (BCPL 2019). Essentially, anyone can go into the BCPL (2019) database, download these ranges, and try to align them geographically and with notes. Further, many people would produce different digitization results post georeferencing and studying these ranges. Overall, this study still contends that the GLO was highly useful in many ways, and that misalignment can be refined further with note parsing and data editing, by multiple individuals if necessary, to come up with a better dataset.

The next township of the study area was T15N. The ranges considered within this township included T15N/R07W-T15N/R05W. Most sections were used, except for in the easternmost R05W. The “Mormon” and “Racoon” Creeks were the largest waterways in T15N besides the Mississippi River. “Prairie La Cross” is in the northwestern corner of T15N/R07W. It is interesting to view the WHS ASI versus the GLO native and historic trail locations. This region was easily traversable by water or via land trails that enter and exit favorable terrains. In terms of tree species, black and white oak continue to dominate the list. Any indication of true township alignment throughout the study area takes a hit in T15N, and this is noted as a trend in Wisconsin by other scholars (Bolliger & Mladenoff 2005). True forest density was also hard to quantify township to township, but somewhere in T14N/R06W the forest notably thickens, with some boundaries and notes (Cogbill et al. 2018). “Tree groves” and “thick timber” are mapped in R05-06W in T15N, and the sketch map quality in T15N and 14N are the highest within the study area. The tree density was also noticeable in the tree counts within T15N’s surveyor section-line notes. In fact, the sketch maps had too much vocabulary on them to the point of convolution, almost too excellent. Further, townships in T15N have prairie colorations on plat maps within them but are intermittently labeled barrens or prairies on the sketch maps. The BCPL (2019) GLO notes for T15N within the twenty-kilometer La Crosse study area switched from reporting entering prairies to simply reporting when one enters and exits timber, no matter how scattered. Essentially, excellent sketch maps exist in T15N, but surveyors are mixing up barrens and prairies, which leaves the plat maps and notes ranked as poor.

Further, it was apparent that surveyors had different techniques in T15N. Oak openings are next to barrens, for example (BCPL 2019). Overall, the mapped bottom and wetland areas in these maps are noted as drier than the townships to the north. It was no surprise then that a historic road runs through some large bottom areas. This also happens in T16N/R07W, and it was a further hint at how dynamic the region could be. Seasonal flooding near the Mississippi River is and was common, especially when considering the second and third rate sandy soils, bluffs, and rivers stemming from the Mississippi with associated creeks and springs. In terms of prairie, the geographic regions especially targeted in relating the GLO to bison, the historic town of "Prairie La Cross" sits at the edge of a huge prairie bottom, and many acres of prairie exist east of this in other ranges within T15N. T15N generally lost tree density as it went west towards the river. Besides roads and trails, farm fields and historic structures made up the null data in T15N. This was all translated to the data in the results, and the decision had to be made on bottom labeling, timber boundaries, and prairie misalignment between T16N/R05W and T15N/R05W. T15N was the southernmost township where Oneota WHS ASI sites occurred with bison remains as of 2014 (Sasso 2014; WHS 2019). Trails clearly linked these sites in a smooth prairie environment near the Mississippi River. T15N supports using density classification by quarter-section instead of drawing out plat map boundaries, shown in the results section. Due to the multiple ways to collect GLO data, sometimes the thesis technique was better within a catchment, yet other times the Mladenoff (2019) lab techniques are better. Regardless, these maps were and are only accurate to a point, and the thesis methodology uncovers this to align with previous literature (Bolliger & Mladenoff 2005; Cogbill et al. 2018).

The next township of the study area was T14N. The ranges considered within this township included T14N/R08W-T14N/R05W. Most sections were used, except for in the easternmost R05W. T14N was quite similar to T15N in that it continued the oak trend, while also containing mystery timber boundaries. Somewhere in T14N/06W a thickening of the "timber" into a southern study area forest seems to occur, shown in the results. For example, if one goes through the GLO section-line notes of T14N/06W, it will be evident along sections 2-11, 5-8, and 6-7 that timber goes from thick to scattered. Further, on the sketch map for T14N/R07W, it was clear the timber became scattered at some point. This was and is an example of why, if one wants to conduct and independent GLO GIS study, one must balance plats, sketches, and notes while also understanding that at times, even this may not be enough. In terms of terrain, the surveyors noted how hilly some areas became. It is assumed that hills, bluffs, and "mountains" are relatable within these notes township to township. Willows were found yet again in T14N. Although unmapped, a willow thicket even existed along the section 26-27 line in T14N/R07 (BCPL 2019). The biggest question area to the collected study area data comes from T14N. Essentially, many note pages contain question marks at the bottom, relaying that the historic surveyor essentially made some stuff up, or estimated. This left the ranking of the notes for this section as poor. This was apparent even in the way trails and roads do not align in places. Overall, based on the notes, the UW-Madison ecology lab's approach seems highly sound for T14N (Mladenoff 2019). The "Raccoon" Creek is the dominant waterway in T14N besides the Mississippi River. The null data within T14N are roads and trails with some large rock outcrops noted. It could be said that if one were to conduct an independent study on T14N within this project area, one should digitize sketch maps and only use the notes on those. Further, the townships are used best solo. This was and is the case with every township in the GLO essentially, but it was especially the case with T14N and T15N in this study. Overall, this contributed to the production of the results, and the collection method was followed as best as possible to align with the study area as a whole.

The last and southernmost township of the study area was T13N. The ranges considered within this township included T13N/R07W-T13N/R05W. Not many sections were mapped from T13N. As noted by the publishers of the original maps and notes, T13N represents a shift of survey style. County boundaries seem to have nothing to do with the survey shifts in the study area, as these maps were mapped just before Wisconsin's statehood. The sketch maps have zero writing on them, which is a far cry from the sketch maps in T14N-15N, leaving them with a poor ranking (BCPL 2019). The notes lack major language, and the plats did not have much in the way of linkage to T14N, and they were also viewed as poor.

Therefore, the maps from T13N were read as a continuation of the timber zone from T14N. Overall, based on the notes, it seems at times the timber scatters. Again, this is difficult to gauge. The Mississippi River's Western bank in Minnesota oddly got picked up and mapped again in T13N. The only null data in T13N was a large historic field. Besides the Mississippi River, the North Bad Axe River watershed just graces the southern buffer boundary in T13N/R06W. The bottoms were not noted as particularly wet in T13N, but they were none-the-less merged with wetlands to avoid confusion. This township could be conceived as a scattered timber region if one were able to find the unmapped boundaries. This study tried to find some sort of boundary but could not. The density class UW-Madison collection technique was suggested yet again for T13N in the results. The main tip to showing the errors between T13N and T14N occur in the northwest corner of T13N/R06W, where a prairie seemed to indiscriminately disappear from the region.

Appendix B:
Thesis Esri (2019) and GIS Adapted Terms and Concepts Table

Adapted Esri Terms (2019):	**Adapted Esri Definitions (2019):**
Editor Toolbar	Allows a user to edit and create attributes and geospatial data within a shapefile or geodatabase file. For example, while editing, one can draw new geospatial data, or merge data within the same set.
File Geodatabase	Usually contains related data. One can manipulate properties and create domains within databases. These have the ability to store vector data, raster data, toolboxes, and models.
Geoprocessing Tools	Esri tools that allow a user to manipulate geospatial data with mapping functions: for example, clipping data within a boundary.
Geoprocessing Tools used in this Thesis	Clip (raster and vector), buffer, merge, polygon to raster, slope, reclassify, and weighted overlay.
Georeferencing Toolbar	Most notably allows a user to use a set of control points to tie a raster to a known set of geographic points, such as township corners.
GIS	Most commonly known as a geographic information system.
Histogram	Can be produced with the spatial analyst toolbar, displaying pixel counts derived from a raster in bar-graph form.
Model Builder and Toolbox	Functions in ArcCatalog/Map. They allow a user the ability to link Esri Geoprocessing tools to generate data. Tools and models are stored inside geodatabase toolboxes.
Shapefile/ Geodatabase File	A shapefile is geospatial vector data tied to a set of attributes, such as the WHS ASI. A geodatabase file is an Esri formatted shapefile tied to a database.
Spatial Analyst Toolbar	Allows a user to analyze raster data with histograms and contours.
Vector or Raster data	Vector data are points, lines, polygons. Raster data are pixels with certain values.

Appendix C:

Final Results Geoprocessing Tool and Modeling Parameters

The figures provided in Appendix C follow the order of the final weighted land viability maps in Chapter 4's results. The tables come directly from Esri's (2019) "weighted overlay" tool and shows how vegetation codes and terrain values are given ranks. These ranks relate to the vegetation types and slope percentages.

Weighted overlay table

Raster	% Influence	Field	Scale Value
LWFinley1Rast	75	Value	↶
		0	Restricted
		5	4
		6	4
		7	4
		8	4
		9	4
		10	4
		11	2
		12	1
		14	3
		15	3
		16	3
		99	Restricted
		NODATA	NODATA
LWDEMReclas	25	Value	↶
	LWDEMReclass1 (2)	1	1
		2	2
		3	3
		4	4
		NODATA	NODATA

Finley Lake Winnebago.
Shows raster entry column and raw codes as examples.

Weighted overlay table

% Influence	Field	Scale Value
25	Value	↶
	1	1
	2	2
	3	3
	4	4
	NODATA	NODATA
75	denclass	↶
	sav	2
	clf	4
	opf	3
	ope	Restricted
	pra	1
	NODATA	NODATA

Mladenoff Lake Winnebago.

Weighted overlay table

% Influence	Field	Scale Value
25	Value	⤺
	1	1
	2	2
	3	3
	4	4
	NODATA	NODATA
75	Value	⤺
	0	Restricted
	9	4
	10	4
	11	2
	12	1
	13	2
	14	3
	15	3
	16	3
	NODATA	NODATA

Finley La Crosse.

Weighted overlay table

Raster	% Influence	Field	Scale Value
LAXDEMReclas	25	Value	⤺
		1	1
		2	2
		3	3
		4	4
		NODATA	NODATA
LAXMladenoff1	75	denclass	⤺
		sav	2
		opf	3
		ope	Restricted
		clf	4
		pra	1
		NODATA	NODATA

Mladenoff La Crosse.

As an example, the DEM and vegetation column are shown. They are entered similar for Finley, Mladenoff, and Saleh reconstructions, and all values relate to the adapted result tables from Chapter 4. Although open forest was considered in forest acreage, as the exception due to tree density, it is ranked the same as wetlands in modeling.

Weighted overlay table

% Influence	Field	Scale Value
25	Value	⤺
	1	1
	2	2
	3	3
	4	4
	NODATA	NODATA
75	Vegetation	⤺
	2	2
	3	1
	0	Restricted
	4	3
	5	Restricted
	1	4
	NODATA	NODATA

Saleh La Crosse.