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THE CENTER FOR GREAT PLAINS STUDIES is a regional research and teaching program established in 1976 at the University of Nebraska. The mission of the Center is to foster the study of the people and the environment of the Great Plains.

- A sparsely-populated region with highly variable weather set against grassy, rolling land, the Great Plains stretches westward from the Missouri River at Omaha and Kansas City to the Rocky Mountains, and northward from the Texas Panhandle into the Canadian Prairie Provinces.
- The region invites inquiry into the relationships between its natural environment and the cultures brought to it by its various inhabitants, as scholars and residents work both to preserve healthy eco-systems and build thriving human communities.

GREAT PLAINS RESEARCH is a peer-reviewed, biannual, multidisciplinary science journal, which publishes original research and scholarly reviews of important advances in the natural and social sciences with relevance to the Great Plains region and with special emphases on environmental, economic, and social issues. It includes reviews of books.

Articles include:
- original research findings, such as have been published in GPR since 1991;
- synopses of the “state of the science” on topics relevant to the Great Plains;
- overviews of critical environmental, economic, and social issues for the plains;
- reviews of knowledge on important questions and their regional application; and
- syntheses and cross-disciplinary analyses relevant to the Great Plains.

Great Plains Research is indexed or abstracted in America: History and Life, BIOSIS Previews, Biological Abstracts, Environment Abstracts, Historical Abstracts, Geographical Abstracts and GEBASE, Meteorological and Geostrophical Abstracts, and CSA Sociological Abstracts, Inc.

The editor encourages those submissions in particular that report general findings in the sciences relevant to this vast region. Articles should include thoughtful reviews of critical scientific findings and issues relevant to the Great Plains, whether the research was done in the Great Plains or not. The key to acceptance will be how well the findings are related to the region, and how well the science is communicated to other scientists outside the specific discipline, in the style of Scientific American, for example. The Board of Governors’ Publication Committee will select annually the best paper in natural sciences and the best paper in social sciences. The author/s of the winning papers will be presented cash prizes for the Charles E. Bessey Award (natural sciences) or the Leslie Hewes Award (social sciences).

Scientists doing interesting work with important implications for this region are invited to synthesize their significant research results and present them to our readers. The overall goals are to develop Great Plains Research as a centralized outlet for science of regional importance, to communicate important scientific findings to as wide an educated audience as possible, and to help keep scientists, interested citizens, and leaders of this region up-to-date on scientific progress relevant to the Great Plains.
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The Center for Great Plains Studies

congratulates

Robert Diffendal

on his completion of nine successful years as

Editor of *Great Plains Research*

and

welcomes

Gary Willson

on his appointment as the new

Editor of *Great Plains Research*
AQUATIC INVERTEBRATE COMMUNITY STRUCTURE IN THE NIOPRARA RIVER, AGATE FOSSIL BEDS NATIONAL MONUMENT, NEBRASKA, 1996–2009

David E. Bowles, David G. Peitz, and J. Tyler Cribbs

Heartland Inventory and Monitoring Network
U.S. National Park Service
Wilson's Creek National Battlefield
6424 West Farm Road 182
Republic, MO 65738
david_bowles@nps.gov

ABSTRACT—Aquatic invertebrates were sampled annually in the Niobrara River, Nebraska, during the period 1996–2009 using Hester-Dendy multiplate samplers. Collections indicated the invertebrate community in the river has shifted from one dominated by Ephemeroptera, Plecoptera, and Trichoptera (EPT) taxa to one dominated by Chironomidae and Amphipoda. Generally, EPT richness and percentage abundance of EPT of the total community, as well as percentage abundance of Heterageniidae and Leptophlebiidae, has declined across the years. During that same period, percentage abundance of Amphipoda and Chironomidae, taxa evenness, Shannon's Index, and the Hilsenhoff Biotic Index have increased. Stream discharge decreased significantly during the 15-year period when invertebrates were collected (Mann-Kendall trend test, \( P = 0.04 \)). Water-surface elevation of the river measured with staff gages also gradually increased over time, although the trends were not significant \( (P \geq 0.15) \). Although not analyzed statistically, water temperature (°C), conductivity (μS/cm), and pH gradually increased over time while dissolved oxygen concentration (mg/liter) decreased over time. Although other factors cannot be ruled out, a proposed reason for the observed changes in invertebrate community structure may be related to changes in the physical habitat condition in the Niobrara River associated with encroachment of the nonnative and invasive emergent aquatic plant, yellow flag (Iris pseudacorus L.). This weed has expanded into the stream channel, where it blocks streamflow.

Key Words: aquatic invertebrates, Niobrara River, Nebraska, Iris pseudacorus

INTRODUCTION

Agate Fossil Beds National Monument (AGFO) is located within the shortgrass and sandhills prairie along the Niobrara River Basin in northwestern Nebraska, and it is part of the Western High Plains ecoregion (Omernik 1987). Approximately 6.4 km of the Niobrara River flows through AGFO. The Niobrara River originates 105 km northwest of AGFO near Lusk, WY, and flows 725 km eastward to its confluence with the Missouri River. Agate Springs, located near the western boundary of the AGFO, provides substantial inflows to the river in this reach. The Niobrara River flowing through AGFO is listed on the National Rivers Inventory, which requires the National Park Service to study its eligibility for possible inclusion in the Wild and Scenic Rivers System. Therefore, water quality, channel condition, and biotic integrity of the Niobrara at AGFO are of chief importance to its natural resources managers.

Benthic aquatic invertebrates are an important biological tool for understanding and detecting changes in stream ecosystem integrity. They can be used successfully to reflect cumulative anthropogenic impacts that cannot otherwise be detected through traditional water quality monitoring such as water chemistry analysis (Bass 1994; Harris et al. 1999; Whiles et al. 2000; Fries and Bowles 2002; Hall et al. 2003). Furthermore, because changes in diversity and community structure of benthic invertebrates reflect the overall integrity of a stream, they are relatively simple to communicate to resource managers, administrators, and the general public. For these reasons, the U.S. National Park Service (NPS) began monitoring aquatic invertebrates in the Niobrara at AGFO in 1988 to assess stream integrity (Boyle et al. 1990).

Although the initial sampling was done in 1988, Peterson (1996) considered 1989 as the "baseline" year because it was the first year with reasonably thorough sampling (Peterson et al. 1999). Harris et al. (1999) summarized the preliminary data collected in 1989 in a broader analysis of prairie streams. No monitoring was conducted from 1990 to 1995, but monitoring has been conducted annu-
ally since 1996. Peitz and Cribbs (2005) further analyzed and summarized aquatic invertebrate sampling data at AGFO from 1989 through 2004. This report examined the condition and trend of the aquatic invertebrate community in the Niobrara River at AGFO from 1996 to 2009 to determine if any impairment to the resource occurred during this time period.

METHODS

The Niobrara River at AGFO (42°25'9"N, 104°2'41"W) is a low-gradient stream about 3 m wide and less than 1 m deep, and it contains copious amounts of in-stream aquatic vegetation and has predominantly sand and silt substrates. Invertebrate sampling was done from 1996 to 2009 at three locations on the Niobrara River at AGFO, each separated by a distance of approximately 3 km (Fig. 1). Invertebrate sampling methods and procedures followed Peterson (1996). At each site, five Hester-Dendy multiplate samplers (0.09 m² surface area) were deployed for approximately 30 days, with samplers being clumped as a group (Bowles et al. 2008). Hester-Dendy samplers were selected for use over other sampling methods because of the soft substrate in the Niobrara River. Samplers
were deployed monthly during a summer index period of July, August, and September 1996–2007, but only in July during 2008 and August during 2009. In some years, not all deployed samplers were retrieved due to flooding and other disturbances. Invertebrates were identified to the lowest practical taxonomic level (usually genus) and counted. Examples of all taxa identified in this study are deposited in the NPS Heartland Inventory and Monitoring Network reference collection.

Invertebrate metrics calculated from the data included taxa richness; taxa diversity (Shannon's Index); taxa evenness; Ephemeroptera, Plecoptera, and Trichoptera (EPT) richness; and the Hilsenhoff Biotic Index (HBI) (Barbour et al. 1999; Bowles et al. 2008). Additional taxa-based metrics, including percentage abundance of Chironomidae (Diptera), EPT, Heptageniidae (primarily *Heptagenia diabasa*), Leptophlebiidae (Ephemeroptera), *Cheumatopsyche* (Trichoptera), and Amphipoda (Crustacea), were included to assess their respective contributions to overall taxa richness. Percentage abundance of EPT, Heptageniidae, and Leptophlebiidae of the total community were used because members of these groups generally are intolerant of anthropogenic stressors. Conversely, percentage abundance of Chironomidae, *Cheumatopsyche*, and Amphipoda were included because these taxa are generally tolerant of certain stressors, and indicative of disturbance. Because chironomids (Diptera: Chironomidae) were not identified to genus in all years, they were analyzed at the family level. Tolerance values used for taxa are from Barbour et al. (1999).

Invertebrate data were averaged across the index period for each site because a preliminary analysis of the taxa and invertebrate community metrics from the July, August, and September sampling dates showed broad overlap among values, suggesting there was little biological difference among these metrics during the index period. Data were tested for normality using the Shapiro-Wilk test (SPSS statistical software, version 16.0), and data that were not normally distributed (taxa richness and percentage Chironomidae) were log transformed prior to further analysis. Because the purpose of this study was evaluation of temporal trend and not comparisons among sites, trend analysis of invertebrate metrics data across years (1996–2009) for each site was conducted using the nonparametric Mann-Kendall test (α = 0.05) (Time Trends software, version 3.0, NIWA 2010). The nonparametric Mann-Kendall test is directly analogous to linear regression, but it does not assume any particular distributional form, and it tests for whether Y values tend to increase or decrease with time (Esterby 1993; Helsel and Hirsch 2002; Stark and Fowles 2006). The Mann-Kendall test is recommended over other trend tests for the evaluation of stream invertebrate samples (Stark and Fowles 2006).

Harris et al. (1999) presented seasonal benthic densities and Shannon's Index diversity values for monitoring data collected at AGFO in 1989, but no additional metrics were provided. The data used by Harris et al. (1999) are stored in the Heartland Inventory and Monitoring Network database, and they were used to calculate invertebrate metrics as described in this paper. However, the 1989 data were not collected under the guidance of the Peterson et al. (1996) protocol and therefore were not used in the trend analyses. Those data are presented in this paper only for historical reference. Rust (2006) sampled aquatic invertebrates at AGFO in 2004–5, but she collected samples with a benthic D-frame net from a variety of habitats, and those data therefore cannot be compared directly to those presented here.

Niobrara River discharge data were taken from a registering staff gage (number 6454100) at Agate, NE, located immediately upstream of the AGFO jurisdictional boundary. This gage was operated by the U.S. Geological Survey from 1958 to 1992 (USGS 2011) and by the Nebraska Department of Natural Resources beginning in 2006 (NDNR 2011). The gage was not operated from 1993 to 2005. Gage data are presented as a mean for the July—September index period for each year. Nonregistering staff gages for determining water-surface elevations were installed in 2000 at the upper and lower sites, and were read directly as water level on the gage during each sampling event. Mean annual precipitation data for Agate, NE, from 1900 to 2011 are summarized from the Western Regional Climate Center (2012). Trend analyses of invertebrate metrics and discharge data across years (1996–2009) was conducted using the Mann-Kendall trend test (α = 0.05).

Water quality data were collected as static (single point) readings at each sampling site (2000–2009) using calibrated handheld meters (YSI Model 63 and YSI Model 55). Measurements were taken at the beginning and at the end of each 30-day sampling period and were calculated as a mean of both measurements across sampling sites and months (n = 18 per index period). Parameters measured included water temperature (°C), dissolved oxygen (mg/liter), pH, and conductivity (μS/cm). Data describing pH were not available for 2008 and 2009 due to instrument malfunction. Because water quality parameters were measured only twice for each sampling event and did not account for diel or seasonal temporal variation, a statistical analysis was judged inappropriate, and we present only summary data for those variables.
RESULTS

Trend analyses across years showed the quality of several invertebrate community metrics declined significantly from 1996 to 2009 (Figs. 2–3; Table 1). The invertebrate fauna in the Niobrara River shifted from one dominated by EPT taxa to one dominated by chironomids and amphipods. During this study, taxa richness among sites ranged from an average high of 10.9 species in 1999 to a low of 6.3 species in 2009. In comparison, mean taxa richness for samples collected in 1989 averaged 12.6 species. However, none of these differences was significantly different across time (Table 1). EPT richness and percentages of EPT, Leptophlebiidae (Leptophlebia nebulosa and Paraleptophlebia sp.), and Heptageniidae (primarily Heptagenia diabasa) generally decreased over time. The observed decrease in EPT richness was significant only at Agate Spring Ranch, but the P values for the other two sites were marginally insignificant (P = 0.07). In contrast, the decreases in percentage abundance of EPT were significant only for Agate Middle and Agate East. The trends for percentage abundance of Heptageniidae at Agate Spring Ranch and Agate East and that of Leptophlebiidae at Agate Middle were not significant (Table 1). However, representatives of Leptophlebiidae and Heptageniidae were not collected in samples taken during 2008 and 2009. Although some of the observed trends were not statistically significant, biological significance cannot be ruled out. Plecoptera (stoneflies) were poorly represented in all samples among years, consisting of a few specimens of Taeniopteryx burksi. Conversely, HBI, Shannon’s Index, evenness, and percentage abundance of Amphipoda (Hyalella azteca and Crangonyx sp.) generally demonstrated significant positive trends over time (P ≤ 0.03) (Table 1); only Shannon’s Index at Agate East was not significant (P = 0.58). Percentage abundance of Cheumatopsyche increased significantly (P = 0.00) at Agate Spring Ranch, but not at the other two sites. Percentage abundance of Chironomidae increased across years, but this trend was significant only for Agate Spring Ranch and Agate Middle (P ≤ 0.04). HBI values at all sites ranged from 4 to 5 in 2000 to over 7 in 2009. Shannon’s Index gradually increased from 1996 to 2007 at all sites, but it declined annually thereafter. Regardless, Shannon’s Index values were low among all years, and values never rose above 1.8. Because Shannon’s Index values typically range from 1.5 (low species richness and evenness) to 3.5 (high species evenness and richness) (McDonald 2003), the invertebrate community diversity in the Niobrara River was low. The significant (P ≤ 0.02) increasing trend in taxa evenness at all sites indicated that the few taxa that dominated the invertebrate community in the Niobrara River have relatively evenly distributed abundances. Collectively, the trends among metrics indicated that the invertebrate community at AGFO has become increasingly tolerant over time.

Discharge data during the July–September index period for the Niobrara River at AGFO show that flows have declined significantly (Mann-Kendall trend test, P = 0.04) since 1958, although more recent readings are certainly within the historic range of flows (Table 2; Fig. 4). In contrast, nonregistering staff gages on the Niobrara River at AGFO showed slightly and gradually increasing slopes, indicating that water-surface elevation in the channel at the sampling sites has increased over time (Fig. 5), but these trends were not significant (Table 2). The rise in water-surface elevation is attributed to aggradation of sediment in the channel. Mean annual precipitation data for Agate, NE (Fig. 6), from 1900 to 2011 were highly variable, ranging from 8 to 55 cm. Since 1996, more than half the years had precipitation levels falling above the mean (35 cm) for the entire period of record (Fig. 6).

Among water quality parameters, temperature, conductivity, and pH generally increased over time while dissolved oxygen concentration decreased over time (Fig. 7). Because water quality data were collected as static readings using handheld instruments, they likely do not reflect the temporal range of variation among those parameters. Also, we recognize that static water quality readings are potentially subject to diurnal, annual, and event-related variation. As such, these data represent only the water quality condition at the time the readings were taken and thus should be cautiously interpreted.

The Niobrara River watershed upstream of AGFO receives little input from industrial or municipal sources, but there are insufficient data for most stream segments in that region to determine if beneficial uses were being met (NDEQ 2004). However, a baseline water quality data report for the Niobrara River at AGFO identified five constituents that exceeded state water quality criteria, including pH, cadmium, copper, lead, and fecal coliform bacteria (NPS 1998). It is unknown if these constituents persist at elevated levels in the Niobrara River. There are livestock feedlots and agricultural irrigation projects in the Niobrara River watershed upstream of the park (NDEQ 2004) that may have contributed to the contaminant loading in addition to sedimentation, nutrient loading, and lowered dissolved oxygen levels associated with increased biochemical oxygen demand related to decomposition of organic materials.
Figure 2. Mean taxa richness, EPT richness, Shannon’s index, taxa evenness, and biotic index of invertebrate samples collected from the Niobrara River, Agate Fossil Beds National Monument, Nebraska. N = 45 for all years except 1989 (5), 1996 (13), 1998 (34), 2002 (44), 2003 (44), 2008 (15), and 2009 (15).

Figure 3. Mean percent Amphipoda, percent Chironomidae, percent EPT, percent Cheumatopsyche, percent Heptageniidae, and percent Leptophlebiidae of invertebrates samples collected from the Niobrara River, Agate Fossil Beds National Monument, Nebraska. N = 45 for all years except 1989 (5), 1996 (13), 1998 (34), 2002 (44), 2003 (44), 2008 (15), and 2009 (15).
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*Positive Kendall statistic values indicate an increasing trend while a negative value represents a decreasing trend.

†P values in bold type are significantly different (α = 0.05).
Figure 4. Mean monthly discharge and standard errors from the Niobrara River, Agate Fossils National Monument, during July—September from 1958 to 2009. Vertical dashed line represents break in data series. Data from U.S. Geological Survey (2011) and Nebraska Department of Natural Resources (2011).

Figure 5. Nonregistering staff gage mean height readings and standard errors from the Niobrara River, Agate Fossils National Monument, Nebraska, July—September, 2000—2009.

Figure 6. Mean annual precipitation for Agate, NE, 1900–2011. The solid horizontal line represents the mean across years. Data from Western Regional Climate Center (2012).

Figure 7. Water quality parameters for the Niobrara River, Agate Fossils National Monument, Nebraska, 2000–2009. N = 18 per year.

<table>
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<tr>
<th>Category</th>
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<th>Z</th>
<th>P†</th>
</tr>
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<td>0.04</td>
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<td>Gage at Agate East</td>
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<td>0.89</td>
<td>0.19</td>
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</table>

*Positive Kendall statistic values indicate an increasing trend while a negative value represents a decreasing trend.

†P values in bold type are significantly different (α = 0.05).
CONCLUSIONS

A recent study by Peg and Pope (2008) reported declines in the fish community structure in the Niobrara River at AGFO similar to that observed for invertebrates; only two species were collected during their survey. The observed declines in both the invertebrate and fish communities in the Niobrara River indicate widespread degradation among its biological communities, but the specific reasons for such declines are not entirely understood.

Although staff gage and water quality data did not demonstrate statistically significant trends in most cases, the predominance of significant slopes among certain invertebrate metrics and stream discharge suggests those trends are related to diminished integrity of physical habitat. Annual mean precipitation levels recorded since monitoring began in 1996 are well within the range of historic values, and they indicate the observed changes in channel condition and invertebrate community structure probably are not due to climatic factors. Given inconclusive information on water quality and quantity, it is not completely clear what disturbances facilitated the decline in the invertebrate community structure.

A contributing, and probably likely, source of the diminished water quality and habitat condition in the Niobrara River at AGFO is the encroachment of the nonnative and invasive emergent aquatic plant yellow flag (*Iris pseudacorus*) into the stream channel, where it blocks or slows water flow. A perennial plant, yellow flag has expanded throughout much of the riparian zone of the Niobrara River within Agate Fossil Beds National Monument since its introduction in the early 1900s (Olson and Olson 2007). Olson and Olson (2007) noted that dense stands of yellow flag were present over about a 3 km stretch of the river in the monument, with sporadic stands elsewhere. While quantitative data documenting the spread of yellow flag in the Niobrara River do not exist, this species currently dominates the stream channel in the monument, where it blocks most of the streamflow (Fig. 8). Wherever yellow flag is introduced, it tends to dominate the stream’s riparian areas by preventing the germination and seedling growth of native plants (Raven and Thomas 1970). The rhizomes form mats that trap sediments, which subsequently clog stream channels, causing local increases in streambed elevation (USGS 2010). The increasing water-surface elevations in the Niobrara River that we document here may be related to lower current velocities and associated increased sedimentation due to yellow flag expanding into the stream channel. The significantly decreasing streamflows in the Niobrara upstream of the monument only serve to exacerbate this problem. Because of the invasive habits of yellow flag, the present situation in the Niobrara River may become more pronounced in coming years.

Although there are few options for mitigating the impairment of the Niobrara River caused by yellow flag, restoring and maintaining riparian buffer zones dominated by native vegetation along this river will aid in protecting aquatic life as well as in-stream habitat from local runoff and sedimentation. The long history and continuing efforts of aquatic invertebrate monitoring at AGFO provide a sound tool to recognize the success of potential restoration actions on improvement of water quality and recovery of the aquatic invertebrate community in the Niobrara River.

ACKNOWLEDGMENTS

Several people assisted in collecting, processing, and reporting on invertebrate samples taken at Agate Fossil Beds National Monument. In particular, we thank Charlie Rabeni, Greg Wallace, Myranda Clark, Jessica Luraas, Lil Mansfield, and Robert Manasek for their assistance on this project. Mike DeBacker, Marcia Wilson, and Stephen Wilson provided valuable constructive comments.
on an earlier version of this article. Views, statements, findings, conclusions, recommendations, and data in this paper are solely those of the authors and do not necessarily reflect views and policies of the U.S. Department of Interior, National Park Service. Mention of trade names or commercial products does not constitute endorsement or recommendation for use by the National Park Service.

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LATE HOLOCENE ACTIVATION HISTORY OF THE STANTON DUNES, NORTHEASTERN NEBRASKA

Rebecca A. Puta, Paul R. Hanson, and Aaron R. Young

University of Nebraska-Lincoln
School of Natural Resources
248 Hardin Hall
Lincoln, NE 68583-0962

ABSTRACT—The Nebraska Sandhills have been an important resource for better understanding dune activation and the nature of prehistoric Great Plains drought events. However, until recently, few studies have focused on documenting the activation histories of smaller dune fields found along the Great Plains' eastern margin. This study focuses on the Stanton dune field, which lies about 145 km east of the Nebraska Sandhills on an alluvial terrace of the Elkhorn River in northeastern Nebraska. Sediments in the Stanton Dunes were dated with optically stimulated luminescence (OSL) to determine when these dunes were active. The ages indicate three activation periods that cluster into the following time periods: ~5,800–3,800, 960–630, and 510–410 years ago. The ages that fall into our two older clusters closely agree with dune activation records from the Nebraska Sandhills and other major central Great Plains dune fields, suggesting that these large-scale droughts also impacted eastern Nebraska. However, our youngest cluster of ages occurs at a time when the Nebraska Sandhills were thought to be largely inactive, suggesting that the Stanton Dunes may have been activated by a locally important drought event that had a more limited impact on dunes found to the west.

Key Words: dunes, drought, OSL dating, eolian activity, Elkhorn River, Nebraska

INTRODUCTION

Recent work on the chronology of activation records in Great Plains dune fields has allowed assessment of when and how dunes were activated. In large dune fields such as the Nebraska Sandhills, dune activation has been directly linked to increased aridity and hydrologic drought (Mason et al. 2004; Sridhar et al. 2006; Miao et al. 2007). The development of optically stimulated luminescence (OSL) dating, a method that estimates the last time sand grains were exposed to sunlight, has greatly improved our understanding of when dunes were active in the Great Plains. Notably, Miao et al. (2007) used OSL dating to show that the Nebraska Sandhills were activated between 9,600 and 6,500 years ago and during events centered on 3,800, 2,500, and 700 years ago.

Numerous other studies have used OSL and radiocarbon dating on dune fields throughout the central Great Plains, including dunes in Colorado (Clarke and Rendell 2003), Kansas (Arbogast 1996; Arbogast and Johnson 1998; Forman et al. 2008), Oklahoma (Lepper and Scott 2005; Werner et al. 2011), and Wyoming (Stokes and Ga}-lord 1993) (Fig. 1). These studies have resulted in a wealth of information about Great Plains dune activations and prehistoric climate; however, most of these studies historically were conducted west of the 98th meridian while several smaller dune fields lie to the east along the eastern margin of the Great Plains (Fig. 1).

However, studies of the impacts that prehistoric drought events have had on the smaller dunes along the eastern margins of the Great Plains have only been conducted in the last few years. Recently, three small dune fields east of the 98th meridian have been studied using OSL dating: the Duncan dune field in Nebraska and the Abilene and Hutchinson dune fields in Kansas (Fig. 1). OSL ages from the Duncan Dunes, located near the confluence of the Loup and Platte Rivers in the east-central portion of Nebraska, show that eolian activity corresponds well with dune activation events in the Sandhills, in which activity occurred around 4,300 to 3,500 years ago and around 900 to 500 years ago (Hanson et al. 2009). The Abilene Dunes, roughly 120 km northeast of the Great Bend Sand Prairie in Kansas, were found to be active 1,100 to 500 years ago (Hanson et al. 2010). The Hutchinson Dunes, located about 50 km northeast of the
Figure 1. (A) Stanton Dunes and other previously studied dune fields in the Great Plains: AD = Abilene Dunes; ARVD = Arkansas River Valley Dunes; CVD = Cimarron River Valley Dunes; DD = Duncan Dunes; FMD = Fort Morgan Dunes; GBSP = Great Bend Sand Prairie; GD = Greeley Dunes; HD = Hutchinson Dunes; NSH = Nebraska Sandhills; WD = Wray Dunes. (B) Stanton Dunes and the other previously studied dune fields in Nebraska: Nebraska Sandhills and Duncan Dunes.

Great Bend Sand Prairie, along the Arkansas River, were found to be active in three major episodes: about 2,100 to 1,800 years ago, 1,000 to 800 years ago, and 600 to 70 years ago (Halfen et al. 2012). The Hutchinson, Abilene, and Duncan Dunes represent the easternmost dune activity of the Great Plains, which, unlike the larger dune fields to the west, do not record all of the multiple drought events of the last 10,000 years.

A small dune field near Stanton, NE, is the easternmost dune field of the central Great Plains (Figs. 1A and 2A) and is thus important for better understanding the geographical extent and impacts of prehistoric droughts on the eastern margin of the Great Plains. However, as noted by Muhs et al. (1996) and Hanson et al. (2009), increased eolian activity in these smaller dune systems, like the Stanton Dunes, may be the result of either a direct or indirect response to drought conditions. A direct response to drought would be a reduction in vegetation cover on the sandy soils of the terrace fill, leading to increased wind erosion and dune mobilization.

Alternatively, dune activation could have been a consequence of changes in sediment availability from the adjacent river system. For instance, drought conditions in the headwaters of the Elkhorn River may have caused an increase in sand moving down the river, and that sand could have been deflated and transported by wind from the valley to the alluvial terrace. This would have been an indirect response to drought and would have significantly different implications for how we interpret past climatic conditions in the Plains. With these scenarios in mind, the purposes of this study were to (1) determine when eolian activity and/or dune formation occurred in the Stanton Dunes, (2) determine the potential causes of dune activation in this area, and (3) compare the dune activity to that
of regional dune fields to identify potential patterns of dune activation histories in the region.

REGIONAL SETTING

The Stanton dune field (~162 km²) is located on an alluvial terrace along the southern bank of the Elkhorn River in northeastern Nebraska, near the town of Stanton (Fig. 1B). It is the easternmost dune field in Nebraska and the central Great Plains, lying about 145 km east of the Nebraska Sandhills and about 110 km northeast of the Duncan Dunes (Fig. 1B). While high-relief complex megabarchan and barchanoid ridge dunes dominate the Nebraska Sandhills (Goble et al. 2004), low-relief (~5 m) barchan dunes are the most prevalent form in the Stanton dune field (Fig. 3A).

The dunes currently overlie alluvial sediments that are found in a terrace along the Elkhorn River, while being bordered to the south by loess-capped uplands (Fig. 2A). These uplands are comprised of 12–16 m of Peoria loess that was deposited between ~25,000 and 14,000 years ago (Mason 2001; Bettis et al., 2003; Mason et al., 2008). The Carlile Shale Formation forms the uppermost bed-rock layer and is buried by Quaternary sediments in the field area, as noted by the geological descriptions in the Nebraska Department of Natural Resources Registered Groundwater Well Logs (NDNR 2011). The groundwater table is located at an elevation of about 1,450 ft, the same elevation of the Elkhorn River, and has fluctuated by about 1–5 ft over the last 10 years (UNL-SNR 2009, 2011).

The primary land uses of the Stanton dune field area are rangeland, pasture, and cropland, and the dune field is currently stabilized by grassland vegetation (Hammond et al. 1982) (Fig. 3B). The 1858 general land office surveys indicated the area was deemed unfit for cultivation, and no bare or unvegetated areas were noted, indicating the dunes were stable over the past ~160 years (Nebraska State Surveyor’s Office 1858).

The climate in the Stanton area is humid continental, with hot, wet summers and cold, dry winters, compared to the semiarid climate of the Nebraska Sandhills (Wilhite and Hubbard 1998). The Stanton dune field area and the eastern portion of Nebraska receive an annual average of 25 to 35 inches of precipitation (High Plains Regional Climate Center 2011) while the drier Sandhills region...
receives an average of only 17 to 23 inches of precipitation each year (Wilhite and Hubbard 1998). The present wind regime of the Nebraska Sandhills and the central Great Plains can be associated with midlatitude cyclones in the cool winter months, and with anticyclonic flow of warm moist air from the Gulf of Mexico during the spring and summer seasons (Sridhar et al. 2006). Data on modern wind patterns for Norfolk, NE, the nearest long-term weather station, indicate that the Stanton dune field receives north—northwest winds from midfall through winter and southerly winds in spring through summer, with an average annual southerly wind (NCDC-NOAA 1998). Modern winds in the Sandhills are primarily controlled by passing frontal systems (Wilhite and Hubbard 1998) and generally flow from the north or northwest in the winter, and from the south or southeast in spring and summer (Sridhar et al. 2006), with an average annual northwest wind (NCDC-NOAA 1998).

MATERIALS AND METHODS

To characterize the stratigraphy and to subsample sediments for particle size analysis and OSL dating at each site, a truck-mounted Giddings probe was used to collect sediment core samples in plastic liners 7.6 cm in diameter and 1.25 m long. This coring method results in the occasional loss of sediment from the bottom of the core barrel, and those portions that were not recovered intact are labeled as “not retained” in the core stratigraphy shown in Figure 4. Thirteen sites, located in four distinct dune areas, were sampled (Fig. 2B). At least two high (5–10 m) dune crests were chosen for sampling in each of the four areas, as well as one interdune location in each area (Stanton 4, 7, 9, and 12) to develop a better overall chronology and to determine the magnitude of activation in the area. We avoided sampling exposures in blowouts, as they would likely contribute only data on localized erosion. Sediments from the cores were described following standard pedologic and geologic nomenclature (Schoeneberger et al. 2002; USDA-NRCS 2003).

For particle size analysis, 160 samples were taken at 30 cm intervals in each core, and samples were taken from soil lamellae-like formations that were present in several cores. The results of particle size analysis were primarily used to identify any significant changes within stratigraphic units and to determine whether significant changes in clay content existed between the lamellae-like features and their surrounding sediment. Samples were pretreated with sodium hexametaphosphate (NaHMP), a dispersant, then subjected to 1 minute of sonication and analyzed on a Malvern Mastersizer 2000E.

For OSL dating, 36 samples were collected in the field from the sediment cores; 24 samples were processed and analyzed and the remaining samples were archived.
Samples were taken at depths of 1.3 m or greater below the ground surface to avoid potential problems related to mixing and bioturbation of surface materials. Pretreatment and data reduction methods followed those of Hanson et al. (2009, 2010). To determine the equivalent dose (D\text{e}) for each sample, the single aliquot regenerative-dose method (Murray and Wintle 2000) was performed on the 90–150 μm quartz grain fractions. A preheat and cutheat temperature of 220°C was chosen, based on the results of a preheat plateau test (Wintle and Murray 2006), and were used in the analyses of all samples on Risø model DA 15 and DA 20 TL/OSL readers. Concentrations of K, U, and Th for the environmental dose rate estimations were determined by inductively coupled plasma mass spectrometry (ICP-MS) and inductively coupled plasma atomic emission spectrometry (ICP-AES) (Table 1). Equations from Prescott and

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<th>Depth (m)</th>
<th>U (ppm)</th>
<th>Th (ppm)</th>
<th>K2O (wt %)</th>
<th>In Situ 1H2O (%)</th>
<th>Dose Rate (Gy/ka) ± 1 Std. Err.</th>
<th>De (Gy)</th>
<th>Aliquots (n)</th>
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</tr>
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<td>1.83 ± 0.20</td>
<td>1.2 ± 0.3</td>
<td>24/31</td>
<td>Eolian Sand</td>
<td>630 ± 90</td>
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</tbody>
</table>

a Dose rate estimate assumes ± 100% variability in measured moisture values.
b Accepted disks/all disks.
Hutton (1994) were used to estimate cosmogenic dose rate contribution. Final D_e values were calculated using the central age model of Galbraith et al. (1999), a commonly used calculation method in OSL dating. All OSL ages are presented in calendar years before 2010.

RESULTS

Dune Stratigraphy

Alluvial sediments, loess, and eolian sands were distinguished from one another by sediment texture and, where present, sedimentary structures (see core stratigraphy in Fig. 4). The alluvial sediments were distinguishable from the eolian sands primarily from the dramatic increases in silt and clay content (Figs. 3A, 5). Loess, which was present only in the lower 2 m of the Stanton 11 core, had an overall very fine sandy loam texture (Fig. 5) with massive to moderate subangular blocky structure. The loess contained soil redoximorphic features that were found throughout the loess portion of the core. Eolian sands were composed of fine to medium sand (Fig. 5), exhibited single grain structure, and often contained soil lamellae-like features (Fig. 3A). Soil lamellae commonly occur in Quaternary sands and are thin bands characterized by an increase of silicate clay and iron (Rawling 2000). Lamellae-like features were present in eolian sand from 11 of the 13 cores taken from the Stanton dune area, occurring at depths ranging from 0.4 m to 7.0 m below the ground surface (Fig. 4).

Particle size analysis showed that clay contents were ~1% greater in the lamellae relative to the surrounding eolian sand. Lamellae thickness varied from 0.1 cm to 2 cm, and often had colors that were lighter or redder than the surrounding eolian sand, ranging from faint light yellow (2.5Y 7/3) to dark grayish brown (2.5Y 4/2) (Fig. 3A).

Geochemical Analysis

A comparison of rubidium (ppm Rb) and potassium (% K_2O) levels (Fig. 6) from the OSL samples showed no meaningful difference between eolian dune sand and the underlying alluvial sands in the Stanton Dunes based on these two elements. When compared to similar geochemical data published in previous studies (Muhs et al. 1997; Hanson et al. 2009), the geochemical properties of the Stanton Dunes are very similar to sediments from streams that drain the Nebraska Sandhills and are similar to the eolian sand in the Nebraska Sandhills.

OSL Age Chronology

For the dune sands and underlying alluvial sediments from the Stanton Dunes, a total of 24 OSL ages were generated (Table 1). For samples taken from the alluvium underlying the dunes, a total of five age estimates ranged from 23,700 ± 4,400 to 16,400 ± 1,700 years ago. Nineteen OSL age estimates taken from eolian sand ranged from ~15,800 years ago to the historical era. The majority of the OSL ages from the eolian sands (15 of 19) fall into three groups: 5,800–3,800, 960–630, and 510–410 years.
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2.1
2.0
1.9
1.8
1.7
1.6
40
50
60
70
80
Rb (ppm)

Figure 6. K₂O (%) versus Rb (ppm) values for eolian (circles) and alluvial (triangles) sediments from the Stanton Dunes in Nebraska.

ago. Two OSL ages were older than these age estimates, with one suggesting eolian deposition at 15,800 ± 1,700 years ago and the other indicating deposition at 9,800 ± 1,800 years ago. Both of the two remaining eolian OSL ages were taken from depths of 1.4 m below the present ground surface and indicated that deposition occurred at 120 ± 50 and 50 ± 10 years ago.

DISCUSSION

Lamellae Formation and Development

The lamellae-like features identified in most of the sediment cores from the study area occur in various thicknesses and amounts across the entire range of elevations sampled, in eolian and alluvial parent materials, and in sediments that were deposited from ~16,000 years ago to historical-age sediments based on our OSL ages. The colors and thicknesses of these features make them visually distinct in these sediments (see Fig. 3A); however, the lack of significant clay accumulation (only 1% maximum increase compared to the surrounding sediment) would not qualify these features as lamellae following Keys to Soil Taxonomy (USDA-NRCS 2003).

Previous studies have designated lamellae with horizon designations such as E/Bt (Schaeztl 1992) or as Bt&C or C&Bt (Holliday and Rawling 2006). In both of these cases there were significant increases in the clay contents relative to the surrounding sand, which adequately justi-

fied these horizon designations. The minor change in clay contents between the lamellae-like features and the sediment in which they were identified in the Stanton Dunes led us to describe soil horizons containing lamellae with more basic horizon designations (i.e., A, Ab, AC, CA, C) and simply noting the lamellae in the description.

Soil lamellae, or thin subsoil layers containing more clay than the layers above and below them, are common in some sandy soils and sediment of humid temperate regions. These features are particularly common in eolian sand, and are of interest because they are thought to have formed from several methods. Most workers attribute their formation to one of the following: (1) pedogenic processes where clay is mobilized from the upper portions of the soil and accumulates in the subsoil due to clay illuviation; (2) petrogenic processes where the higher clay content results from the deposition of the sediments and has not been mobilized by soil processes; and (3) pedo-petrogenic where clay accumulates from illuviation along bedding or sedimentary structures (Dijkerman et al. 1967; Rawling 2000). Holliday and Rawling (2006) note that in areas with abundant sources of aeroosic dust, such as loess and floodplain alluvium, the dust is deposited on the land surface and then translocated through the soil via water, thus making that dust the likely source of the clay comprising the lamellae.

The loess-capped uplands and alluvial sediments from the Elkhorn River could provide the Stanton dune field with two sources of aeroosic dust that would move through the sandy eolian soils via water to produce these features. However, without further investigation of these lamellae-like features, we cannot determine precisely how they formed.

Alluvial Sediments

Alluvial sediments were present in the lower portions of four of the 13 sediment cores taken from the Stanton Dunes, and OSL ages were collected from alluvium both near the ground surface and at depth (Fig. 4; Table 1). OSL dating is ideally suited to eolian sediments, as sand grains are adequately exposed to sunlight when transported by the wind, and in most cases the OSL signals are reset prior to burial. However, in many alluvial environments, sunlight exposure can be inadequate, leaving remnant OSL signals in deposited grains (Olley et al. 1998). This phenomena is called “partial bleaching” and can result in age estimates that are too old for some alluvial sediments. While this can be problematic in some areas, OSL dating of alluvial sediments was successful in the study of Platte
River sediments underlying the Duncan Dunes (Hanson et al. 2009) and near the town of Grand Island, NE (Horn et al. unpublished data).

With dating procedures and protocols similar between this study and those previously mentioned, and with minimal evidence for partial bleaching of the sediments, confidence in the validity of the alluvial ages from the Stanton Dunes is high. The OSL age estimates from these five alluvial samples range from 23,700 ± 4,400 to 16,400 ± 1,700 years ago. Overall, these ages suggest the alluvial fill within the terrace mantled by dunes was deposited during the last ice age, and during the deposition of Peoria loess in Nebraska (Mason 2001).

**Dune Chronology**

Of the OSL age estimates from eolian sediments, most (17 of 19) indicate dune movement in the last ~6,000 years (Fig. 4). With the exception of three relatively low-lying sites (Stanton 8, 9, and 10) and Stanton 12, each of the surface sediment samples indicates that the Stanton Dunes were active within the past 1,000 years. Cores from the interdune areas (Stanton 4, 7, 9, and 12) contained several alluvial OSL ages at maximum depth, and a few eolian OSL ages near the surface that were all older than 820 ± 150 years old. The remaining seven OSL age estimates from the eolian sediments indicate much older activation periods. Seven of these ages range from 5,800 to 3,800 years ago, and two age estimates indicate eolian activity occurred around 9,800 and 15,800 years ago. We attribute the two historic age eolian deposits to local blowout activity that is commonly found in dune areas of the Great Plains.

**Regional Dune Comparisons and Climatic Implications**

A comparison between the Stanton Dunes and the Nebraska Sandhills and other regional dune field records in the Great Plains shows important similarities, as well as some distinct differences (Figs. 7 and 8). The oldest eolian age from the Stanton Dunes, at 15,800 years ago, was deposited during the Late Pleistocene, also during the deposition of Peoria loess in Nebraska, and corresponds to many eolian sand ages from this period recently found deep in large dune structures in the Nebraska Sandhills (Mason et al. 2011).

Dune studies conducted in the Nebraska Sandhills indicate that there were four significant and distinct periods of dune activation in the past 10,000 years, including a period of continuous drought and eolian activity from 9,600 to 6,500 years ago, as well as later, shorter-lived events centered around 3,800, 2,500, and 700 years ago (Goble et al. 2004; Mason et al. 2004; Miao et al. 2007). Two early to middle Holocene dune ages from the Stanton Dunes, at 9,800 and 5,800 years ago, fall within 1σ error of the earliest Holocene activation period in the Nebraska Sandhills, from 9,600 to 6,500 years ago, though similar ages were not found in the nearby Duncan or Abilene Dunes (Fig. 7).

Three dune ages from the Stanton Dunes that range from 4,600 to 4,500 years ago overlap with a single 4,980-year age for eolian sand from the Duncan Dunes (Hanson et al. 2009). These ages fall within a notable gap in dune activation between 6,500 and 4,000 years ago in the Nebraska Sandhills (Miao et al. 2007). While localized blowouts could explain these ages of eolian activity in the Stanton Dunes during a known period of dune stability in the Sandhills, it is possible that these ages reflect the limited preservation of a larger-scale dune activation event present in the Stanton Dunes. This interpretation is based on the fact that these ages occur within five of the 13 sediment cores found throughout the Stanton Dunes. Because this hypothesis is based on a limited number of ages, additional data are needed to further explore its validity.

Two dune ages, from 4,400 to 3,400 years ago, correlate to several similar ages from the Duncan Dunes at approximately 4,400 to 3,400 years ago (Hanson et al. 2009) and fall within 1σ error of the Nebraska Sandhills activation period centered around 3,800 years ago (Miao et al. 2007) (Fig. 7). These ages further support the significance of a drought event dating to this time period as indicated from records of the Nebraska Sandhills. The next major drought event recorded in the Nebraska Sandhills occurred around 2,500 years ago (Miao et al., 2007), but the only dune record that contains evidence for this drought in the eastern Plains dunes is from the Hutchinson Dunes in Kansas (Halfen et al. 2012). This could be the result of an extensive and widespread drought and dune activation event that is not well preserved in the other three eastern dune fields of the Great Plains, or is merely due to sampling biases in these dune fields.

Our two youngest clusters of eolian ages (Fig. 8) include nine age estimates that indicate dune activity occurred between 960–630 and 510–410 years ago. The ages in the older of these two clusters closely overlaps dune activity identified from other dune fields in the Great Plains, including the Nebraska Sandhills, Duncan Dunes, Abilene Dunes, and Hutchinson Dunes (Figs. 7 and 8). These ages overlap the so-called Medieval Warm Period or Medieval Climatic Anomaly, when droughts were like-
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Figure 7. Plots of OSL age estimates with 1σ error from three eastern-lying dune fields in the Great Plains, including data from this study. Gray bars represent megadroughts identified in the Nebraska Sandhills (Miao et al., 2007).
Figure 8. Plots of OSL age estimates with 1σ error during the last 1,000 years from three dune fields in the Great Plains, including data from this study.
ly present throughout much of the western United States (Cook et al. 2004).

Six ages from the Stanton Dunes indicate significant sand movement occurred between ~510 and 410 years ago. The upper portion of five of our 13 core sites contained sand that dated to this time period; at the Stanton 1 core site up to 4 m of eolian sand was deposited during this interval (Fig. 4). Interestingly, these ages do not overlap with Miao et al.'s (2007) drought events recorded in the Nebraska Sandhills, which suggests the last large drought event ended by ~600 years ago. Other studies have also shown that the last activation period for dune movement in the Nebraska Sandhills occurred prior to 650 years ago (Goble et al. 2004; Mason et al., 2004). This apparent discrepancy could be explained by one of three possible causes.

First, these six ages from the Stanton Dunes could be younger than their "true" depositional age due to problems with the OSL dating, such as inaccurately measuring moisture content and/or the concentrations of K, U, and Th for the dose rate estimate. This is probably not likely to be a significant problem, as our dose rate values are very consistent in the Stanton Dunes, yet our OSL age estimates range from ~24,000 to the modern era (Table 1). The second possible explanation suggests that the OSL ages are accurate, and that these young dunes formed from an increase in sediment supply from the Elkhorn River rather than from a drought-related reduction in vegetation cover on the dunes. In this scenario, north-northwest winds may have blown sediment from the Elkhorn River floodplain onto the adjacent land surface to the south of the river between ~510 and 410 years ago. If valid, we would expect that these dunes would be concentrated along the Elkhorn River, in areas near or adjacent to the floodplain. However, dune ages that date to this time period are scattered throughout the dune field (Fig. 2B). In fact, these six young ages were found at Stanton 1, 3, 5, 6, and 11 study sites and not exclusively in the area closest to the Elkhorn River (Stanton 8, 9 and 10; Fig. 2B).

The third explanation for the young set of ages, and the one that we prefer, is that regional droughts impacted areas differentially in the central Great Plains in the past ~500 years. This hypothesis suggests that dune activity identified between ~510 and 410 years ago in the Stanton Dunes resulted from drought conditions that directly impacted sediment availability to wind erosion. This would most likely have been facilitated by a reduction in vegetation cover on the eolian sand that was mobilized during previous drought events. While these ages may not correspond to most dune records from the Nebraska Sandhills, several studies have shown eolian activity and drought conditions existed in Kansas and Nebraska during this time period (see Fig. 8).

Forman et al. (2005) showed sand movement occurred in the western Nebraska Sandhills from ~500 to 400 years ago. Similarly, several ages from the Hutchinson Dunes in central Kansas suggest dune activation at this time period (Halfen et al. 2012). In addition, a recent study of diatoms in the lacustrine records of five shallow interdunal lakes of the Nebraska Sandhills noted a shift in the diatom community structure around this time, which suggests a period of drought conditions and low lake levels (Schmieder et al., 2011). These records show that this may have been a period of smaller scale or locally important drought events that impacted different areas of the central Great Plains to different degrees. The Stanton dune record suggests that this drought period had a significant impact in the Stanton, NE, area at this time.

CONCLUSIONS

Our OSL chronology shows that the sediment found in the alluvial terrace that underlies the dunes was deposited between 23,700 and 16,400 years ago. The dune activation history of the Stanton Dunes was determined based on 19 OSL age estimates, with fifteen of these ages clustered into the following time periods: ~5,800–3,800, 960–630, and 510–410 years ago. Additional ages indicate dune movement at ~15,800 and 9,800 years ago, as well as during the historic period at ~120 and 50 years ago. Ages from our two oldest clusters correspond to dune activation events identified from other dune fields in the central Great Plains including the Nebraska Sandhills. However, the Stanton dune activation event that dates to 510–410 years ago does not correspond to dune records from the Nebraska Sandhills, indicating that drought events at this time may have been locally, rather than regionally, important.

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RELATIVE ABUNDANCE OF NORTHERN FLYING SQUIRRELS AND RED SQUIRRELS IN DIFFERENT FOREST TYPES, BLACK HILLS, SOUTH DAKOTA

Melissa Hough

89 Brook Road
Cochecton, NY 12726
Melahough18@hotmail.com

and

Charles Dieter

Department of Natural Resource Management
South Dakota State University
Northern Plains Biostress, Room 139B
Brookings, SD 57007
Charles.Dieter@sdstate.edu

ABSTRACT—Northern flying squirrels (Glaucomys sabrinus) and red squirrels (Tamiasciurus hudsonicus) in the Black Hills National Forest (BHNF) of South Dakota represent isolated populations. Because data on both species in the region are limited, and because the northern flying squirrel in South Dakota and the Black Hills National Forest has species of concern status, we trapped throughout BHNF to determine relative abundance in different forest types for both populations. For northern flying squirrels, capture rate was higher in the northern and western hills compared to the southern and eastern hills, whereas for red squirrels, capture rate was higher in the western hills, followed by the southern and eastern hills. The northern hills are classified as mesic coniferous forest transitioning to a dry coniferous forest in the southern hills. In addition, the northern hills is characterized by a mixed coniferous-deciduous forest, whereas the southern and eastern hills are characterized by even-aged managed coniferous stands. Understanding the abundance of these two isolated squirrel populations in the different forest types of the BHNF is important in intensively managed forests, because management decisions can impact isolated populations.

Key Words: Black Hills National Forest, Glaucomys sabrinus, northern flying squirrel, red squirrel, small mammal, Tamiasciurus hudsonicus

INTRODUCTION

In the Black Hill National Forest (BHNF) of western South Dakota, disjunct and isolated populations of both the northern flying squirrel (Glaucomys sabrinus bangsi [Rhoads]; King 1951; Wells-Gosling and Heaney 1984) and red squirrel (Tamiasciurus hudsonicus dakotensis; Turner 1974) occur and coexist. Due to the limited abundance, isolation from source populations (Kiesow 2008), and changes to forest structure due to forest management practices, northern flying squirrels in the BHNF are considered a species of concern (USDA Forest Service 2005; South Dakota Department of Game, Fish, and Parks 2006). Disjunct populations of northern flying squirrels at the southern edge of their range have not been well studied (Weigl 2007). Northern flying squirrels are mycophagous and play an important role in dispersing mycorrhizal fungal spores (Carey et al. 1999; Loeb et al. 2000; Pyare and Longland 2001; Vernes 2004). Flying squirrels are part of a squirrel-fungus-tree mutualism that may help maintain forest ecosystems such as those in BHNF (Weigl 2007).

The population of red squirrels (Tamiasciurus hudsonicus dakotensis; Turner 1974) in the Black Hills is isolated, and there are no previous studies on red squirrels there. Red squirrels may be considered a keystone species because of their larderhoarding behavior (Pearson and Ruggiero 2003). Middens produced by red squirrels serve as a storage area for seeds and add structure to managed
and even-aged forests, and decaying matter in the midden provides nutrient stores (Koprowski 2005).

Northern flying squirrels and red squirrels coexist throughout most of their range; however, northern flying squirrels are nocturnal (Wells-Gosling and Heaney 1984) and red squirrels diurnal (Steele 1998). The two squirrel species are sympatric and depend on mature coniferous forests for nest sites and food resources, such as fungi and seeds. However, currently no data exist on distribution and abundance of northern flying squirrels or red squirrels throughout BHNF and across their range within forest stands dominated by ponderosa pine (Pinus ponderosa: 83% [USDA Forest Service 2005]) and intensively managed for timber. Studying BHNF populations is important for both species because there is a threat to disjunct squirrel populations, which may be impacted by human activities such as clear-cutting, development, or any activity destroying extensive tracts of habitat (Koprowski 2005; Weigl 2007). Our objectives were to use live trapping to determine relative abundance of northern flying squirrel and red squirrel populations in different forest types in the BHNF. All methods were approved by South Dakota State University Institutional Animal Care and Use Committee (04-A021).

METHODS

Study Area

This study was conducted in the Black Hills National Forest, located in western South Dakota (43°26'20"-44°32'7" N, 104°4'36"-103°13'9" W) (Fig. 1). The BHNF is a unique ecosystem that consists of forest surrounded by Great Plains grasslands (Froiland 1990). The ponderosa pine—dominated hills extend 900–1200 m above the surrounding Great Plains prairie. The Black Hills were formed by mountain uplift, extend 200 km north to south and 100 km east to west, and encompass 486,000 ha. Their elevation range is approximately 1,200 to 2,207 m, with the forested region extending to 2,102 m (Froiland 1990).

The southern Black Hills has a warmer (9.3°C) and drier (45–51 cm/yr) annual climate than the northern portion of the range (7.2°C and 61–66 cm/yr; Shepperd and Battaglia 2002). Ponderosa pine is found throughout the BHNF and is the most abundant tree species, dominating 83% of the landscape (USDA Forest Service 2005). In the central to southern hills, quaking aspen (Populus tremuloides) and paper birch (Betula papyrifera) are interspersed with pine in the bottomlands and along water sources; spruce occurs sporadically and is commonly found along streams; and there is little to no understory.

In the northern hills, white spruce (Picea glauca) is more abundant, comprising 2% of the vegetation (USDA Forest Service 2005). The northern hills has an understory component, primarily bur oak (Quercus macrocarpa), but may also include American elm (Ulmus americana), green ash (Fraxinus pennsylvanica), box elder (Acer negundo), and eastern hop hornbeam (Ostrya virginiana) (Hoffman and Alexander 1987). Quaking aspen and paper birch dominate moister environments, particularly in disturbed areas, of the central to northern BHNF (Hoffman and Alexander 1987).

Trapping

From May through August 2005, we trapped both squirrel species along established transects throughout the southern to southeastern BHNF (Fig. 1). Ten Tomahawk live traps (Model 201: 40 × 13 × 13 cm, Tomahawk Live Trap Co., Tomahawk, WI) were placed 50 m apart; this distance ensures at least four traps were in each northern flying squirrel's home range (Hough and Dieter 2009a) and three traps were in each red squirrel's home range (Kiesow 2008). This distance also accounts for home range overlap between squirrels (Carey et al. 1991). Trap placement was alternated between the ground at the base of a tree and on a branch of a tree, secured at a height of 1 to 2 m. We covered traps with ground litter and bark and baited each with oil-packed tuna or a mixture of peanut butter, oatmeal, and bacon grease.
From May through August 2006 and 2007, we trapped both squirrel species along established transects throughout the northern and western BHNF, respectively (Fig. 1). We placed all traps in trees, because during 2005 more squirrels of both species were captured in tree traps than ground traps. We alternated 10 single-door Tomahawk live traps and 10 double-door Havahart live traps (Model 1025: 45.7 x 12.7 x 12.7 cm, Woodstream Corporation, Lititz, PA). All traps were baited with a mixture of peanut butter, oatmeal, and bacon grease. During all years, we set traps for at least 14 trap nights and checked them each morning.

Captures
Each individual squirrel was weighed and classified as an adult (>100 g for northern flying squirrels and >200 g for red squirrels) or juvenile. We determined the sex and reproductive condition of adults by examining the condition of male scrotums and female teats (Godin 1960). We inserted a passive integrated transponder (PIT) tag (Biomark, Boise, ID) subcutaneously into each squirrel using a 12-gauge sterile syringe implanter. Each PIT tag microchip had a unique number for identifying individual squirrels to monitor recaptures.

Statistical Analysis
Statistical analyses were conducted using JMP IN 4.0 (SAS Institute Inc., Cary, NC) using an α = 0.05. Shapiro-Wilk’s test was used to test all variables for normality. Because assumptions of normality and heterogeneity were not always met, we performed nonparametric tests. Sex ratios for adults were determined for each squirrel species and ratios were compared to a 1:1 ratio with likelihood ratio \( \chi^2 \). We tested for differences in trapping success between years using chi-square analysis.

RESULTS
In the southern and southeastern hills (2005 study year), we captured 34 northern flying squirrels with 13 recaptures in 3,489 trap nights, for a trapping success of 1.4% (Table 1). In the northern hills, we captured 97 northern flying squirrels with 80 recaptures in 4,220 trap nights, for a trapping success of 4.2%. In the western hills, we captured 35 northern flying squirrels with 38 recaptures in 2,624 trap nights, for a trapping success of 2.8%. Overall, the trapping success was 2.9%. Capture rate was higher in the northern hills than in the southern hills (\( \chi^2 = 59.38, P = <0.0001 \)). There was no difference in capture rate between the northern and western hills (\( \chi^2 = 0.65, P = 0.80 \)) when comparing capture rates for the same trapping months (May and June). Capture rate was higher in the western hills than in the southern hills (\( \chi^2 = 38.07, P = <0.0001 \)) when comparing capture rates for the same trapping months (only May and June). Overall, there was an increase in trapping success as summer progressed (\( \chi^2 = 93.65, P = <0.0001 \)) (Fig. 2).

In the southern hills, we captured 40 red squirrels with 7 recaptures in 3,489 trap nights, for a trapping success of 1.4% (Table 1). In the northern hills, we captured 17 red squirrels with 5 recaptures in 4,220 trap nights, for a trapping success of 0.5%. In the western hills, we captured 82 red squirrels with 12 recaptures in 2,624 trap nights, for a trapping success of 3.6%. Overall, the trapping success was 1.6%. Capture rate was higher in the southern hills than in the northern hills (\( \chi^2 = 92.21, P = <0.0001 \)). Capture rate was higher in the western hills than in the southern hills (\( \chi^2 = 26.90, P = <0.0001 \)) and northern hills (\( \chi^2 = 103.08, P = <0.0001 \)) when comparing capture rates for the same trapping months (only May and June). Overall, trapping success during June was two times higher than trapping success during May, July, and August (\( \chi^2 = 15.20, P = 0.002 \)) for red squirrels (Fig. 2). When years were combined, the sex ratio for adult northern flying squirrels was not different from 1:1, but we caught more male adult red squirrels than females (Table 2).

DISCUSSION
Distribution
The highest trapping success for northern flying squirrels (4.2%) occurred in the northern hills. The northern BHNF is classified as mesic coniferous forest (Marriott et al. 1999), which typically supports higher population densities of northern flying squirrels than xeric forest (Lehmkuhl et al. 2006; Hough 2008). Gabel et al. (2006) found that 90% of the contents of northern flying squirrel feces collected from captured squirrels in the northern BHNF were fungal spores. Hypogeous fungi fruiting bodies require moist, nutrient-rich and cool environments to grow (Pyare and Longland 2001). An increase in moisture results in an increase in fungal community diversity (Carey and Johnson 1995) and abundance (Luoma et al. 1991). In a related study, northern flying squirrels in BHNF were positively associated with higher precipitation and closer distances to streams (relative to availability) (Hough and Dieter 2009b).

Trapping success for red squirrels was low in the
TABLE 1.

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</table>

northern hills and higher in the western and southern hills. Red squirrels rely heavily on conifer seeds (Kemp and Keith 1970; Rusch and Reeder 1978; Kiesow 2008) and are adapted to drier environments, conditions found in the western and southern hills. Kiesow (2008) determined 94.5% of stomach content from red squirrels captured in BHNF consisted of pine seeds.

The northern hills is characterized by well-developed forest understory, more snags and coarse woody debris, and a mixed coniferous-deciduous forest, whereas the southern and eastern hills are characterized by even-aged managed coniferous stands with little to no understory or ground cover (Marriott et al. 1999). Red squirrels are associated with coniferous forests, as the resources they required, including food and shelter, are provided by conifers (Kemp and Keith 1970). Northern flying squirrel abundance has been linked to increased understory cover (Smith et al. 2004), snags, and down, dead, decaying wood (Carey et al. 1999). Understory provides increased foraging opportunities by providing cover from predators (Carey 1995; Carey et al. 1999; Pyare and Longland 2002), and some understory species may provide food for northern flying squirrels (Smith et al. 2004). Snags provide nesting locations for northern flying squirrels. Down woody debris provides cover, travel paths, burrow sites, and a substrate for northern flying squirrel food such as fungi and lichen (Maser et al. 1985; Carey and Johnson 1995).

Northern flying squirrel trapping success was higher in the northern hills and western hills than the southern-southeastern hills. Juvenile recruitment for northern flying squirrels was earlier in the northern and western hills than in the southern hills. In the southern hills, the first juvenile was captured in August, whereas in the northern hills the first juvenile was captured on July 4 and in the western hills on June 20. After the first juvenile capture, juveniles were regularly captured throughout the rest of the summer. In both study areas, trapping success increased as the summer progressed, but there was a marked increase during the months of juvenile recruitment.

The month with highest trapping success for both species was the month with highest juvenile recruitment. This occurred during August (6.0%) for northern flying
squirrels and during June (2.2%) for red squirrels. For northern flying squirrels, the increase in trapping success during July reflects the beginning of the juvenile recruitment period, and recruitment peaks during August (Fig. 2). Red squirrel capture success peaks during June, with a marked decrease in August.

**Sex Ratio**

Sex ratios for northern flying squirrels are not normally skewed (Smith 2007), as was found in this study (Table 2). Vernes (2004) had similar results in New Brunswick. In western Oregon, Rosenberg and Anthony (1992) found no sex ratio difference for northern flying squirrels in old-growth stands, but they found a higher proportion of females in second-growth stands. Rosenberg and Anthony (1992) also found more juveniles in second-growth stands and suggested these stands were sink habitats.

There were more male than female red squirrels trapped in the BHNF (Table 2). Vernes (2004) reported a sex ratio difference in favor of males during one year of study in New Brunswick. In other areas across their range, male and female juvenile red squirrel sex ratios were similar, but adult sex ratios increased in favor of males as age increased (Kemp and Keith 1970; Davis and Sealander 1971; Rusch and Reeder 1978). Higher capture rates for males may exist because males move around while females are caring for their young (Kemp and Keith 1970) or because of habitat conditions, as Rosenberg and Anthony (1992) suggested for northern flying squirrels.

Our results indicate that northern flying squirrels were present throughout the BHNF but were most abundant in the mesic mixed coniferous-deciduous forest in the northern hills, with well-developed forest understory and more snags and coarse, woody debris. Northern flying squirrels were also most abundant in the western hills, which is a transition from the northern hills to the southern hills. The western hills are dominated by coniferous trees with aspen and birch in the bottomlands and along water sources. In addition, there is some understory and ground cover, as these forests are not as intensively managed as the even-aged coniferous forests in the southern-southeastern hills. Juvenile recruitment was earlier in the northern and western hills, resulting in higher capture rates. Red squirrels were also present throughout the BHNF but were most abundant in the less intensively managed coniferous forests of the western hills, where there is some understory and ground cover, followed by the southern-southeastern hills, which is comprised of intensively managed even-aged coniferous stands with little to no understory or ground cover. Very few red squirrels were captured or observed in the mesic mixed coniferous-deciduous forests in the northern hills.

Understanding the abundance of these two isolated squirrel populations in the different forest types of the BHNF is important in intensively managed forests, because across their range the two squirrel species play important roles in the forests they occupy, and management decisions can impact isolated populations. The results of this study contribute to the knowledge gap for populations of northern flying squirrels at the southern portion of their range (Smith 2007; Weigl 2007), and they also provide information on red squirrels, which have not been well studied in the Black Hills National Forest.
ACKNOWLEDGMENTS

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Abundance of Northern Flying Squirrels and Red Squirrels

Melissa Hough and Charles Dieter


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ACCURACY OF ANTLER METRICS IN PREDICTING AGE OF WHITE-TAILED DEER AND MULE DEER

Casey W. Schoenebeck, Brian C. Peterson, and Jason A. Obermiller

Department of Biology
2401 11th Avenue
University of Nebraska at Kearney
Kearney, NE 68849
schoenebeccw@unk.edu

ABSTRACT—Electronic deer check systems offer state natural resource agencies alternatives to mandatory in-person check stations, resulting in potential savings in money and personnel. However, a reliable means for hunters to classify the age of harvested antlered deer must be established so that important management indices such as antlered yearling harvest can continue to be used to set future management goals. Therefore, we evaluated the use of six different antler metrics to predict age class of white-tailed and mule deer (1.5 and ≥2.5 years). We used discriminant analysis to determine the number of deer correctly classified into each age class based on the antler metric with the greatest degree of separation for each species. Of those evaluated, main beam length and inside spread were the two most accurate measurements for both species. For white-tailed deer, 93% (114 of 123) of the 1.5-year age class and 93% (251 of 271) of the ≥2.5-year age class were correctly classified using main beam length with a cutoff of 364 mm. For mule deer, 100% (12 of 12) of the 1.5-year age class and 97% (35 of 36) of the ≥2.5-year age class were correctly classified using main beam length with a cutoff of 352 mm. Antler metrics of both deer species can be used to accurately classify age class while likely saving funds and personnel hours.

Key words: antler metrics, electronic deer check, mule deer, Odocoileus virginianus, Odocoileus hemionus, white-tailed deer

INTRODUCTION

Recreational hunting of white-tailed deer (Odocoileus virginianus) and mule deer (O. hemionus) contribute millions of dollars annually to state and regional economies. Within Nebraska, deer are the most sought-after big game species, totaling 141,573 deer permits sold in 2010 (Taylor 2011), which generated over $5.9 million in revenue, according to the Nebraska Game and Parks Commission (NGPC) (K.M. Hams, NGPC, pers. comm. 2012).

Since 2009, the NGPC has transitioned from a mandatory, in-person deer check to the use of an automated “Telecheck” program (phone or Internet) for all seasons (i.e., archery, muzzleloader, early and late antlerless firearm seasons), with the exception of the nine-day November firearm season. Although optional during 2009, the Telecheck program became mandatory during 2010 and 2011 for all deer seasons outside the nine-day November firearm season. From 2009 to 2011, deer checked by the Telecheck program increased from 16% to 26% (Taylor 2012). In 2011, 64,447 deer were checked by hunters at NGPC-sponsored check stations while 22,162 deer were checked via the Telecheck program (Taylor 2012). The mandatory, in-person deer check process requires hunters to transport their harvested deer to the nearest NGPC-sponsored check station. Some of these check stations are staffed by NGPC personnel to collect species-, age-, and sex-specific harvest information for population dynamics and diseases testing (e.g., tuberculosis and chronic wasting disease). In addition, the NGPC contracts additional manual check stations, but because these contracted stations are not staffed by NGPC biologists, ages of harvested deer and samples for disease testing are not collected. In both types of manual check stations and the Telecheck program, hunters are asked to provide information on their harvested deer, including date, county, public or private land, species, and sex. From the data collected, the NGPC are able to make informed recommendations for the following year (Taylor 2010).

Because deer hunting occurs in rural areas across Nebraska, it is costly for both the NGPC to operate and for hunters to travel to NGPC-sponsored check stations during the nine-day November firearm season. State agencies
Harvested deer were brought by hunters to the NOPC stations during 1998, equaling $1.74 per hunter checked (Rupp et al. 2000). By comparison, the Telecheck program cost the NGPC only $0.80 per deer to operate in 2010 (K.M. Hams, NGPC, pers. comm. 2012). With 26% of all deer being checked by the Telecheck program, the NGPC observed cost savings of $11,000, while hunters estimated savings through reduced transportation costs of $400,000 (Taylor 2011). The Missouri Department of Conservation estimated savings of $667,000, or a reduction in cost by 85%, when Telecheck was implemented in place of in-person checking for deer and turkey (Hansen et al. 2006). Similar reductions in cost could be expected if the NGPC could employ the Telecheck program for all deer seasons.

In-person deer check provides the NGPC with valuable information regarding population dynamics of the deer herd. Similar to what is done in other states, the NGPC uses harvest information, including number of yearling bucks harvested, to set future deer management goals (Roseberry and Wolf 1991; Evans et al. 1999; Taylor 2012). If the NGPC is to transition from an in-person check to the Telecheck program for all seasons, it must find ways to provide accurate population age structure dynamics. Antler metrics may provide a reliable means to index age of deer because antler size has been shown to increase with age in Alaskan moose (Alces alces) (Bowyer et al. 2001) and white-tailed deer (Ditchkoff et al. 2001). If basic antler metrics can be used by hunters to accurately classify deer age class (1.5 and ≥2.5 years), the Telecheck program would be able to provide the NGPC with important harvest data. The goal of this study was to investigate the use of antler metrics to accurately predict white-tailed and mule deer age class.

**MATERIALS AND METHODS**

Our study area was located in south-central Nebraska, which is composed of two physiographic regions: the Central Nebraska Loess Plains and the Platte River Lowland (Weaver and Bruner 1948). White-tailed deer were harvested proximal to the river valleys while mule deer were harvested in the upland plains.

Harvested deer were brought by hunters to the NGPC Kearney Field Office where we measured antlers and determined the age of deer. Deer checked by hunters during the 2009–11 November firearm seasons were identified to species, and age was determined by one of three experienced NGPC wildlife biologists by analyzing tooth wear and replacement similar to methods described in Severinghaus (1949). Initially, in 2009, we sampled deer to test whether significant differences (using paired t-tests) occurred between antler sides. Thereafter, we randomly sampled known-aged deer antler metrics using the most accessible antler. We used six antler metrics, including inside spread (of main beams), main beam length, two main beam diameters, and two main beam circumferences. We measured the inside spread using a measuring tape to the nearest 2.5 cm using procedures described by the Boone and Crockett Club (Nesbit and Wright 2009). We measured main beam length and circumferences 1 and 2 using a measuring tape to the nearest 1 mm as specified by the Boone and Crockett Club (Nesbit and Wright 2009). We measured diameters 1 and 2 (2010 and 2011 only) using digital calipers to the nearest 0.01 mm at the same locations as those used for the circumference measurements.

Because all six antler metrics were significantly different between the 1.5-year and ≥2.5-year age classes for both species (P < 0.05) using classical statistics (t-test), we determined the best antler metric by quantifying the means and variability between age classes. Simply, the antler metric with the greatest distance between the upper 95% confidence interval for the 1.5-year-old age class and the lower 95% confidence interval for the ≥2.5-year-old age class provide the greatest degree of separation, with half of this distance serving as a cutoff. We then used discriminant analysis to determine the number of deer correctly classified into each age class based on the antler metric with the greatest degree of separation for each species.

**RESULTS**

We measured 108, 108, and 185 white-tailed deer and 22, 9, and 17 mule deer in 2009, 2010, and 2011, respectively. We pooled the mule deer metrics over the three-year study due to low sample size (n = 48). Antler sides were not significantly different when we measured main beam length (t = 0.19, df = 17, P = 0.84), circumference 1 (t = -0.56, df = 17, P = 0.58), circumference 2 (t = 0.47, df = 16, P = 0.64), and diameter 1 (t = -0.38, df = 17, P = 0.71).

Main beam length had the greatest degree of separation of all six antler metrics measured for both deer species, with inside spread having the second largest degree of separation. The cutoff separating age classes using main beam length averaged 364 mm and ranged from 363 to 366 mm among years for white-tailed deer (Table 1) and was 352 mm for mule deer (Table 2). The cutoff sepa-
### TABLE 1.
DIFFERENTIATING YEARLING WHITE-TAILED DEER FROM THOSE ≥2.5 YEARS OLD IN SOUTH-CENTRAL NEBRASKA FOR EACH ANTLER METRIC USING CUTOFF VALUES, 2009–11

<table>
<thead>
<tr>
<th>Metric (mm)</th>
<th>Year</th>
<th>Age 1.5 yr</th>
<th>Age ≥2.5 yr</th>
<th>Cutoff</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td>Lower</td>
<td>Upper</td>
</tr>
<tr>
<td>Inside spread</td>
<td>2009</td>
<td>238</td>
<td>224</td>
<td>252</td>
</tr>
<tr>
<td></td>
<td>2010</td>
<td>229</td>
<td>209</td>
<td>249</td>
</tr>
<tr>
<td></td>
<td>2011</td>
<td>223</td>
<td>206</td>
<td>239</td>
</tr>
<tr>
<td>Main beam length</td>
<td>2009</td>
<td>296</td>
<td>281</td>
<td>310</td>
</tr>
<tr>
<td></td>
<td>2010</td>
<td>270</td>
<td>250</td>
<td>290</td>
</tr>
<tr>
<td></td>
<td>2011</td>
<td>271</td>
<td>251</td>
<td>290</td>
</tr>
<tr>
<td>Diameter 1</td>
<td>2009</td>
<td>22</td>
<td>22</td>
<td>23</td>
</tr>
<tr>
<td></td>
<td>2010</td>
<td>21</td>
<td>20</td>
<td>23</td>
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<tr>
<td></td>
<td>2011</td>
<td>22</td>
<td>21</td>
<td>23</td>
</tr>
<tr>
<td>Diameter 2</td>
<td>2009</td>
<td>21</td>
<td>19</td>
<td>22</td>
</tr>
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<td>2010</td>
<td>21</td>
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<td>22</td>
</tr>
<tr>
<td></td>
<td>2011</td>
<td>21</td>
<td>19</td>
<td>22</td>
</tr>
<tr>
<td>Circumference 1</td>
<td>2009</td>
<td>72</td>
<td>69</td>
<td>75</td>
</tr>
<tr>
<td></td>
<td>2010</td>
<td>66</td>
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<td>70</td>
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<tr>
<td></td>
<td>2011</td>
<td>67</td>
<td>64</td>
<td>70</td>
</tr>
<tr>
<td>Circumference 2</td>
<td>2009</td>
<td>61</td>
<td>57</td>
<td>65</td>
</tr>
<tr>
<td></td>
<td>2010</td>
<td>59</td>
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<td>63</td>
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<tr>
<td></td>
<td>2011</td>
<td>60</td>
<td>56</td>
<td>63</td>
</tr>
</tbody>
</table>

### TABLE 2.
DIFFERENTIATING YEARLING MULE DEER FROM THOSE ≥2.5 YEARS OLD IN SOUTH-CENTRAL NEBRASKA FOR EACH ANTLER METRIC USING CUTOFF VALUES, 2009–11

<table>
<thead>
<tr>
<th>Metric (mm)</th>
<th>Year</th>
<th>Age 1.5 yr</th>
<th>Age ≥2.5 yr</th>
<th>Cutoff</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td>Lower</td>
<td>Upper</td>
</tr>
<tr>
<td>Inside spread</td>
<td>2009</td>
<td>241</td>
<td>219</td>
<td>264</td>
</tr>
<tr>
<td></td>
<td>2010</td>
<td>262</td>
<td>234</td>
<td>290</td>
</tr>
<tr>
<td>Main beam length</td>
<td>2009</td>
<td>19</td>
<td>17</td>
<td>21</td>
</tr>
<tr>
<td></td>
<td>2010</td>
<td>14</td>
<td>9</td>
<td>20</td>
</tr>
<tr>
<td>Diameter 1</td>
<td>2009</td>
<td>59</td>
<td>55</td>
<td>63</td>
</tr>
<tr>
<td></td>
<td>2010</td>
<td>43</td>
<td>35</td>
<td>50</td>
</tr>
</tbody>
</table>
rating age classes using inside spread averaged 300 mm and ranged from 297 to 303 mm among years for whitetailed deer (Table 1) and was 314 mm for mule deer (Table 2). We pooled the white-tailed deer data for discriminant analysis due to low variability among years. For whitetailed deer, 93% (114 of 123) of the 1.5-year age class and 93% (251 of 271) of the ≥2.5-year age class were correctly classified using main beam length. For mule deer, 100% (12 of 12) of the 1.5-year age class and 97% (35 of 36) of the ≥2.5-year age class were correctly classified using main beam length.

DISCUSSION

While many factors influence antler characteristics (e.g., range quality and genetics), Bender et al. (1994) suggested that if antler characteristics can discriminate ages within a local population, it could be used as an assessment tool for managers. Antler metrics were able to correctly classify 1.5-year-old bull elk (Cervus elaphus) 100% of the time (Bender et al. 1994). Similarly, all six metrics evaluated were reliable at determining 1.5-year-old from ≥2.5-year-old bucks for white-tailed deer and mule deer. Main beam length and inside spread were the most accurate metrics when determining 1.5-year-old from ≥2.5-year-old bucks for both white-tailed deer and mule deer. Based on our results, main beam length may provide state natural resource agencies with a tool to provide reliable age classification of antlered males. However, because antler characteristics are likely to vary by region, managers must evaluate their own regional cutoffs to most accurately classify age class within their deer populations.

The potential for variability in antler metrics among both years and regions exists and should be considered. Strickland and Demarais (2000, 2008) have demonstrated geographic differences in antler metrics of white-tailed deer. Therefore, antler metrics from this study may not reflect those in different regions of Nebraska or in other states. Information should be collected statewide prior to implementation so that statewide cutoffs can be determined. Results from this study suggest future efforts should focus on the main beam length and inside spread metrics. In addition, antler metrics may change among years, given that forage quality and quantity and environmental variables change among years (Ditchkoff et al. 2000, 2001; Harris et al. 2002).

Several considerations should be taken into account by natural resource agencies before the full implementation of an electronic deer check system. First, educational efforts to teach hunters proper measuring methods should be developed to ensure reliable data. Traditional sources of hunter education like state-maintained web pages, big game regulation publications, and youth hunter education programs should be utilized. In addition, standardized methods (i.e., instrumentation needed, ability of hunters to replicate methods) of metric measurements should be developed. While obtaining metrics such as diameters may not be practical because of the instrumentation involved (i.e., digital calipers), others such as main beam length and inside spread need only a measuring tape. Managers may consider transitioning the contracted stations to the Telecheck program prior to those staffed by NGPC personnel, as this would allow for comparison between biologist- and hunter-measured data. In addition, the continued use of high traffic stations as mandatory in-person check stations while closing low traffic stations in favor of an electronic deer check could serve to (1) sample disease, (2) increase public outreach and education, and (3) provide biologist-verified harvest-age dynamics to compare to an electronic deer check system.

In conclusion, antler metrics of both white-tailed and mule deer provide an accurate means of classifying harvest-age dynamics. While other considerations must be evaluated prior to implementation, the use of antler metrics via an electronic deer check system could save state natural resource agencies both funds and personnel hours. The need for the NGPC to save funds and time must be balanced with the need for accurate harvest data to ensure proper deer management; an electronic deer check system may provide that balance.

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We would like to thank the NGPC’s Nic Fryda, Bob Medina, Brad Eifert, and Shawn Warner for assistance during the November firearm season. We also thank Scott Taylor and Kit Hams for providing detailed harvest and Telecheck program information. We also would like to thank Josh Kreitman, Brett Roberg, Seth Lundgren, and Chris Uphoff for field assistance. This manuscript was improved by the comments provided by two anonymous reviewers.

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REVIEW OF THE NEGATIVE INFLUENCES OF 
NON-NATIVE SALMONIDS ON NATIVE FISH SPECIES

Kelly C. Turek

School of Natural Resources
University of Nebraska—Lincoln and Nebraska
Cooperative Fish and Wildlife Research Unit
Lincoln, NE 68538
kturek4@unl.edu

Mark A. Pegg

School of Natural Resources
University of Nebraska—Lincoln
Lincoln, NE 68538

and

Kevin L. Pope

U.S. Geological Survey—Nebraska Cooperative Fish and Wildlife
Research Unit and School of Natural Resources
University of Nebraska—Lincoln
Lincoln, NE 68538

ABSTRACT—Non-native salmonids are often introduced into areas containing species of concern, yet a comprehensive 
overview of the short- and long-term consequences of these introductions is lacking in the Great Plains. Several authors have 
suggested that non-native salmonids negatively influence species of concern. The objective of this paper is to review known 
interactions between non-native salmonids and native fishes, with a focus on native species of concern. After an extensive 
search of the literature, it appears that in many cases non-native salmonids do negatively influence species of concern (e.g., 
reduce abundance and alter behavior) via different mechanisms (e.g., predation and competition). However, there are some 
instances in which introduced salmonids have had no perceived negative influence on native fishes. Unfortunately, the majority 
of the literature is circumstantial, and there is a need to experimentally manipulate these interactions.

Key Words: non-native, fish, competition, predation, review, threatened, species of concern, salmonid

INTRODUCTION

Great Plains streams represent some of the most unique and endangered freshwater systems in the world. Although these 
streams historically had a rich mixture of native species, several Great Plains fishes have become threatened or endangered as a result of introduced fishes, lack of suitable habitat, anthropogenic flow regime alterations, or a mixture of these factors. Here we examine the effects of introducing non-native salmonids on native fish species of concern. In many of the studies listed throughout this paper, introduced fishes are not the only contributors to declines in native populations. In most cases, effects are facilitated or amplified by habitat deterioration. Combined effects of multiple stressors on native populations can lead to further endangerment of species of concern. Mitigating all stressors is essential to the protection and recovery of these species; however, here we focus solely on influences of non-native fish species. Species of concern, as used in this paper, are defined as species that are (1) listed as threatened or endangered under
the U.S. Endangered Species Act of 1973 (ESA), (2) listed as threatened, endangered, imperiled, or vulnerable in an individual state, (3) endemic, or (4) in need of conservation actions, which are considered vital to their survival. Anticipating potential interactions between introduced non-native fishes and fish species of concern will ensure proper conservation and management of these important species. In addition, no comprehensive review of non-native salmonid interactions with species of concern currently exists for systems like those found in the Great Plains. Therefore, the objective of this paper is to review known interactions between introduced fishes and native fishes with a focus on salmonids and species of concern.

**METHODS**

We reviewed primary literature focusing on the influence of non-native salmonids on native fishes. The original search included a title and abstract search of articles published in or after 1970. Original journals searched were *Ecology of Freshwater Fish, Fisheries, North American Journal of Fisheries Management,* and *Transactions of the American Fisheries Society.* Additionally, a general search using key words such as "fish species of concern," "non-native salmonids," and "impacts of non-native fishes" were used and appropriate papers were included. Relevant articles cited within papers identified in the original search were included as well.

This review is broken down into two parts. The first part is a quantitative synthesis of peer-reviewed literature examining non-native salmonid interactions with native fishes in the Great Plains (mostly experimental studies), excluding non-native salmonid and native salmonid interaction studies. The Great Plains, as used in this paper, refers to the area encompassed by North Dakota, South Dakota, Nebraska, Kansas, and Oklahoma. However, when we examined non-native trout introductions, we expanded our search to the continental United States because species-specific information was limited in the Great Plains. We summarized the geographic area where the study took place and whether or not the study design was empirically based. We also asked which non-native and native species were involved: Did the non-native species have a significant influence on the native species, and if so, what were the influences on the native species? Were the influences positive, neutral, or negative? What biological organization levels were influenced? Were the mechanisms of the influences identified, and if so, what were the mechanisms? How much time elapsed since introduction of the non-native species? For empirical studies, what were the methods of introduction? The second part of this review is a qualitative review of papers encompassing a more global perspective, which may provide helpful insight into what may occur in the Great Plains with continued introductions of non-native salmonids.

**QUANTITATIVE RESULTS**

We identified 133 articles pertaining to influences of non-native sport fish introductions on native fishes. This list was reduced to 77 articles, published in over 30 peer-reviewed journals from 1972 to 2011, that more specifically examined the effects of non-native salmonid introductions. Of these, 25 were excluded from further analysis because they occurred outside the continental United States. Interactions, mostly competitive in nature, between introduced salmonids and native salmonids of concern are well studied and reviewed (Krueger and May 1991; Kruse et al. 2000; Peterson and Fausch 2003; Dunham et al. 2004; Cucherousset and Olden 2011). We therefore excluded an additional 17 articles examining these interactions from analysis.

**Geographic Area.** We identified only one peer-reviewed journal article that examined the influences of stocking non-native trout on native fishes in the Great Plains. Walsh and Winkelman (2004) monitored changes in a fish assemblage before and after the introduction of non-native rainbow trout (*Oncorhynchus mykiss*) in an Oklahoma stream. Although they observed a change in assemblage in some pool habitats, they were not able to definitively conclude it was the result of the introduced trout. We did find several state and federal reports, as well as some theses, from the Great Plains that suggested non-native trout introductions influence native species. However, we did not include them due to their speculative nature.

Although there is a lack of information from the Great Plains, studies of regions bordering the Great Plains provided some additional insight. The west and southwestern United States, more specifically the Colorado River system, appears to be the best-studied region. Unlike the Great Plains, these areas often constitute parts of some salmonid native ranges. Though these areas were home to salmonids historically (e.g., cutthroat trout [*Oncorhynchus clarki*]), non-native salmonids (e.g., rainbow trout) are often introduced into these areas, providing valuable insight into potential impacts of stocking non-native salmonids in areas like the Great Plains.
Study Design. Forty percent of the articles examining influences of non-native trout were classified as empirical. Studies not considered empirical were reviews, opinions, surveys, historical accounts, and those not containing a field or laboratory component. Of the empirical studies \( n = 14 \), two were observational studies of behavior (Freeman and Grossman 1992; Olsen and Belk 2005), three included diet analyses (Marrin and Erman 1982; Marsh and Douglas 1997; Yard et al. 2011), seven manipulated interactions using in-stream enclosures or laboratory streams (e.g., Blinn et al. 1993; Rinne and Alexander 1995; Bryan et al. 2002), two introduced non-native fishes into stream reaches and monitored response in native fishes (Garman and Nielsen 1982; Walsh and Winkelman 2004), and one removed non-native fishes and monitored response in native fishes among other things (Yard et al. 2011).

Species Evaluated and Their Influence. In the empirical studies we reviewed, brown trout \((Salmo trutta)\) or rainbow trout were at least one of the non-native species examined. Forty percent of empirical studies included at least one species of concern. In most cases, the non-native species did cause some change in individual behavior, prey on native species, and so forth; however, few authors specified whether or not this would have a significant impact on the population or community as a whole. The influence was always suggested to be negative or neutral, although in many cases, conclusions could be classified as speculative. In about 60% of the studies, authors at least suggest potentially negative influences of non-native species. In an additional 36% of the papers we reviewed, the authors suggested negative or neutral influences (responses often differed among different non-native species within the same study), and in only one case did authors conclude there was a neutral effect of non-native species.

Biological Organization Level and Type of Influence. Most studies observed influences on native fishes at the individual and population level; however, there were a few papers that examined community responses to non-native fishes (e.g., Walsh and Winkelman 2004). The most commonly measured influence on native species was reduction in survival or verified predation, reduction in abundance, and reduced growth. Additional influences included reduced feeding time and rate (Freeman and Grossman 1992), shifts in habitat use (Olsen and Belk 2005), and potential changes in assemblage structure (Walsh and Winkelman 2004).

Mechanism of Influence. The mechanism of the influence on native species was identified about 50% of the time. In those that examined mechanisms, predation was identified as a mechanism in approximately 80% of studies. Competition was suggested as a mechanism in about 20% of cases.

Time since Introduction. Over 70% of the studies stocked non-native trout into enclosures, laboratory streams, or stream segments as treatments. Therefore, the majority of the time these studies were examining the immediate effects of introductions, and long-term consequences of introductions were not evaluated. Methods of introduction other than experimental introduction included stocking for recreational purposes and accidental introductions.

QUALITATIVE RESULTS

The second part of this review is a qualitative review covering a broader range of papers, which may provide helpful insight into what may occur in the Great Plains with continued introductions of non-native salmonids. Here we also included international papers as well as papers discussing non-native salmonid interactions with native salmonids, which we felt provided pertinent information to managers considering stocking non-native salmonids in the Great Plains.

The potential effects of non-native salmonids may be expressed at one or several levels of biological organization (Cambray 2003; Simon and Townsend 2003; Dunham et al. 2004; Cucherousset and Olden 2011). Here we explore the range of possible effects on fishes and the mechanisms that might influence changes.

Individual. Influences of non-native salmonids can change individual behavior, diet, habitat use, fitness, and daily and seasonal movements of species of concern. Studies of alterations in habitat use and behaviors, or displacement of native species following the addition of non-native salmonid species, are prevalent in the literature (Blinn et al. 1993; Taniguchi et al. 2002; Olsen and Belk 2005; McHugh and Budy 2006; Blanchet et al. 2007; McGrath and Lewis 2007; Kadye and Magadza 2008; Penaluna et al. 2009). Salmonid introductions can also result in shifts in diet or decreases in foraging efficiency of native species (Taniguchi et al. 2002; McHugh and Budy 2006; Kadye and Magadza 2008), which may lead to decreased growth in the presence of non-native salmonids (Taniguchi et al. 2002; Ruetz et al. 2003; McHugh and Budy 2006; Blanchet et al. 2007; Zimmerman and Vondracek 2007;
Presence of brown trout decreased growth, shifted habitat use, and changed behavior of native brook trout (*Salvelinus fontinalis*) in an artificial stream channel (Dewald and Wilzbach 1992). Similarly, survival rates of native chinook salmon (*Oncorhynchus tshawytscha*) were greater in streams without non-native brook trout than in streams with brook trout, although the underlying mechanisms were not examined (Levin et al. 2002). Impacts specifically on species of concern have also been recorded. Threatened Little Colorado spinedace (*Lepidomeda vittata*) changed habitat use and behavior in the presence of non-native rainbow trout (Blinn et al. 1993). Not all the above-listed interactions have proven detrimental, yet any change in normal behavior could be of concern, as it may lead to decreased fitness.

Introduced non-native chinook salmon had little effect bioenergetically on native brook trout even though they significantly increased short-term brook trout movements in Michigan streams (Janetski et al. 2011). Non-native trout and tui chub (*Gila bicolor*) successfully partitioned resources and avoided competition in a California reservoir (Marrin and Erman 1982). In the presence of rainbow trout and brown trout, some native species (*Brachygalaxias bullocki*, *Galaxias maculates*, and *Trichomycterus areolatus*) demonstrated changes in habitat use, while other native species (*Geotria australis*) were unaffected due to differences in niche overlap (Penaluna et al. 2009). Size-selective predation led to an increase in size of individual dace (*Phoxinus spp.*) in lakes stocked with non-native salmonids compared to those that were not stocked (Nasmith et al. 2010). Similarly, non-native brook trout did not appear to affect the condition of adult greenback cutthroat trout (*Oncorhynchus clarkia stoma*) in Colorado streams (McGrath and Lewis 2007).

**Population.** Abundance is the most commonly observed and measured response of native populations to non-native salmonids. Several studies have attributed the declines in abundance of native fishes (Arismendi et al. 2009) and threatened native fishes (Rinne and Alexander 1995) to the introduction of salmonids. Abundance of native spotted galaxias (*Galaxias truttaeus*) in Tasmanian streams was explained better by the presence of non-native brown trout than by habitat and was lower in the presence of trout than expected based on habitat alone. Similarly, brown trout was the best predictor of presence and abundance of native *Galaxias vulgaris* in New Zealand catchments (i.e., *Galaxias vulgaris* presence was best predicted by brown trout absence; Townsend and Crowl 1991). Conversely, Nasmith et al. (2010) saw that although introduced trout (brook, rainbow, and brown trout) caused a shift in habitat use of native dace in Alberta ponds, trout had no overall effect on the population density of the dace.

**Community.** Introduced non-native fishes can affect species richness, composition, and size distribution of native communities as well as alter food webs. These changes have been recorded for numerous introduced fishes but are less well known for introduced salmonids. Walsh and Winkelman (2004) reported a shift in fish assemblage in pools in an Oklahoma stream. Assemblage changes included a decline in seven species following the introduction of rainbow trout (Walsh and Winkelman 2004). Flecker and Townsend (1994) saw decreases in insect density and biomass that resulted in increased algal growth in the presence of non-native brown trout. Konishi et al. (2001) found that the presence of rainbow trout and freshwater sculpin (*Cottus nozawae*) reduced foraging activity of the dominant amphipod (*Jeso gammarus jenensis*) and thus influenced stream leaf litter processing efficiency.

**Ecosystem.** Alterations in food webs, nutrient cycles, and physical habitats can result from introductions (Eby et al. 2006). Introductions of non-native rainbow trout to Japanese streams caused a shift in the diet of native dolly varden (*Salvelinus malma*) (Baxter et al. 2004, 2007). The shift in diet of dolly varden in turn caused a decrease in herbivorous insects and a corresponding increase in algal growth. The decrease in insect abundance, and thus emergence, resulted in lower aquatic to terrestrial flux and a reduction in riparian spiders (Baxter et al. 2004, 2007). Similar ecosystem-level influences of non-native trout may occur in Great Plains streams with historically simple community structures. For example, the headwater community of a typical Great Plains stream may consist of a few species of drift-feeding cyprinids and some benthić-feeding catostomids. Introduction of drift-feeding rainbow trout could likely reduce the abundance of invertebrates available for cyprinids. Cyprinids may then shift to a more benthic diet, and therefore also influence catostomid food resources. Increased benthic feeding may then result in alterations to the benthic macroinvertebrate community, which could have ramifications throughout the food web. In Great Plains communities, characteristic low diversity may amplify the effects of introductions, because the presence of fewer trophic levels means that effects cascade through the system at a more direct and rapid rate than in more complex systems.
Mechanisms that Affect Native Species of Concern

There are four main mechanisms by which salmonids can negatively affect species of concern: predation, competition, hybridization, and disease transmission. Several local, state, and federal agencies have warned against the potential negative interactions between non-native salmonids and native fishes. Each mechanism is reviewed below.

Predation. Direct non-native salmonid predation on several native fish species of concern has been documented (see review Taylor et al. 1984). Many studies have theorized that predation has contributed to the decline of species of concern, but here we discuss only those where direct predation has clearly been documented through observation, experimental studies, or diet analysis. Salmonid predation has been validated on endangered razorback suckers (Xyrauchen texanus) (Carpenter and Mueller 2008), endangered humpback chub (Gila cypha) (Marsh and Douglas 1997), threatened Little Colorado spinedace (Blinn et al. 1993; Rinne and Alexander 1995), and threatened Galaxias auratus (Stuart-Smith et al. 2007). Yard et al. (2011) confirmed rainbow trout and brown trout predation on several native Colorado River species including the endangered humpback chub. The trout consumed a much greater proportion of native fish than non-native fish despite the greater abundance of non-native fishes in the river (Yard et al. 2011).

Although there are few instances of salmonid predation on species of concern, predation on the same or similar species in areas where their populations are considered stable has been documented. For example, stocked brown trout greater than 280 mm consumed native nongame species 25 mm to 110 mm in length in a Virginia creek (Garman and Nielsen 1982). Among these, the three most commonly consumed species—torrent sucker (Moxostoma rhothoecum), roseyside dace (Clinostomus funduloides), and central stoneroller (Campostoma anomalum)—are morphologically similar in size and shape (e.g., fusiform bodies, soft rayed fins) to many dace species of concern in the Great Plains. Brown trout were also found to be piscivorous at 130 mm (L’Abee-Lund et al. 1992) and found to consume Phoxinus phoxinus, an abundant cyprinid species in Norway (L’Abee-Lund et al. 2002). Similarly, East and Magnan (1991) found redbelly dace (Phoxinus eos) can comprise up to 30% by weight of brook trout diets in Ontario lakes. In the United States, Phoxinus species are listed as species of concern in several states including Great Plains states, and two members of the genus Phoxinus are federally listed as threatened and endangered (Williams et al. 1989). Stocking of non-native salmonids may be of concern, as these species are often found in preferred salmonid habitat, and introduction could result in increased predation risk.

Non-native piscivores may pose an increased risk to native populations due to a lack of coevolutionary history resulting in the inability of native fish to recognize non-native fish as a threat (Townsend and Crowl 1991; Blinn et al. 1993; Bryan et al. 2002; Nannini and Belk 2006). This is a potential reason introduced rainbow trout were able to easily prey on Little Colorado spinedace even in the presence of increased cover (Blinn et al. 1993). Bryan et al. (2002) also suggested that spinedace decreased activity in the presence of non-native rainbow trout due to an inability to recognize them as a threat. Lack of coevolutionary history suggests some adaptations, such as color, may pose increased risk of predation. Many small cyprinid species are sexually dimorphic and display bright breeding colors that can be retained far beyond the breeding season. These colors may attract or increase the probability of visible detection by introduced sport fishes such as salmonids.

It is unclear whether non-native salmonids will have an impact on the overall population of native species even if salmonids do prey on native species. Rainbow trout predation on native fishes in an Oklahoma Ozark stream was low and probably did not constitute a significant impact on the population (Walsh and Winkelman 2004). Some predation by brook trout on greenback cutthroat trout was observed in Colorado streams, but again, it probably had little effect on the greenback cutthroat trout population (McGrath and Lewis 2007). However, the magnitude of the impact of predation is amplified in threatened fishes (Knight and Gido 2005). Even if a predator randomly selects prey, the overall effect on a population will be greater for threatened or endangered species due to their already low numbers. For this reason, the possibility of predation by non-native salmonids should be of concern for threatened and endangered species.

Competition. Competitive interactions with non-native trout are often cited as possible causes of declines in abundance, species richness, and fitness, and changes in distribution, behaviors, and life histories of native species (McIntosh et al. 1994; Gido and Propst 1999; Taniguchi et al. 2002; Ruetz et al. 2003; Baxter et al. 2004; Olsen and Belk 2005; Baxter et al. 2007; Kadye and Magadza 2008; Penaluna et al. 2009). Few studies, however, have been
able to provide evidence of interspecific competition between non-native salmonids and native species in natural streams (Fausch 1988). The lack of evidence for competition is because of the relatively difficult task of proving competition. Although empirical evidence is apparently lacking, there is circumstantial evidence of direct and indirect competitive interactions.

Direct competitive interactions in this case include both exploitative and interference competition. When introducing non-native salmonids, the potential for direct competitive interactions with native species due to shared habitats and diets should be of concern. Competition for space between natives and introduced species has been suggested to lead to declines in native fish populations (McIntosh et al. 1994; Gido and Propst 1999; Taniguchi et al. 2002; Olsen and Belk 2005; Kadye and Magadza 2008; Penaluna et al. 2009). Proving diet competition remains difficult, as diet overlap does not guarantee competition. However, it is still helpful to recognize potential sources of competition for food resources that may lead to the decline of a species. For example, *Gammarus pseudolimnaeus* consumption by brown trout may lead to competitive interactions between the introduced trout and native slimy sculpin *Cottus cognatus*, also a predator of *G. pseudolimnaeus* (Ruetz et al. 2003). Johnson and Johnson (1982) documented diet overlap betweenbrook trout, blacknose dace (*Rhinichthys atratulus*), and pearl dace (*Semotilus margarita*) in a small Adirondack stream, and although they did not examine competition, they did confirm diet overlap with native species, which should caution future stockings where the dace are found. Both blacknose dace and pearl dace are found in parts of the Great Plains where non-native salmonids have been stocked. Salmonids are omnivorous and generalists, and the potential for diet overlap with these and other species of concern is present.

Although competitive interactions are likely in many areas, non-native salmonids and native fishes may successfully partition resources with no observable negative impacts. Most often this occurs in lakes where salmonids prefer deeper, cooler, more pelagic areas, and small-bodied native fishes prefer shallower, warmer, more littoral areas. Little competition between introduced trout and native species in Ontario lakes was observed because native species were isolated from trout during crucial periods due to thermal preferences (MacRae and Jackson 2001). Similarly, trout (brown trout and rainbow trout) and tahoee suckers (*Catostomus tahoensis*) occupied different areas in a California reservoir, thus potentially reducing diet overlap (Marrin and Erman 1982). In the same study, small trout and tui chub occupied similar habitats but successfully partitioned resources, making coexistence possible (Marrin and Erman 1982).

Size (Griffith 1972) and age structure (Peterson et al. 2004) may also play a role in the ability of introduced salmonids to outcompete native species. Age-1 masu salmon (*Oncorhynchus masou*) in Japan were superior competitors compared to age-0 rainbow trout, but age-1 rainbow trout competitively decreased growth and foraging efficiency of native age-0 masu salmon (Taniguchi et al. 2002). Adult greenback cutthroat trout were unaffected by brook trout, but the population was instead limited by interactions between brook trout and age-0 greenback cutthroats (McGrath and Lewis 2007). Likewise, brook trout may affect the survival of juvenile, but not age-2 or older Colorado River cutthroat trout (Peterson et al. 2004). Changes in diet, habitat use, and behaviors with ontogeny may result in differing competitive interactions among age groups. Therefore, examining all age groups is of the utmost importance (Peterson et al. 2004).

Introduced salmonids can also create competition between two normally co-occurring native salmonids. Hasegawa and Maekawa (2006) showed that in the absence of rainbow trout, white-spotted char *Salvelinus leucomaenis* and masu salmon partitioned habitat successfully. However, when brown trout or rainbow trout were introduced, interspecific competition between the two native species increased (Hasegawa and Maekawa 2006).

Indirect competitive interactions are also of concern. The overall results of cascading effects from salmonids on native species of concern have not been well studied. However, cascades themselves are well documented, and potential impacts on native species can be implied. Flecker and Townsend (1994) examined differences in community responses to non-native and native fishes, finding that density and biomass of insects were lower in the presence of non-native brown trout relative to control treatments. This suggests introduced salmonids may reduce food resources for native fishes, leading to increased risk of competition in food-limited areas.

Most studies that investigated competitive interactions between native and non-native fishes reported harm to native fishes; however, established fishes (either native or non-native) can also outcompete introduced fishes (Weber and Fausch 2003). This may be especially true in the case of hatchery-raised sport fishes. Stream stocking often results in high initial mortality of stocked trout. Some researchers have suggested this is due, at least partially, to the superior competitive abilities of established fishes compared to hatchery-raised fishes (Miller 1958).
The species or population first established in an area tends to have the competitive advantage over newly introduced fishes (Miller 1958; Glova and Field-Dodgson 1995; Deverill et al. 1999; Harwood et al. 2003), and in some cases hatchery-raised fishes may be at a disadvantage behaviorally, physiologically, or morphologically compared to native fishes (Leary et al. 1983). This may produce a bias in the literature toward not reporting instances where hatchery stockings were not successful. If stockings are unsuccessful because stocked salmonids have low survival rates, interactions between native species and introduced species are likely to go unrecorded (e.g., the stocking was not successful), whereas if the natives are the ones being outcompeted, it may be more likely to be recorded.

**Hybridization.** Although not a concern in the Great Plains due to a lack of native salmonids, hybridization is a common mechanism by which non-native salmonids influence native fishes. Examples of negative impacts of hybridization between introduced salmonids and native fishes are abundant, as many salmonid species readily hybridize with each other. Non-native brook trout have been shown to hybridize with native brown trout, potentially reducing brown trout reproductive success in France (Cucherousset et al. 2008). Similarly, in the United States, non-native brown trout reduce native brook trout fitness through hybridization (Leary et al. 1983). Hybridization is also a concern for at-risk species and has been cited in the decline of several threatened and endangered species. Hybridization of native salmonids with non-native salmonids, especially rainbow trout, has been implicated in the decline of threatened westslope cutthroat trout *Oncorhynchus clarki lewisi* (Allendorf et al. 2004) and in the elimination of threatened Paiute cutthroat trout *Oncorhynchus clarki seleniris* from historic habitat (USFWS 2004). Non-native salmonids were considered a factor in the decline of native Apache trout (*Oncorhynchus apache*) in Arizona (Carmichael et al. 1993; Rinne and Alexander 1995) and Gila trout (*Oncorhynchus gilae*) in New Mexico (review USFWS 2002a), and were listed as a primary threat to California golden trout (*Oncorhynchus mykiss aguabonita*) (USFWS 2002b) and Rio Grande cutthroat trout (*Oncorhynchus clarki virginalis*) (Pritchard and Cowley 2006). Additionally, non-native brook trout have been shown to hybridize with native threatened bull trout (*Salvelinus confluentus*) in the western United States (Leary et al. 1983).

There is a negative connotation associated with hybridization, especially between two distinct species. Hybridization has been shown to increase risk of extinction in threatened species and often results in a reduction or loss of genetic integrity (Cucherousset and Olden 2011). However, the negative implications are less clear when it comes to hybridization between two subspecies or even two populations of the same subspecies. Introduced species could be used in some cases to "rescue" endangered native strains of some fish species of concern through intentional hybridization, as has been done for some mammals (Land and Lacy 2000; Allendorf et al. 2004).

**Disease and Pathogens.** Disease and pathogen transfer is always a concern when new species are introduced. Many diseases have been introduced with the arrival of non-native fishes (Hoffman and Schubert 1984; Krueger and May 1991) and have negatively influenced native populations. Viral hemorrhagic septicemia (VHS) was first recorded in the Great Lakes basin in 2005 (although it was recorded previously in some coastal areas) and is easily transferred from fish to fish (Bowser 2009). Intense precautionary methods are underway to further prevent the spread of the disease. Both brown and rainbow trout are listed under the Viral Hemorrhagic Septicemia Federal Order, which now regulates interstate and international movement of species in VHS-infected areas (Bowser 2009). Because of this order, there is little chance of known infected individuals being stocked in uninfected areas; however, accidental introductions or intentional introductions by anglers unaware of the disease are still a concern (Bowser 2009). Aside from VHS, salmonids are also susceptible to infectious hematopoietic necrosis (IHN) and can transfer it to native populations. First recorded in the United States in the 1950s, IHN continues to threaten hatchery and wild stocks (CFSPH 2007). It can be spread between individuals via contact with infected excretory products or through infected water and often results in mortality of young fish (CFSPH 2007). Young fish mortality can reach 95%, but mortality decreases with age as resistance to infection builds (CFSPH 2007). Introductions of non-native fishes have potentially harmful effects on native fishes via disease transmission if care is not taken to ensure introduced fish are disease free.

**Species-Specific Mechanisms and Potential Benefits of Non-Native Species**

Introduced trout species can affect native fish species in various ways. Garman and Neilsen (1982) and Crowl et al. (1992) both suggested that brown trout are more detrimental to other fishes than rainbow or brook trout.
This may be due to the brown trout’s more piscivorous nature, lower susceptibility to angling, more aggressive behavior, and greater survival rates (Garman and Neilsen 1982). However, the higher perceived risk of brown trout compared to other trout may be due to differences in the mechanisms that ultimately influence the native species (Crowl et al. 1992). As Crowl et al. (1992) point out, hybridization is the most common mechanism by which rainbow trout influence native fishes in the United States (due in part to the large number of salmonid-salmonid hybrids), whereas predation is the most often cited mechanism of brown trout impacts. Brook, brown, and rainbow trout, however, are all capable of predation, competition, and hybridization, and where introduced, could potentially negatively interact with native species. The relative importance of these mechanisms depends on both the native and non-native species present as well as other environmental factors and resource availability.

Species of concern may also benefit from introduced salmonids. The growth and condition of some native species have benefited from the consumption of introduced salmonids’ eggs. Janetski et al. (2011) observed that energy lost from increased movements of brook trout following non-native chinook salmon runs was offset by that gained from consumption of the introduced salmonids eggs. Similarly, native brook trout diets were comprised of 95.6% salmon eggs during October salmon spawning runs (Crawford 2001) and condition factor increased significantly as a result in a Lake Ontario tributary (Johnson and Ringler 1979). Non-native salmon eggs may be an especially important food source during times of the year in which resources would normally be diminished.

**SUMMARY**

Non-native species do interact with native species via predation, competition, and hybridization and can have both positive and negative effects. There seem to be more recorded cases of negative interactions, but there may be some bias associated with published studies that show an impact as opposed to those that show no impact, especially for species of concern. Much of the literature we reviewed was highly circumstantial in concluding that non-native salmonids had any effect on native fishes. Nonetheless, these studies lend helpful insight into what may be occurring, and should be considered before potential introductions are made. Specific interactions and consequences of introductions should be investigated prior to any introduction.

We agree with many others that there is an apparent lack of empirical evidence evaluating influences of non-native fishes on native fishes (Fausch 1988; Shafland 1996). This is especially so in the Great Plains. This lack of information emphasizes the need to gain a better understanding of how non-native fishes influence at-risk species. Exhibiting caution when proposing such introductions is a prudent approach to ensure that negative, long-term, and irreversible outcomes are prevented until the specific outcomes from such activities can be determined.

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ROLES OF PERCEIVED CONTROL AND PLANNING IN RANCH DROUGHT PREPAREDNESS

Tonya Haigh and Cody Knutson

National Drought Mitigation Center
School of Natural Resources
University of Nebraska—Lincoln
810 Hardin Hall
3310 Holdrege Street
Lincoln, NE 68583-0988
thaigh2@unl.edu

ABSTRACT—Ranchers in the Great Plains and across the United States face the threat of periodic drought. Though ranchers might minimize losses through drought-preparedness activities, many do not adequately prepare for drought, in part because of perceptions that the outcomes of drought management are not controllable. We explore how drought planning activities affect ranchers' perceptions of control and drought preparedness using the theories of planned behavior and goal attainment as guiding frameworks. Ten Great Plains ranchers who had engaged in drought management activities were interviewed about their plans. From the interviews, three activities emerged that appeared to increase ranchers' perceived control during drought: maximizing the health and flexibility of the ranch operation, monitoring precipitation and forage, and implementing "decision rules" as drought conditions became apparent and progressed. The actions supported greater perceived control in the face of drought by increasing the number of desirable options available to ranchers, increasing ranchers' confidence in predicting the effects of their actions, and providing "mental practice" for decision making during a drought event. This exploratory research demonstrates the value of incorporating theories of planned behavior and goal attainment into applied research on rangeland management and drought planning behavior, and suggests directions for future research and education.

Key Words: drought, planning, ranching, management, perceptions, control, preparedness

INTRODUCTION

Drought is a threat to the financial and natural resource health of Great Plains ranches that rely on nonirrigated rangeland. For example, during the drought of the early years of the first decade of the 21st century, ranchers in Wyoming and Nebraska experienced reductions in grazing capacity, irrigation capacity, and winter feed production, leading to reduced sale weights and weaning percentages, and reductions in brood herd numbers and owner equity (Bastian et al. 2006; Knutson et al. 2006). It has been demonstrated, though, that drought losses can be reduced through ranchers' management decisions. In a striking example of the benefits of drought preparedness, Coppock (2011) found that 25% of Utah ranchers reported only neutral or positive impacts following the especially severe 1999–2004 drought, because they had access to reliable water sources and ample feed supplies.

Despite the threat of drought-related losses and the potential for lessening those losses, Great Plains ranchers are often less prepared for drought than they should be (Thurow and Taylor 1999; Dunn et al. 2005). Dunn et al. (2005) observed that South Dakota ranchers differed greatly in their response to the 2002 drought, and the researchers explored barriers that may keep ranchers from responding to drought with uniform success. Building on past research on farmers' experience with drought (Saarinen 1966; Taylor et al. 1987; Woudenberg et al. 2008), Dunn et al. suggested that rangeland managers who lack drought experience or who have had a recent run of good years may have less awareness of drought as a hazard and the full range of potential effects, and thus undervalue drought preparedness. They also posited that a rancher who is more concerned with pounds of beef produced than the long-term health of their rangelands may delay or fail to take action during drought.

In addition, both Dunn et al. (2005) and Thurow and Taylor (1999) highlighted the unpredictability and uncontrollability of ranch drought management as a significant barrier. The nature of drought itself makes management problematic. Thurow and Taylor (1999:413) say, "The be-
Subjective norms (Does person feel social pressure to do behavior?)

Perceived control (Does person feel in control of behavior?)

Theory of Planned Behavior

Figure 1: Simplified combined model of theory of planned behavior and goal attainment theory, based on Azjen 1991 and Gallo and Gollwitzer 2007.

The effects of drought often accumulate slowly as a dry period begins and may linger after expected rainfall patterns have resumed. Cattle inventories, price cycles, other commodity markets, interest rates, and the chance of federal government intervention may also add to ranchers' perceptions that the outcomes of their actions during drought are unpredictable and uncontrollable, and keep ranchers from taking action in an effective manner.

We believe that the discussion of why ranchers don't adequately prepare for drought may benefit from the inclusion of social-psychological insights into planning behavior. In particular, research using the theory of planned behavior has provided insight into the influence that an individual's attitudes toward a behavior, beliefs about what others think he or she should do, and perceived control over the outcome of the behavior has on his or her intentions to perform a behavior (Ajzen 1991, 2002). Related work in goal attainment theory has further explained how individuals move from intending to perform a behavior to actually performing the behavior (Gollwitzer and Moskowitz 1996; Gallo and Gollwitzer 2007). A simplified diagram of the components and relationships between the two theories is shown in Figure 1.

This article focuses on one component of the theory of planned behavior that appears to be a problem for ranch drought preparedness, that of perceived behavioral control. Perceived behavioral control may describe both beliefs about one's ability to perform a behavior and beliefs about the "controllability" of the outcomes of the behavior (Sparks et al. 1997; Azjen 2002; Rodgers et al. 2008). The relationship between perceptions of control and behavior has potentially interesting applicability in ranch drought preparedness; however, rancher perceptions of control with regard to drought-preparedness behavior have not been extensively studied.

We are particularly interested in the connection between perceived behavioral control and planning. Many rangeland researchers and advisors have recommended the development of a drought plan as an essential component of ranch drought preparedness (Reece et al. 1991; Hamilton 2003; Pratt 2000; Hart and Carpenter 2001; Clark and Adams 2002; Thurow and Taylor 2003; Thorne et al. 2009; Knutson et al. 2011). Little has been done to document the effect of having a ranch drought plan, and again, we may need to look outside the discipline to explore how having a plan might actually help a rancher. Research in goal attainment theory has found that having a plan (or "implementation intentions" in the language of the theory) effectively moves people toward achieving their goals (Gollwitzer and Moskowitz 1996; Brandstätter et al. 2001; Jackson et al. 2005; Gollwitzer and Sheeran 2006; Gallo and Gollwitzer 2007). Further, having a plan may be particularly helpful in moving people toward behaviors in which they experience low perceived control (Gärling and Fujii 2002; Kidwell and Jewell 2010). Much of this research has been done in an experimental context, often with students, but effects have also been found related to health behavior goals (Jackson et al. 2005).

Intrigued by potential applications of behavioral theory to ranch drought planning, in this article we ask, How does having a drought plan affect a rancher's perceptions of control over drought and management during a drought?

METHODS

We used a qualitative approach to elicit ranchers' perceptions of their experiences with planning and drought management, per Berg (1995). Ranchers who had implemented a drought plan were identified using purposive sampling methods. Some of the ranchers identified themselves to the National Drought Mitigation Center at previous drought workshops. We also asked rangeland advisors and researchers to recommend ranchers they knew who were involved in drought planning and management. Ten ranchers from five Great Plains states (South Dakota, Nebraska, Kansas, Colorado, and Texas) were identified to interview. We focused the study on the Great Plains be-
cause ranchers in the region are relatively similar in their management of grass-dominated ecological landscapes and threats from drought. We obtained approval from the University of Nebraska—Lincoln Institutional Review Board to interview them about their planning activities.

Ranchers received an introductory letter by mail or e-mail, and were contacted by phone to request an interview. All the identified ranchers agreed to be interviewed. We conducted telephone interviews with these individuals during the summer of 2009 and spring of 2010. The interviews were conducted with a guiding script, but with flexibility to pursue the interests of the participant. During the interviews, ranchers were asked to tell us about their operations, and also to describe their drought plan, how they had put their drought plan together, how well they thought their drought plan (if implemented) had worked, what problems they encountered in planning for drought, and what they would recommend to other ranchers. Interview lengths ranged from approximately 30 minutes to 1 hour 15 minutes. From the interviews, the project team obtained approximately 8 hours of taped recordings.

The recordings were transcribed and open-coded by hand, first to identify ranchers’ descriptions of the components of their drought plans, how effective they thought their drought plans were, and what barriers they had encountered. We further coded drought plan components based on emergent commonalities and characteristics, per Glaser and Strauss (1967) and Strauss and Corbin (1990).

The first round of interviews focused on ranchers from South Dakota, Nebraska, Kansas, and Texas during the summer of 2009. After the first round of seven interviews, in September 2012 the participating ranchers were invited to attend, at the researchers’ expense, a workshop in Lincoln, NE, on ranch drought planning. Five of the ranchers were able to attend the workshop, along with nine ranch advisors who were also interested in ranch drought planning. The workshop included a presentation of interview results, including the categories and processes of drought planning highlighted in the pre-workshop interviews. The ranchers at the workshop verified the categories and process that had emerged through the coding process, and advisors verified that other ranchers had gone through similar processes. After the workshop, three additional interviews were conducted with ranchers in Colorado, Nebraska, and Texas to further verify the emergent drought planning tactics and perceptions.

Interview transcripts were then analyzed through the lens of the theories of planned behavior and goal attainment. Using guiding concepts from the literature (Francis et al. 2004), we examined, for example, how ranchers described their perceived control over drought management outcomes, and how they thought the components of their drought plan impacted their control over drought management. The outcomes of this analysis were compared to results from other fields of study to provide verification and depth of analysis.

RESULTS

The Ranchers

The ranchers we interviewed ran operations that were relatively diverse in type and size. Operations ranged from approximately 100 hectares to 100,000 hectares. Seven of the ten ranchers ran cow-calf operations, with some incorporating stockers, yearlings, bred heifers, custom grazing, or recreational hunting; the other three ranchers had custom grazing operations. Seven were exclusively range-based, while three of the ranchers also had crop ground or pivot irrigation.

Interviewees displayed attitudes consistent with their drought management intentions, per the theory of planned behavior framework. Specifically, the ranchers valued natural resources as highly as production, or showed appreciation of aspects of their ranch ecosystems beyond their livestock or forages. Six ranchers made it a point to mention that they were part of a larger family operation, that their children were involved in the operation, or that they were planning for the future of the ranch, with one saying, “This ranch will be here way after I’m gone. And my goal, my number one position in life, is to keep this property in good shape for the future, including my own.”

Many of the ranchers noted experiences with drought that had led them to believe in the value of preparing for drought. A few had learned from the school of hard knocks. One rancher noted, “I’ve done it myself too many times, held onto them, put more feed in them. I’ve fed two cow herds up in drought. Instead of having 100 head of cows when I was through, the last time I had 15 cows paid for. Once you go through that...” And another rethought her entire operation after experiencing financial loss during the 2002 drought. This rancher admitted that before her reorganization, “I’d always been cow-calf so I didn’t have a clue to buy some stockers or understand what the undervalued animal was... All I could think of was how was I going to buy back cows and calves.”

All the ranchers used drought-preparedness strategies and saw those strategies pay off during earlier droughts, adding to the value they saw in the behavior. Most pointed to the health of their grass and quality of their rangeland.
One said, “I think that our country came back faster than the guy that just hunkered down, kept his cows there, went to feeding, [and] went to caking. [That] really did degrade the range conditions enough that it took longer to come back than country that [we] got off of right away.” Four ranchers also said that because of their grazing methods and their efforts to adjust stocking rates at the earliest sign of drought, they had avoided having to destock to the extent that they would have had to without a drought plan. And another rancher said his drought planning process had helped reduce his debt level.

While their beliefs and attitudes may have predisposed these ranchers to value drought preparedness, some of the ranchers acknowledged the controllability and predictability problems that make the behavior difficult. One rancher called drought planning “the least precise and most troublesome” part of his overall ranch management. Two ranchers mentioned that uncertainty in weather prediction makes decision making difficult, and others said that uncertainty in predicting how the livestock markets would respond during a drought made drought planning difficult. One rancher noted that each drought is unique and may vary in its severity and impacts on resources and on livestock markets. And one rancher pointed out that when no rain falls, his ranch couldn’t be considered drought-proof. He said,

In 2002, on that ranch for that 12-month period we had 3.8 inches ([9.7 cm] of rain total, of precipitation of any kind. And I can tell you this, you cannot drought-proof a ranch. You can help and you can delay the effects and you can minimize them, but you can’t drought-proof your ranch.

**Strategies that Address Rancher Perceptions of Control**

The ten ranchers described drought-preparedness strategies that were as diverse as the ranchers and their operations themselves; however, emerging from the interviews were three common strategies that ranchers used to increase their perceived control during drought. We focus here on ranchers’ descriptions of maximizing the health and flexibility of their operations before drought, monitoring the health of their resources, and implementing decision rules on critical dates when drought conditions appear.

**Maximizing Health and Flexibility of Operations Pre-Drought.** All the ranchers said that one of the most important things they did to prepare for drought was to develop a healthy ranch operation. Each rancher used a grazing management system that is believed to increase pasture health, including rotation grazing, managed intensive grazing, rest deferral, stocking conservatively, or not grazing grass too short. Two ranchers also noted improving pastures through fertilizing, overseeding, or brush control. One rancher described how these actions improved his control over drought impacts: “Your root system of your plants is maintained much better in a planned system than it is in a season-long continuous grazing system, and so it gets you further into or through a drought. And as you come out of that drought, your recovery is quicker too.” Five of the ranchers also emphasized making water improvements before drought occurred, either to facilitate their rotation grazing program or to meet livestock water requirements during drought.

Eight of the ten ranchers built flexibility into their operations as a way to increase the desirable options available to them when drought hit. Two ranchers diversified beyond cattle to other livestock and even wildlife for hunting operations. Three ranchers included custom grazing in their operations as a means to increase flexibility and improve range management during drought, with one explaining, “It gives us flexibility during drought. It’s a more liquid asset that can be moved more quickly than a cow-calf pair can. It allows us to liquidate, or destock, in a much quicker fashion.” Three ranchers stressed planning hay or forage reserves into their operations, to increase their options during drought. Regarding this strategy, one rancher said, “We build enough in the good years that we can stand a two-year drought. . . . In the good years we build lots of reserve. In the drought years we take off.” One rancher also emphasized minimizing or eliminating debt as a way to improve flexibility during drought.

**Monitoring Resources.** Monitoring, a long-time cornerstone of conservation planning, was mentioned in almost every operation. Nine out of ten ranchers monitored precipitation or soil moisture to identify the onset of drought and to predict the amount of forage their rangelands would produce that season. Some said they used climate prediction resources in addition to their on-farm monitoring data. One rancher had been developing a historical record of rainfall and forage production on his ranch since the mid-1980s. As a result of monitoring, one rancher described the confidence he felt in making decisions early in the season: “Our big moisture months are April, May, and June. So . . . if you know you’re dry in April and May, you’ve already lost two-thirds of your growth [window].”

In addition, many ranchers monitored their pastures
and forage production. One had been measuring how much forage had been harvested off his rangelands since the early 1990s. Another said that by tracking his forage production over time, he could see trends in time to act on them. He said, “I could see a steady decline over those [dry] years. And so I felt like I was more ready [to act] in 2006 than I would have been if I didn’t have those records to fall back on.” Another described a benefit of monitoring pasture composition: “Over time you gain experience in looking at grass and at your key species that you make decisions from.” In these ways, monitoring appears to increase awareness of drought severity and impacts and to increase perception of the control ranchers had over range conditions and the timing of their actions.

Critical Dates and Decision Rules. All the ranchers described developing and implementing some form of decision rules, or “if-then” strategies. The decision rules, in general, outlined when decisions needed to be made, the conditions that would trigger decision making (the “if”), and what types of decisions should be made (the “then”).

Seven of the ten ranchers designated specific dates or months for monitoring and making grazing and other range management decisions. Some tied dates to key precipitation times or peak growth periods for their primary forages. One rancher said, “The most critical [date], if I might share that with you, is May 1. If we don’t have good moisture by then, we know we’ve got trouble. Not that we can’t come out of it, not that we can’t manage around it. It just makes life a lot simpler if it’s wet May 1.” Other ranchers set dates based on marketing schedules or grazing contracts. For example, one rancher with a custom grazing operation said, “My decision point is back in March when I have to tell my customer how many cattle to bring.” Another rancher with a large number of acres set his dates around cattle-working schedules.

The “if-then” was a blueprint of management alternatives that ranchers had thought through ahead of time. While all said they worked with some type of decision rule, the formality of the rules varied among ranchers. Seven of the ranchers had put their decision rules in writing, including two ranchers who wrote into their grazing contracts the actions to be implemented when monitoring indicated drought or forage deficiency. One rancher said, “I think it’s real important to have that discipline, and writing it out is probably as good a way as any to get that discipline.” Three ranchers said their decision rules were kept in their heads.

Ranchers said their decision rules included making stocking rate modifications when precipitation or forage deficits triggered the action. Some had general strategies for destocking or accessing alternative forages, while others had more specific plans. Two ranchers had also developed decision rules for other pasture management considerations, such as ceasing prescribed burns when forage and precipitation were below critical levels.

The ranchers emphasized that because they had worked on their ranch health and flexibility before drought, they knew they could take actions that would help them protect their range, finances, and other resources during drought. Those that had purposefully created flexibility in their operation knew they would bring in fewer contract grazers in the spring if it looked dry, and they wrote contracts to ensure that livestock would go home when drought conditions required it, or knew which stockers they would sell. Some planned to feed hay that had been stored for drought, graze meadows that were normally hayed, lease cornfields to graze, or even purchase feed when deemed cost effective.

Those ranchers who had a date or time of year when they monitored conditions and made decisions said that one of the main strengths of their drought management was their determination to make decisions based upon their best knowledge at that time and to not second-guess or delay their decisions. They emphasized that it was important, once conditions triggered the drought plan, to be committed to following the plan without second-guessing it or looking back. One rancher said, “The consequences are a lot better if you’re prepared than . . . if you either don’t make decisions or [if] the ones that you make are too late.” Another gave an example: “We were so dry the first of March. The first of March I was on my last feeding, I had maybe 100 bales of hay left, and I was making decisions [that] everything I had, probably 75% of the livestock I had, was going to go by the 15th of April. . . . If it hadn’t rained, these cattle were going to go, and yeah, you take a loss on it. But this has always been pretty well a fact, your first loss is your least loss. You’ve got to make the decision.”

Another rancher said,

I’ve never known I’m going into a drought. And you don’t. Is this just a dry spell? Is it going to rain next week? Is it not going to rain for another five years? You know, there’s no such thing as knowing you’re going into a drought. And so what you’ve got to do is, you’ve got to say, for my present, current conditions, how do I need to adjust my stocking rate? You’ve got to say, what are my current conditions, and with the amount of grass I’ve got, what can I run? And I think that’s a mindset that’s
important, because like I say, every time you get a little shower during a drought, that gives you false hope if you’re not careful.

In some cases, having a date in mind kept the rancher from panicking and making a decision too soon, as described by this rancher: “Back in middle March, one of my customers called me [saying],”

‘Oh, it’s so terribly dry, what are we going to do?’ I said, look, this website [predicts] normal weather rainfall. Yes, it’s dry right now . . . but we still have the rest of March and April and May. I said, you don’t generally bring the cows until the 10th of May, let’s wait until mid-April to make that call. Well, the next six weeks we got eight inches of rain.

A few of the ranchers directly addressed the impact of the decision rules on the emotional side of making decisions during drought. One said, “I think you’ve got to have it to remove the emotional side of it. It’s like when I’m hedging cattle in the futures market. I need to have a game plan to go in.” Another said, “It’s all that planning and understanding, so that you don’t have to think about it when you are in the depths of the emotion. That is the number one key.” The rancher added, “You’ll only see and find the things to reinforce what you’re thinking, rather than truly critical thinking, if you haven’t done [your thinking] ahead of time.”

DISCUSSION AND CONCLUSION

The ranchers we interviewed were engaged in activities that helped them prepare for, and minimize, the effects of drought. The actions they found helpful—maximizing the health and flexibility of their operations, monitoring precipitation and forage, and implementing decision rules on critical dates when drought conditions arise—are three factors that appear to affect their perceptions of their ability to control the outcomes of their drought management efforts.

First, by maximizing the health and flexibility of their operations, the ranchers positioned themselves to be able to take what they perceived to be the most desirable actions possible. By thinking through options ahead of time, they also may have increased the number of potential desirable actions available to them. According to Burton et al. (1993:117), “Often there is a significant difference in the number of alternatives when an individual is forced by rude circumstances, rather than by communicated information, to canvass ways of reducing loss.” Perceiving more options, and more desirable options during drought, may have made it easier for ranchers to decide to take action.

Second, monitoring of rangeland and precipitation provided ranchers with information tailored to their operations, and provided evidence of the effects of their range management under different precipitation scenarios. Monitoring and evaluating the results of their actions appear to have increased the ranchers’ confidence in predicting future conditions and what future actions will accomplish, increasing the ranchers’ sense of perceived control.

Third, the creation of a drought plan, or “if-then” strategy, was perceived by ranchers to positively impact their ability to take timely and effective action during drought. This finding is consistent with goal attainment theory, which maintains that the development of a plan facilitates achievement of behavioral goals. Gärling and Fujii (2002) refer to planning as “mental practice.” Further, according to Gallo and Gollwitzer (2007), the “if-then” link may make it easier to detect a need to act, and may make the process of acting more automatic. Experimental as well as observational research has indicated that people who have a plan may be able to act in a more efficient manner than people who do not have a plan, because they have already deliberated and evaluated the actions that might be taken to reach one’s goal (Xiaio et al. 1997; Webb and Sheeran 2007). Descriptions of ranchers’ planning and decision making reflect similar processes.

This exploratory research demonstrates the value of incorporating theories of planned behavior and goal attainment into applied research on rangeland management and drought planning. This theoretical lens may be used to provide structure for identifying factors that affect behaviors and effective educational interventions in range management, just as it is currently used in other fields such as management of health behaviors. Additional research may consider whether learning about someone else’s plan for drought affects an individual’s perceived control; whether the process of developing the drought plan affects perceived control; or whether new technologies, such as grazing management software that allows ranchers to develop “if-then” scenarios, affect perceived control.

Further research might also explore how ranchers with and without a drought plan act during drought, and whether they are able to meet their ranch goals during drought. Additional research is also needed to explore these relationships in other geographic regions and among other types of agricultural producers.

Following on this research, the National Drought Mitigation Center at the University of Nebraska—Lincoln has developed an online drought planning resource called
Managing Drought Risk on the Ranch, found at www.drought.unl.edu/ranchplan. The resource offers guidance on monitoring ranch resources, maximizing ranch health and flexibility, identifying critical dates, and developing decision rules. It is our hope that efforts such as this will increase ranch drought preparedness and minimize future losses resulting from drought.

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TAKING THE MEASURE OF A MARK:
EXPLORATORY SIZE AND SHAPE ANALYSIS OF CUT MARKS

Eileen Johnson

Museum of Texas Tech University
Box 43191
Lubbock, TX 79409-3191
eileen.johnson@ttu.edu

Patrick J. Lewis

Department of Biological Sciences
Sam Houston State University
Huntsville, TX 77341
pjI001@shsu.edu

and

Leland C. Bement

Oklahoma Archeological Survey
111 E. Chesapeake
Norman, OK 73019-5111
lbement@ou.edu

ABSTRACT—A database of 128 measured incised butchery marks (i.e., the classic cut mark) was the basis for exploratory statistical tests of length and width measurements from late Pleistocene mammoth localities and an early Holocene bison locality. The tests reveal several trends. The initial approach uses univariate descriptive statistics, regression, and ANOVA to examine differences in size and shape of marks. Significant differences are noted in length and width of marks based on location, element, and type. Length and width variables demonstrate low variability within incised marks. Results demonstrate a consistency in incised marks across the two taxa. Other consistencies are noted that indicate a regular or standardized way of producing marks in particular places on bones and on particular elements. Location or placement of marks appears to influence mark length, and in general, mark width is constrained. Mark orientation can at times influence mark length. Shape of mark ends may be related to the type of tool and size of tool bit. Using a morphometric approach (size and shape) removes some of the subjectivity in evaluating marks on a visual basis. While exploratory in nature, this morphometric approach crosscuts time and space boundaries and should be applicable to any bone assemblage.

Key Words: cut marks, morphometrics, mammoth, bison, butchery, taphonomy

INTRODUCTION

Issues of evidence recognition, human intervention in bone beds, and subsistence strategies are being investigated in various areas of the late Pleistocene North American grasslands (Fig. 1). Such studies incorporate different landscape settings, climate, and environments. The protocol being used to examine bone from early sites has a focus on methodology that is based on taphonomy, biotechnology, and morphometrics (size and shape). The focus is on marks made on bone by people (hereafter referred to as cultural marks), and particularly those made during carcass processing. Research has been undertaken to explore mark parameters, potential patterns and consistencies, and interpretive value.

Following the seminal work of Shipman (1981a, 1983,
1988, 1989), cultural marks made on bone are distinguished from natural agencies and are described using both qualitative and quantitative means (Johnson 2005, 2006, 2007a, 2007b; Johnson and Bement 2009). Qualitative means involve identifying features that characterize cultural marks, provide a basis for the range of variation of such marks, and enhance the classic definition of a cut mark (Shipman 1981b; Shipman and Rose 1983, 1984). Quantitative means involve length and width measurements and other aspects of the size and shape of cultural marks and the number of actions that went into creating the mark.

The current analysis is exploratory in nature, and involves statistical examination and comparison of marks between two taxa. Although a variety of cultural marks occur (e.g., percussion [Johnson, 1985; Blumenschine and
Figure 2. Map showing the relationship of the localities in southeastern Wisconsin.
Selvaggio 1988; Pickering and Egeland 2006]), the focus for this exploratory analysis is on cut marks, and in particular, marks made during the butchery process by flaked lithic tools. Specifically, the type of mark examined is that of an incised mark (the classic cut mark [Shipman 1981a; Shipman and Rose 1983; see also Potts and Shipman 1981; Lyman 1994; Fisher 1995; Blumenschine et al. 1996]) produced as the result of a sharp-edged object slicing into the bone. These marks are noted as mark type 1 in Johnson’s (2007b) categorization scheme.

Previously determined cut marks on different large species (Johnson 2007b; Johnson and Bement 2009) were used for comparative purposes in order to provide an initial range of interspecies variation and explore generalizations across species. The purpose was not to assess whether the marks on the Wisconsin mammoth were the result of human agency (i.e., cultural marks). From the authors’ perspective, that determination had been made (Johnson 2006, 2007b) and the intent was not to repeat that analysis here. The purpose was to advance a method using morphometrics that would remove some of the subjectivity in evaluating marks on a visual basis and specifically for the type of cultural mark being examined.

The analysis, while using statistical tests, was exploratory, with the objective being to probe the data for patterns and trends using the available information. These initial findings, then, could form the basis for further examination of interspecies incised marks using an increased sample size and additional species. The intent, then, was not to examine behaviors involved with carcass acquisition, processing, or consumption based solely on the initial findings. Exploration was driven by five assumptions: (1) that the cut marks were related to the butchering process in which flaked lithic tools were used; (2) that the cut marks would exhibit consistent characteristics; (3) that length and width provide the simplest approach to a standardized description of the general morphology; (4) that cut marks would share the same characteristics regardless of taxon, with the constants being bone material and use of flaked lithic tools in butchering; and (5) that exploratory analysis would detect behavioral information and provide a direction for future research. The hypothesis, then, is that the morphology of incised marks across species would be the same.

Data from two distant locations on the North American grasslands involving two taxa have been used in the exploratory analysis (Fig. 1). The standard used for dates is that of radiocarbon years before present, that is, dates have not been calibrated to calendar years. A cluster of four mammoth localities in close proximity to each other in southeastern Wisconsin represents the northernmost location (Figs. 1, 2). We know that these sites involve early peoples, based on cultural marks on bones (Johnson 2007b; Johnson et al. 2007) and lithic artifacts found at two of the localities (Overstreet 1993, 1996, 1998; Overstreet et al. 1993, 1995). Radiocarbon dates provide a time period of ~13,530 to 11,200 years before present (Dallman et al. 1996; Overstreet and Stafford 1997; Overstreet 1998; Overstreet and Kolb 2003; Joyce 2005). The Cooper site (Bement 1999), along the northern bluff of the Beaver River in northwestern Oklahoma, represents the southernmost location (Figs. 1, 3). Cooper is an arroyo-trap bison kill site recording three episodes within the Folsom period. Both Folsom points and lithic tools are in association with the kills. Radiocarbon dates provide a time period of ~10,600 to 10,500 years before present, indicating a 100-year time span for the kills (Johnson and Bement 2009).

Examining marks on bones and what constitutes butchery marks (e.g., Blumenschine and Selvaggio 1988; Olsen and Shipman 1988; Fiorillo 1989; Calpaldo and Blumenschine 1994; Blumenschine et al. 1996; Dominguez-Rodrigo and Piqueras 2003; Johnson 2006; Dominguez-Rodrigo et al. 2009; Galán et al. 2009) speaks to regional, national, and global issues. Regionally, demonstrating cultural marks and examining butchering patterns are significant in Paleoindian studies of resource utilization, subsistence, and landscape use (Hofman et al. 1989; Tankersley and Isaac 1990; Bement and Buehler 1997). Nationally, three of the mammoth localities date earlier than Clovis and would indicate people and the use of mammoth prior to that time, and therefore are significant in terms of the timing of human entry into the Americas (Dillehay and Melzer 1991; Grayson 1998; Dillehay 2000; Haynes 2002; Melzer 2009; Pitblado, 2011).

On a global basis, another consideration is the type of evidence accepted as demonstrating the early presence of people. The cut marks on the Wisconsin mammoth have been questioned as natural or modern modifications,
primarily due to the age of the sites and general lack of lithics (Cannon and Meltzer 2004; Krasinski and Haynes 2008; but see Collins et al. 2008). Age should not be a factor in deciding whether marks are cultural or natural (e.g., recent controversy in Ethiopia [Dominguez-Rodrigo et al. 2010, 2012; McPherron et al. 2010]. Nor should the absence or minimal presence of lithics be factors. Cut marks are a direct link to people, as people had to make the marks regardless of whether the implements used to make the marks were left behind with the bone refuse. Examining marks in more detail should provide the basis for a more rigorous protocol and stronger definition of cultural marks that could be applied across time lines and prey species to aid in identifying the early presence of hominids and examine their subsistence patterns. Researchers are beginning to examine cut marks more closely, to debate what constitutes a cut mark, and to call for more standardized terminology (e.g., Dominguez-Rodrigo et al. 2009; de Juana et al. 2010; James and Thompson 2012; McCarthy 2012; Merritt 2011, 2012; Otárola-Castillo et al. 2012; Welch et al. 2012). This study reflects that trend.

SITES

Wisconsin Mammoth

The mammoth localities (Figs. 1, 2) are Fenske (47KN240), Mud Lake (47KN246), Schaefer (47KN252), and Hebior (47KN265). Each represents a single disarticulated carcass ranging in completeness from one element to ca. 90% (Overstreet 1998; Johnson 2006). These localities are within a glacial landscape that was formed through the wasting ice of the Lake Michigan lobe or water plane fluctuations of glacial Lake Chicago (Hansel 1983; Schneider 1983; Hansel et al. 1985). They lie within lowlands between moraine ridges (Schneider 1983; Overstreet 1998).

The localities were discovered accidentally through water diversion projects from the 1920s to 1960s. Subsequent fieldwork in the 1990s confirmed the stratigraphic context of the remains at each locality (Overstreet 1996) and recovered the undisturbed portions of the Schaefer and Hebior mammoth carcasses (two localities with associated lithics) through excavations that also detailed the stratigraphy and paleovegetation (Huber and Overstreet 1990a, 1990b; Huber and Rapp 1992; Overstreet et al. 1993; Fredlund et al. 1996; Overstreet 1996, 1998; Overstreet and Kolb 2003). Bones of the Schaefer and Hebior mammoths were located well below intact peat layers and unaffected by modern agricultural plowing. Given the similar stratigraphy, remains from the other two localities most likely also lay well below any impact from modern plowing activities.

Summarized by Overstreet and Kolb (2003:94) and Joyce (2005:76, 2006:53), 25 purified bone collagen dates are published for the four localities and 16 wood dates for Schaefer. Fenske is dated −11,240−11,220 years before present. Mud Lake dates range from −13,530 to 13,440 years before present, while dates for Hebior range from −12,590 to 12,480 years before present. The Schaefer bone collagen ages date the locality between −12,900 and 12,570 years before present. Wood associated with the Schaefer mammoth comes from underneath, within, and on top of the bone concentration. The wood dates provide a range of −12,940−11,980 years before present.

A detailed taphonomic analysis indicated that both natural and cultural processes had influenced the bone beds (Johnson 2006). Rodent gnawing was absent and carnivore activity was limited, with tooth punctures being the most common damage. The frequency of trample marks was low. Bone axis orientation data, examined statistically through two different approaches, indicated no significant departure from a random distribution of bone. Water transport was not a factor in bone bed formation nor was water movement within the bone piles a disturbance factor. Neither beaver gnawing nor ice rafting were the cause of the bone damage, nor could carnivore activity or trampling account for creation of all the marks.

Approximately 7.6% of the combined assemblage, affecting 30 bones from the four carcasses, exhibits evidence of cultural modification. A total 200 marks on bones from the localities are identified as cultural, 84 of which are incised marks (i.e., the classic cut mark; Johnson's [2007b] mark type 1). These marks occur primarily on appendicular elements, as demonstrated by a chi-squared goodness-of-fit test (Johnson 2007b). The other 116 marks are pry marks (created as a result of a pointed to rounded object being moved along the bone surface primarily at joints; Johnson 2007b).

Cooper Bison

The Cooper site (34HP45; Bement 1999) is located on the Southern Plains (Figs. 1, 3) along the Beaver River (or North Canadian) in the western Sand Dune Belts. This area as a whole is grassland with riparian deciduous wooded valleys today, and was grassland during Cooper occupation (Bement et al. 2007).

Three episodes of bison trapping took place in the arroyo over a very short time span within the Folsom period
Radiocarbon ages on petrosals from skulls in each of the kills provided sequential dates of ~10,600 years before present (lower kill), ~10,530 years before present (middle kill), and ~10,505 years before present (upper kill) (Johnson and Bement 2009). Each episode was a kill of a cow-calf herd during late summer—early fall (based on age, sex, and seasonality data). Kill size varied from a minimum 20 bison in the lower kill to 29 in the other kills (Bement 1997, 1999). As up to 50% of each kill had been removed through bluff erosion (Bement 1999:52), each episode potentially contained twice that number of bison. The Cooper site, both in terms of individual episodes and as an aggregate, represented large-scale kills.

Bison for all three episodes primarily were intact carcasses, with incomplete carcasses or disarticulated remains primarily at the eroded edge of the site. Taphonomic analysis indicated that both natural and cultural processes had influenced the bone beds (Bement 1999). Gourmet butchering was the focus of cultural activity, involving only meat-stripping of the carcasses (Bement 1999:138).

Based on an independent assessment of the bison bones, ca. 2.5% of the assemblage, affecting 99 elements from 36 carcasses, exhibited evidence of cultural modification (Johnson and Bement 2009). Of the carcasses, 96 bones came from 34 excavated carcasses; three were from slump deposits. This rate indicated that ca. 42% of recovered carcasses reflected cultural damage. The number of carcasses that had elements exhibiting cultural modification varied by kill, with decreasing frequency from upper to lower kills. That pattern was attributed at least partially to worsening bone preservation with depth. A total 149 marks on bones from the three kill episodes were identified as cultural, 45 of which are incised marks (i.e., the classic cut mark; Johnson’s [2007b] mark type 1). These marks occurred exclusively on vertebrae and ribs (Johnson and Bement 2009). While the lower kill exhibited other types of cultural modifications to the bones, the incised marks came from the upper and middle kills. The rest of the marks consisted of percussion blow marks made by a hammerstone and indentations made by a bone butchering tool (Johnson and Bement 2009).

**METHODOLOGY**

The raw cultural mark data and procedure used to determine cultural and natural agencies are in Johnson (2006, 2007b) for the Wisconsin localities and in Johnson and Bement (2009) for Cooper. Images of cut marks from the Wisconsin localities and Cooper provided here (Fig. 4) are for reference purposes, and additional images are in Johnson (2007b), Johnson et al. (2007), and Johnson and Bement (2009). Potential cultural marks have not been subjected to multivariate analysis (e.g., Domínguez-Rodrigo et al. 2009, 2012) to verify segregation of cultural from trampling marks. Nevertheless, the procedure followed has eliminated the noncultural modifications and has produced a final subset of elements that exhibited cultural modification. A total 129 cut marks (i.e., incised marks; mark type 1) are within that final subset (Wisconsin = 84 cut marks; Cooper = 45 cut marks).

All marks were observed visually using a binocular microscope up to 63× magnification. Equipment and software to produce three-dimensional images and measurements (Bello and Soligo 2008; Bello et al. 2009) were not available at the time of this study. Nevertheless, molds were taken, replicas were made and coated following the protocol developed by Shipman (1981a, 1988, 1989, 1997; Shipman and Rose 1983), and the replicas were scanned using a Hitachi S-570 scanning electron microscope. These scans and images provided supplemental information to the observed data.

Variables (set forth in Johnson 2000, 2007b) used in the exploratory analysis were mark length, width, location, orientation, and morphology. Length and width measurements were recorded to the nearest 0.1 mm using a digital caliper; depth could not be taken reliably. Location referred to the placement of the mark on the element. Bone line drawings were used to record the mark placement. Placements were grouped and categorized to general location such as distal or proximal end, diaphysis, articular surface, or facet. Mark orientation to the long axis of a bone was categorized as right diagonal, left diagonal, perpendicular, parallel, or subparallel.

Morphology included shape of trough, shape of adjacent walls, number of strokes, and shape of stroke end. Trough shape was characterized as V-shaped or U-shaped. The angle between the arms of the V varied from tightly narrow through broad (as noted by other authors, e.g., Bello and Soligo 2008; de Juana et al. 2010). Wall configuration was categorized as at different heights and angles or at the same height and angle. With the first configuration, one wall is a steep-sided, taller wall and the other a shallow-sided, shorter wall (also noted by Bello and Soligo 2008). The number of strokes was a count of the number of actions (impacts or hits) that contributed to the creation of the mark. The number was recorded and categorized as simple (1 stroke) or complex (more than 1 stroke). Each mark had two ends (termini), that is, one at either end of the stroke. Eight descriptors characterized a
mark's end: blunted, tapered, flared, flat-pointed, lazy-V, feathered, obliterated, eroded).

For statistical analysis, length and width measurements were treated as continuous data. Small samples can be problematic, so two approaches were taken to minimize the effect. Groups with small sample sizes either were eliminated from a particular analysis or were combined with similar data types (e.g., all vertebrae types grouped together).

The initial approach used univariate descriptive statistics and regression and one-way analysis of variance (ANOVA) to test for significant differences in size and shape of marks (Sokal and Rohlf 2011). On occasion, an analysis of covariance (ANCOVA) was used. A confidence level of 0.05 was set for all statistical tests unless otherwise noted.

One-way ANOVA evaluates whether two or more sample means differ more than would be expected by chance. The one-way ANOVA is more general than regression analysis, as it can be used for identifying relationships between criterion variables (length and width) and predictor variables (the groups, e.g., element, terminus, trough), whether or not the predictor variables are quantitative or qualitative. ANOVA tests for variation within the group as a whole, the results of which indicate whether the groups vary by the variable or not. ANCOVA is a more accurate method for testing significance between large numbers of populations (Sokal and Rohlf 2011). The main significance test in ANCOVA is the homogeneity of the Y-intercept for all groups. Testing the parallelism of slopes for length and width for all groups eliminates the dependence of one variable, and allows the data to be tested in its relationship of two variables (Sokal and Rohlf 2011). The observations are grouped according to a single criterion that in this analysis is mark type. All tests have been run with Minitab 11.2 software.

This set of statistical tests is exploratory. Others have applied statistical tests to examine cut marks. Domínguez-Rodrigo et al. (2009, 2012), for example, have used multivariate analysis (analysis of variance, principle component analysis, and logistic regression analysis) to determine differences between trampling and butchery cut marks. De Juana et al. (2010) also has used multivariate analysis (principle component analysis, ANOVA, and discriminant analysis) to differentiate cut marks made by retouched flakes from those made by handaxes. Capaldo (1995) has examined frequencies and binning data through nonparametric means that are suitable for qualitative data (Sokal and Rohlf 2011). What is being examined here is quantitative data, namely length and width, and how those vary according to different variables. Quantitative data almost always are normally distributed, and parametric tests are by far the best approach to use for these data (Sokal and Rohlf 2011).

The results of an ANOVA did not indicate the group or groups responsible for the significant variation found. Therefore, pairwise tests were used whereby each group was tested against all other groups to determine the group(s) responsible for significant results in the ANOVAs. These pairwise tests were run to explore the dataset, rather than answer specific hypotheses about the dataset, because of the absence of a priori expectations. Alpha values were adjusted for pairwise tests in accordance with the Bonferroni correction to minimize the chance of recording a false positive (Sokal and Rolf 2011). T-tests subsequently were performed to examine specific questions as appropriate.

**RESULTS AND COMMENTS**

Although the Wisconsin mammoth and Cooper bison datasets consist of more than one mark type, they both have what was identified as mark type 1 (i.e., an incised mark; Fig. 4) with the Wisconsin mammoths. Overall, the damage morphology associated with this type of mark is a clean, precise incision or slice into the cortical surface. Comparison between the two datasets, then, is made only with incised marks (type 1). Other mark types are taxon-specific and include the pry marks on mammoth articular surfaces and percussive marks on bison vertebrae made by bone butchering tools (Johnson 1985, 2007; Johnson and Bement 2009). Results of the ANOVA and ANCOVA runs are presented in Table 1, with significant results bolded.

**Wisconsin Dataset**

**Length.** An ANOVA of the Wisconsin length variables found that length for incised marks was significantly different among the four groups. Post hoc Fisher's pairwise tests (alpha adjusted to 0.006) indicated that the significant difference is driven by the shorter marks from Mud Lake and Schaefer, both significantly shorter than marks from Fenske and Heibor (Fenske mean length = 16.0 mm; Heibor mean length = 15.4 mm; Mud Lake mean length = 9.5 mm; Schaefer mean length = 10.5 mm). Mud Lake and Schaefer incised marks exhibited similar mean length values, while those from Fenske and Heibor are similar to each other.
Width. When width is tested with ANOVA for incised marks, the results are not significant. Heibor and Schaefer, however, demonstrate narrower incised marks than Fenske and Mud Lake (Fenske mean width = 2.2 mm; Mud Lake mean width = 2.1 mm; Heibor mean width = 1.29 mm; Schaefer mean width = 1.4 mm). Post hoc Fisher’s pairwise tests (alpha adjusted to 0.006) also found an insignificant difference between the localities. While Heibor and Schaefer incised marks are ca. 40% narrower than Fenske and Mud Lake incised marks, differences in the number of samples (Fenske = 14; Mud Lake = 44; Heibor = 5; Schaefer = 9) between the localities negatively impact the statistical tests.

Length and Width. Linear regression found no correlation between length and width ($r^2 = 0.03$). ANCOVA likewise was insignificant, suggesting no differences in the relationship between length and width of incised marks among the four Wisconsin localities.

Cooper Dataset

Length and Width. Using ANOVA, no significant difference was found in mark length or width between the upper and middle kills of the Cooper incised marks. The length to width relationships of incised marks between the upper and middle kills also were consistent, with ANCOVA finding no significant difference and linear regression with no correlation ($r^2 = 0.001$). Mark size was consistent between the kills, and all marks are short and narrow.

Combined Wisconsin and Cooper Datasets

Length. An ANOVA testing length grouped by locality (i.e., Wisconsin localities and Cooper) found that the groups differed significantly. Post hoc Fisher’s pairwise tests (alpha adjusted to 0.005) found that Cooper marks are not significantly different in length from Mud Lake...
### TABLE 1.

**RESULTS OF STATISTICAL TESTS ON THE WISCONSIN MAMMOTH AND COOPER BISON DATASETS**

<table>
<thead>
<tr>
<th>Locality</th>
<th>Category</th>
<th>Test</th>
<th>Results*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wisconsin</td>
<td>Length</td>
<td>ANOVA</td>
<td>(F = 7.16; df = 3; p &lt; 0.01)</td>
</tr>
<tr>
<td></td>
<td>Width</td>
<td>ANOVA</td>
<td>(F = 1.01; df = 3; p = 0.39)</td>
</tr>
<tr>
<td></td>
<td>Length and width</td>
<td>ANOVA</td>
<td>(F = 1.41; df = 3; p = 0.74)</td>
</tr>
<tr>
<td></td>
<td>Length and trough shape</td>
<td>ANOVA</td>
<td>(F = 0.492; df = 2; p = 0.689)</td>
</tr>
<tr>
<td></td>
<td>Width and trough shape</td>
<td>ANOVA</td>
<td>(F = 31.60; df = 2; p &lt; 0.001)</td>
</tr>
<tr>
<td></td>
<td>Length and strokes</td>
<td>ANOVA</td>
<td>(F = 5.10; df = 1; p = 0.27)</td>
</tr>
<tr>
<td></td>
<td>Width and strokes</td>
<td>ANOVA</td>
<td>(F = 2.67; df = 1; p = 0.11)</td>
</tr>
<tr>
<td></td>
<td>Length and trough wall</td>
<td>ANOVA</td>
<td>(F = 0.04; df = 1; p = 0.85)</td>
</tr>
<tr>
<td></td>
<td>Width and trough wall</td>
<td>ANOVA</td>
<td>(F = 0.03; df = 1; p = 0.87)</td>
</tr>
<tr>
<td></td>
<td>Length and R mark end</td>
<td>ANOVA</td>
<td>(F = 2.41; df = 4; p = 0.05)</td>
</tr>
<tr>
<td></td>
<td>Width and R mark end</td>
<td>ANOVA</td>
<td>(F = 2.07; df = 4; p = 0.09)</td>
</tr>
<tr>
<td></td>
<td>Length and L mark end</td>
<td>ANOVA</td>
<td>(F = 2.12; df = 4; p = 0.08)</td>
</tr>
<tr>
<td></td>
<td>Width and L mark end</td>
<td>ANOVA</td>
<td>(F = 1.57; df = 4; p = 0.19)</td>
</tr>
<tr>
<td></td>
<td>Length and orientation</td>
<td>ANOVA</td>
<td>(F = 1.43; df = 3; p = 0.24)</td>
</tr>
<tr>
<td></td>
<td>Width and orientation</td>
<td>ANOVA</td>
<td>(F = 0.95; df = 3; p = 0.42)</td>
</tr>
<tr>
<td></td>
<td>Length and element</td>
<td>ANOVA</td>
<td>(F = 10.23; df = 5; p &lt; 0.01)</td>
</tr>
<tr>
<td></td>
<td>Width and element</td>
<td>ANOVA</td>
<td>(F = 5.36; df = 5; p &lt; 0.01)</td>
</tr>
<tr>
<td>Cooper</td>
<td>Length</td>
<td>ANOVA</td>
<td>(F = 0.59; df = 1; p = 0.45)</td>
</tr>
<tr>
<td></td>
<td>Width</td>
<td>ANOVA</td>
<td>(F = 2.68; df = 1; p = 0.11)</td>
</tr>
<tr>
<td></td>
<td>Length and width</td>
<td>ANOVA</td>
<td>(F = 0.06; df = 1; p = 0.81)</td>
</tr>
<tr>
<td></td>
<td>Length and strokes</td>
<td>ANOVA</td>
<td>(F = 1.92; df = 2; p = 0.16)</td>
</tr>
<tr>
<td></td>
<td>Width and strokes</td>
<td>ANOVA</td>
<td>(F = 2.05; df = 2; p = 0.14)</td>
</tr>
<tr>
<td></td>
<td>Length and trough wall</td>
<td>ANOVA</td>
<td>(F = 2.86; df = 1; p = 0.10)</td>
</tr>
<tr>
<td></td>
<td>Width and trough wall</td>
<td>ANOVA</td>
<td>(F = 1.27; df = 1; p = 0.27)</td>
</tr>
<tr>
<td></td>
<td>Length and R mark end</td>
<td>ANOVA</td>
<td>(F = 1.76; df = 2; p = 0.019)</td>
</tr>
<tr>
<td></td>
<td>Width and R mark end</td>
<td>ANOVA</td>
<td>(F = 0.92; df = 2; p = 0.41)</td>
</tr>
<tr>
<td></td>
<td>Length and L mark end</td>
<td>ANOVA</td>
<td>(F = 4.17; df = 2; p = 0.02)</td>
</tr>
<tr>
<td></td>
<td>Width and L mark end</td>
<td>ANOVA</td>
<td>(F = 1.25; df = 2; p = 0.30)</td>
</tr>
<tr>
<td></td>
<td>Length and orientation</td>
<td>ANOVA</td>
<td>(F = 4.13; df = 2; p = 0.02)</td>
</tr>
<tr>
<td></td>
<td>Width and orientation</td>
<td>ANOVA</td>
<td>(F = 0.75; df = 2; p = 0.48)</td>
</tr>
<tr>
<td></td>
<td>Length and element</td>
<td>ANOVA</td>
<td>(F = 7.38; df = 1; p = 0.01)</td>
</tr>
<tr>
<td>Combined</td>
<td>Length</td>
<td>ANOVA</td>
<td>(F = 14.31; df = 4; p &lt; 0.001)</td>
</tr>
<tr>
<td></td>
<td>Width</td>
<td>ANOVA</td>
<td>(F = 11.57; df = 4; p &lt; 0.001)</td>
</tr>
<tr>
<td></td>
<td>Length and width</td>
<td>ANOVA</td>
<td>(F = 2.32; df = 4; p = 0.058)</td>
</tr>
<tr>
<td></td>
<td>Length and width</td>
<td>ANOVA</td>
<td>(F = 5.10; df = 4; p &lt; 0.01)</td>
</tr>
<tr>
<td></td>
<td>Length and trough shape</td>
<td>ANOVA</td>
<td>(F = 4.21; df = 2; p = 0.02)</td>
</tr>
<tr>
<td></td>
<td>Width and trough shape</td>
<td>ANOVA</td>
<td>(F = 100.695; df = 2; p &lt; 0.001)</td>
</tr>
<tr>
<td></td>
<td>Length and strokes</td>
<td>ANOVA</td>
<td>(F = 0.87; df = 2; p = 0.92)</td>
</tr>
<tr>
<td></td>
<td>Width and strokes</td>
<td>ANOVA</td>
<td>(F = 1.67; df = 2; p = 0.19)</td>
</tr>
<tr>
<td></td>
<td>Length and trough wall</td>
<td>ANOVA</td>
<td>(F = 2.45; df = 1; p = 0.12)</td>
</tr>
<tr>
<td></td>
<td>Width and trough wall</td>
<td>ANOVA</td>
<td>(F = 0.59; df = 1; p = 0.44)</td>
</tr>
<tr>
<td></td>
<td>Length and R mark end</td>
<td>ANOVA</td>
<td>(F = 9.61; df = 6; p &lt; 0.01)</td>
</tr>
<tr>
<td></td>
<td>Width and R mark end</td>
<td>ANOVA</td>
<td>(F = 3.28; df = 6; p &lt; 0.01)</td>
</tr>
<tr>
<td></td>
<td>Length and L mark end</td>
<td>ANOVA</td>
<td>(F = 3.82; df = 6; p &lt; 0.01)</td>
</tr>
<tr>
<td></td>
<td>Width and L mark end</td>
<td>ANOVA</td>
<td>(F = 2.30; df = 6; p = 0.04)</td>
</tr>
<tr>
<td></td>
<td>Length and orientation</td>
<td>ANOVA</td>
<td>(F = 2.88; df = 3; p = 0.04)</td>
</tr>
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<td></td>
<td>Width and orientation</td>
<td>ANOVA</td>
<td>(F = 1.00; df = 3; p = 0.40)</td>
</tr>
<tr>
<td></td>
<td>Length and orientation</td>
<td>ANOVA</td>
<td>(F = 11.45; df = 11; p = 0.01)</td>
</tr>
</tbody>
</table>

*Results in bold are statistically significant.
and Schaefer marks, but they differ significantly from Heibor and Fenske marks (Fig. 5A). Incised marks, then, were not significantly different between the taxa.

**Width.** An ANOVA testing width grouped by locality found that the groups differed significantly. In post hoc pairwise Fisher’s tests (alpha adjusted to 0.005), marks on Cooper bison were significantly narrower than marks from all of the Wisconsin localities (Fig. 5B).

**Length and Width.** An ANCOVA examining the length to width relationship (gross shape) of incised marks in the combined datasets found that the groups differed significantly. In post hoc pairwise Fisher’s tests (alpha adjusted to 0.005), significant results were found in the incised mark length-to-width relationship between Cooper and Mud Lake and between Mud Lake and Schaefer. The pairwise tests did not find any significant difference between Cooper, Schaefer, and Heibor, meaning that incised mark length-to-width relationship was similar. With a very low alpha, any difference between these three sites would have to be extreme to get a significant result.

ANOVA found a similar significant result. Post hoc pairwise Fisher’s tests (alpha adjusted to 0.005) again found that incised marks on Cooper bison remains were significantly different in their length to width relationship from those at all the Wisconsin localities. Cooper incised marks were shorter and narrower than the Wisconsin incised marks. Linear regression found little correlation between length and width of incised marks ($r^2 = 0.05$). In general, the width of the mark did not increase as the length of the mark increases. This result underscores both the consistency and constraints in the marks across the taxa.

**Mark Consistency in the Combined Datasets**

To explore mark consistency, we examined the relationship between mark length and width and five nonmetric morphological characters: trough shape, stroke number, trough wall, mark ends, and mark orientation. Using these datasets, we defined a narrow trough as 2.2 mm or less in width. The data did not show a natural break, so the average of the mean and median were used to arrive at this arbitrary number. In examining trough width, the majority of measurements were in a tight cluster where no natural break was detected. That tight cluster indicated a limited range of variation in the width of the marks. This limited range, then, indicated the marks are very consistent.

**Length and Width versus Trough Shape.** For the Wisconsin dataset, ANOVA found no significant difference in mark length and trough shape, but a significant difference was found for width. This result was driven primarily by the broad V-shaped marks that are more than twice as wide as all other trough types.

For the Cooper dataset, all marks are even more constrained, and they formed a subgroup within the narrow trough definition of 2.2 mm (Cooper maximum width at 1.2 mm; Fig. 5A). Width does not appear to correlate with length ($r^2 = <0.01$), as short marks can be wide, relatively speaking. All marks wider than 0.8 mm are from marks shorter than 10 mm.

For the combined incised mark dataset, a significant difference occurs in length. This result appears driven primarily by Wisconsin broad V-shaped marks, which tend to be longer than the V- and narrow V-shaped marks (Fig. 6A). When width is tested, again a significant difference is found. Broad V-shaped marks are more than twice as wide as V- and narrow V-shaped marks (Fig. 6B).

**Length and Width versus Number of Strokes.** For the Wisconsin dataset, ANOVAs on number of strokes versus length or width found no significant difference in length
or width. The vast majority of marks (91%) had only one stroke. Marks having three or four strokes constituted one example each, and therefore were not used in the ANOVA. Two stroke examples occurred nine times (9%).

For the Cooper dataset, ANOVAs on number of strokes versus length or width also indicated no significant difference. Marks having four, five, or six strokes were represented by only one example each, and therefore were not appropriate for inclusion in the test. The mean values for both mark length and width, however, increased with the number of strokes. Marks having one, two, or three strokes accounted for 93.3% of the marks, while those marks having one or two strokes each accounted for 40% of the sample. Results from both the Wisconsin and Cooper datasets, then, indicate that the number of strokes did not dictate trough width.

For the combined datasets, an ANOVA found that neither length nor width grouped by steep wall differed significantly. These results suggest that length and width do not vary based on which wall is the steep-sided wall, even though the upper wall as the steep-sided one is more frequent (57%).

Length and Width versus Mark Ends. When we examined the datasets for a relationship between the ends of a mark (termini) and the size of the mark, we found variable results. For the Wisconsin dataset (Fig. 7A), the right terminus varies significantly by length but not by width. Shape and length of this end of a mark are related. The left terminus does not vary significantly by width or by length. Tapered ends, however, are associated with the shortest marks for both ends, and also with the narrowest for both mark end types.

For the Cooper dataset (Fig. 7B, 7C), neither length nor width varies significantly by right terminus, with pointed ends the shortest and narrowest. For the left terminus, length varies significantly. Results from pairwise Fisher’s tests suggest that the left terminus significant result is driven by a difference between blunted and pointed shapes, in that marks with blunted ends are much shorter than pointed ends. Width is not significantly different for the left terminus shapes, although marks with a pointed left terminus again are the narrowest marks.

For the combined datasets, length is significantly different for right terminus shapes. Pairwise Fisher’s tests indicate that the results are driven by marks with blunt, feathered, pointed, and flared shapes being shorter than
marks with the other shapes. Width also varies significantly for right terminus shape. Pairwise Fisher’s tests indicate that the results are driven by marks with feathered, pointed, and tapered shapes being narrower than marks with the other shapes with other shapes.

The results for length grouped by left terminus shape are significant. Pairwise Fisher’s tests indicate that the results are driven by marks with blunt, feathered, and flared shapes being shorter than marks with the other shapes. Width also varies significantly for the left terminus. Pairwise Fisher’s tests indicate that the results are driven by marks with feathered, pointed, and tapered shapes being narrower than marks with the other shapes. Incised marks having a feathered left terminus are the shortest and narrowest of the incised marks across taxa.

Mark length and width appear to have some influence in the shape of the ends of incised marks. While entry or exit end may be a factor in the shape of mark ends, at this point neither can be determined by shape and width for incised marks. The type of tool and size of tool bit also may influence the shape and size of mark ends.

**Length and Width by Orientation.** For the Wisconsin dataset, ANOVA found that orientation does not vary significantly by length or by width. For the Cooper dataset, orientation varied significantly by length but not by width. Pairwise Fisher’s tests indicated that right diagonal marks are the longer ones.

Using the combined datasets, length varies significantly but width does not. Pairwise Fisher’s tests indicate that parallel and right diagonal marks are longer.

**Mark Placement**

For the Wisconsin dataset, incised marks were located more commonly along long bone diaphyses. An ANOVA of length by element found significant variation with the alpha adjusted to 0.007. A series of post hoc pairwise Fisher’s tests found that incised marks on femora were longer than those on radii, ulnae, or ribs, and that marks on humeri also were longer than those on radii, ulnae, or ribs. An ANOVA of width by element likewise found significant variation with the alpha adjusted to 0.007. Post hoc pairwise Fisher’s tests found that incised marks on femora were narrower than those on ribs, and that marks on metacarpals, radii, and ulnae are all narrower than those on ribs. In general, marks on ribs are twice as wide as those in all other categories examined. While length results may be an artifact of element size, all these elements present fairly sizeable surfaces relative to mark length. The result may be influenced by the location or placement of the mark. For example, marks on the radius and ulna frequently were along the narrow anterior muscle ridge.

For the Cooper dataset, incised marks occur only on ribs and vertebrae. An ANOVA testing mark length variation between ribs and vertebrae returns significant results. Marks on ribs are shorter. This result again may be an artifact of element size. Bison ribs present a much narrower surface than vertebral spines (spinous process).

For the combined dataset, ANOVA found a signifi-
TABLE 2.
FINDINGS FROM STATISTICAL ANALYSES OF MORPHOMETRICS OF INCISED MARKS (CLASSIC CUT MARKS) ON WISCONSIN MAMMOTHS AND COOPER BISON REMAINS

<table>
<thead>
<tr>
<th>Category</th>
<th>Wisconsin mammoth</th>
<th>Cooper bison</th>
<th>Across taxa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>Significantly different between two sets of localities</td>
<td>No significant difference between kills</td>
<td>No significant difference; consistent relationship</td>
</tr>
<tr>
<td>Width</td>
<td>Difference between narrower and broader incised marks</td>
<td>No significant difference between kills</td>
<td>Limited range of variation; marks on bison narrower than on mammoth</td>
</tr>
<tr>
<td>Length and width</td>
<td>Length-to-width relationship consistent</td>
<td>Length-to-width relationship consistent</td>
<td>Incised marks on bison shorter and narrower than on mammoth; length-to-width relationship consistent</td>
</tr>
<tr>
<td>Morphology:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trough shape</td>
<td>No significant difference for length; no significant difference for length</td>
<td>No significant difference for length or width</td>
<td>Broad, long marks on mammoth significantly different than narrower, shorter marks on mammoth and bison</td>
</tr>
<tr>
<td>Stroke number</td>
<td>No significant difference for length or width</td>
<td>No significant difference for length or width</td>
<td>No significant difference; number of strokes did not influence length or width; consistent relationship</td>
</tr>
<tr>
<td>Trough wall</td>
<td>No significant difference for length or width</td>
<td>No significant difference for length or width</td>
<td>No significant difference; length and width do not vary based on wall height; consistent relationship</td>
</tr>
<tr>
<td>Mark ends</td>
<td>Right end varies significantly by length but not width; tapered ends associated with shortest and narrowest marks</td>
<td>Left end varies significantly by length but not width; pointed ends associated with narrowest marks</td>
<td>Both ends vary significant by length and width; feathered ends shortest and narrowest; length and width has some influence on shape of incised mark ends; consistent relationship</td>
</tr>
<tr>
<td>Orientation</td>
<td>No significant difference for length or width</td>
<td>significance difference by length but not width</td>
<td>Significant difference by length; orientation influenced length; no significant difference by width; consistent relationship</td>
</tr>
<tr>
<td>Location</td>
<td>Significant difference in length and width</td>
<td>Significant difference in length but not width</td>
<td>Significant difference in length; length varied on ribs and upper and lower limbs; consistent relationship</td>
</tr>
</tbody>
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cnt difference in length of marks. A series of post hoc pairwise Fisher’s tests found that marks on upper limbs tended to differ significantly from those on lower limbs and ribs.

DISCUSSION
To reiterate, the statistical tests were chosen to explore the data for patterns and trends rather than answer specific hypotheses about the data. To determine the validity of patterns and trends found in this exploratory analysis, we would need similar data collected from the same taxa. Additional taxa would add to a more robust analysis. Nevertheless, to summarize the current findings, the marks have a consistency in mark production across taxa and a consistency in mark size (Table 2). These consistencies, as well as the overall pattern and internal complexity, indicate that the marks were not random occurrences.

Incised marks (mark type 1) are interpreted as the classic cut mark. This type occurs on a highly select group of
elements, although not the same groups between the Wisconsin mammoth and Cooper bison datasets. Statistical tests have explored three main areas. First, tests of length versus width indicate the incised marks are in two main groupings of shorter and longer marks. While these marks on the Wisconsin mammoth could be either narrower or broader, those on the Cooper bison always are narrow and more constrained in width than those on the Wisconsin mammoths. Nevertheless, results indicate that the length to width relationship is similar for Cooper, Schaefer, and Heibor and significantly different from that of Mud Lake and Fenske. These results mirror the interpretations that Cooper, Schaefer, and Heibor carcasses were fresh when butchered while those from Mud Lake and Fenske were stiffened (Johnson 2007b; Johnson and Bement 2009).

Our exploration of the internal relationships of the morphological characters of the marks in the combined datasets reveals that neither length nor width varied significantly. The number of strokes per mark versus length or width was inconclusive, as the vast majority of marks had only one stroke. No significant difference was found in terms of length or width for which wall was the steep-sided one in incised marks. Variation by terminus was inconsistent. For the Wisconsin mammoth dataset, the right end of the mark varied significantly by width but not length while the left end showed no significant difference. For the Cooper bison dataset, the left end varied significantly by length while neither end varied significantly by width. Shape of the end varied significantly by length, with pointed ends being longer for the Wisconsin mammoth dataset and feathered ends for the Cooper bison dataset. Feathered ends were the result of a mark being composed of more than one stroke. While the number of strokes within a mark appears not to influence width, that number can affect the length of the mark.

In terms of external relationships for the marks, mark orientation varied highly significantly by length but not by width. Although the dominant orientation was not consistent across the databases, nevertheless, mark orientation influenced mark length across taxa. If orientation is related to hand and tool position, the addition of orientations other than the dominant one on the same element would indicate a range of hand or tool motion being used to accomplish the task.

Cut marks have been noted on a wide variety of taxa representing all vertebrate classes. Mid- to large-size mammals appear the common target. Examples, however, of much smaller and less common prey animals as determined through the presence of cut marks on their elements include fish (e.g., Willis et al. 2008; Jurgens 2010), tortoises (e.g., Blasco 2008), birds (e.g., Cassoli and Tagliaacozzo 1997; Steadman et al. 2002; Haury 2008; Blasco and Peris 2009; Bochenksi et al. 2009), rodents (e.g., Johnson 1987), and rabbits (Hockett 1994; Lloveras et al. 2011). Generally, little comparison has been made to determine whether differences or consistencies exist between the taxa in their cut marks and what that might mean methodologically in recognizing cut marks or behaviorally in creating them.

Merritt (2012) examined whether cut marks could be an indicator of tool type, experimentally butchering large (cow) and small (goat) carcasses. He measured the width and depth of cut mark cross sections. While his analysis was mostly in the framework of carcass size (by large or by small mammal), he noted that cut marks on cow elements tended to be deeper and wider than on goat elements. He attributed the difference to the greater effort required in butchering a large carcass.

Bello et al. (2009) provided a different experimental perspective but a similar interpretation of differences in cut marks across taxa. Using three-dimensional reconstruction of marks, they compared experimentally generated cut marks on roe deer with cut marks on a small variety of large mammals from a Lower Paleolithic site. They interpreted the difference between the experimental and archeological sets of cut marks to indicate a greater effort or force needed in butchering a large mammal carcass, variation in the angle of the cut, and robustness of these early hominins. The underlying assumption in both experiments would appear to be that interspecies cut marks would be the same, exhibiting the same features, and therefore, behavioral inferences could be made.

The recent works by Boschin and Crezzini (2012) and Schmidt et al. (2012) also used three-dimensional images of experimental and archeological cut marks and morphometrics to explore discriminating between marks made by metal knives and those by stone tools. The profiles of the cut marks made by metal versus stone showed different patterns, as did those of unmodified chert flakes and bifaces. While Boschin and Crezzini (2012) used various statistical analyses to confirm the morphological findings, they were not able to discriminate between flakes and retouched tools within the stone tool category. Schmidt et al. (2012) used profile images to discriminate within the stone tool category. Neither study explored interspecies cut marks.

Bunn (1994) reported multiple mammalian taxa with cut marks in Koobi Fora assemblages, but no morphological or interspecies comparative analyses of the cut marks were done. This early study was instrumental in arguing
that even in the absence of stone tools, bones exhibiting cut marks were evidence of hominin activity. On the basis of that assertion, Bunn (1993) expanded on foraging strategies used by these early peoples in acquiring carcasses and different strategies of carcass utilization.

A number of studies (e.g., Lyman 1992, 2005; Lupo and O'Connell 2002; Egeland 2003; Dominguez-Rodrigo 2003; Dominguez-Rodrigo and Yravedra 2009) have looked at cut mark frequencies or percentages across mammalian taxa. Carcass size appears to play a major role in frequency differences, but frequency differences across sites for the same taxon also occur. These studies, however, neither address the morphology of the cut marks nor provide a comparison of cut marks among the taxa represented.

Frequency of cut marks also was examined by tool material type within an experimental approach using unmodified flakes as the tools (Dewbury and Russell 2007). Obsidian flakes were found to leave fewer cut marks on bones than chert flakes. Sharpness and durability were influencing factors in how tools were used. Another experimental study use unmodified flakes to examine tool attrition (Braun et al. 2008). While the creation of cut marks apparently was not linked with edge attrition, the occurrence of tool edge attrition was higher with skinning and disjointing activities.

Various other studies (Potts and Shipman 1981; Abe et al. 2002; Lupo and O'Connell 2002; Lyman 2005; de Juana et al. 2010; Schmidt et al. 2012) often employ experimental methodologies that utilize a variety of lithic tools ranging from unmodified flakes to bifaces and hand axes. Lithics are sparse with the Wisconsin mammoths, with only a few found at two of the sites. The lithic assemblage at Schaefer consists of an unmodified flake and a broken biface edge while two small bifaces, an unmodified flake, and a chopper come from Hebior (Overstreet 1998; Overstreet and Kolb 2003). These lithics have been subjected to microwear analysis. Those from Schaefer do not exhibit any wear patterns, while the two bifaces from Hebior have wear patterns of meat and hide polish, indicating their use in butchering activities (Yerkes and Weinberger 1998; Overstreet and Kolb 2003).

The most common butchering tools found at Cooper are large flake knives that display resharpening on the dorsal surface (Bement 1999). These flake tools create cut marks with sharp troughs and minimally striated walls (Schmidt et al. 2012). Bifaces generally leave cuts with broader troughs and walls displaying multiple striations. Overlapping morphologies occur when the edges of flake knives dull and microflaking from use mimics bifacial flaking. The differences in tool assemblages and generally broader troughs of the cut marks on the Schaefer and Hebior mammoths and tightly constrained troughs of the Cooper marks are concordant with these findings. This situation implies that the types of tools being used have a greater influence on the micromorphology of cut marks than either size or species of the carcass being butchered.

The results of this analysis demonstrate a consistency in incised marks across the two taxa (Table 2). The marks on the Wisconsin mammoths identified as mark type 1 are not outliers in any of the statistical tests and share the same characteristics as the cut marks on the Cooper bison bones.

**CONCLUDING REMARKS**

Research is exploratory, and mark size, shape, and variation were examined. The focus is on one mark type (incised mark) that overlaps in the two datasets. Based on these two datasets representing different taxa and time periods, initial findings are:

1. Incised marks have a consistency in mark production that can be identified by a series of microfeatures that characterized it.

2. Mark location or placement appears to influence mark length.

3. While mark width can be categorized as narrow or broad, in general, mark width is constrained.

4. The number of strokes per mark versus length or width was not significant.

5. Which wall was the steep-sided wall for incised marks in terms of length or width was not significant.

6. The shape of mark ends varied significantly by length across taxa, with the shortest and narrowest generally having feathered ends.

7. Mark orientation appears to influence the length of a mark.

8. The condition of the carcass (fresh or stiffened) and the types of tools used appear to have a much greater influence on cut mark micromorphology than either carcass size or species.

Cut marks are accidental occurrences, by-products of carcass processing. While their absence on an element does not necessarily mean the bone did not undergo processing, their presence, type, location, complexity, and intensity provide clues to the processing strategy and tasks involved. At both the Wisconsin localities and at the Cooper site, these marks appear primarily on a highly select category of elements, and then only on particular elements. Certain parts of the carcasses are being targeted: for the Wisconsin mammoth primarily the limbs, and
for Cooper bison the ribs and vertebrae (Johnson 2007b; Johnson and Bement 2009). Very directed activities are taking place within limited task parameters.

This morphometric approach to marks on bones crosscuts time and space boundaries and should be applicable to any bone assemblage. This approach reduces subjectivity and reliance on only one or two microfeatures to determine hominid intervention by examining statistically a suite of internal and external variables. The central question in dealing with any bone assemblage is whether or not marks are caused by hominid agency (e.g., Binford 1977, 1981; Bunn 1983; Shipman 1989, 1997; Haynes 2002; Johnson 2006, 2007b). The approach utilized here can be useful in addressing that central question. And if the marks are the result of hominid behavior, then questions about that behavior can be addressed, regardless of age or lithic context.

ACKNOWLEDGMENTS

The senior author greatly appreciates the opportunity provided by Dr. David Overstreet (Center for Archaeological Research at Marquette University, Milwaukee) to conduct the taphonomic analysis of the four Wisconsin mammoth localities, funded by National Science Foundation grant SBR-9708616; the continued encouragement, review of work, and friendship of Pat Shipman (Penn State University, University Park, retired); photography by James A. Clark Jr. (Center for Archaeological Research at Marquette University, Milwaukee); and help with the database by Sarah Willett (formerly of the Museum of Texas Tech University). The authors thank Kent Buehler (Oklahoma Archeological Survey) for his interest and help while examining the Cooper material, and the various staff and students at the Museum of Texas Tech University for help with the Cooper collection and the database, in particular Katherine Bell Ehlers. Any errors in interpretation, however, are those of the authors. Funding for the Cooper research was through a Texas Tech University Big 12 Fellowship (senior author) and the Museum of Texas Tech University. Both studies and this manuscript represent part of the ongoing Lubbock Lake Landmark regional research into late Quaternary hunter-gatherer grasslands adaptations in the Americas.

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BOOK REVIEWS


The best way to fall in love with rivers is to have a relationship with them. Lisa Knopp does this by looking, experiencing, and contemplating what each river looked like in its wild state; how historical and contemporary travelers viewed them; how they were named; how First Americans lived near and depended upon them; how industry and agriculture have used them; what each river is like after two centuries of human tinkering and engineering; and how the culture, politics, and philosophy of people living along these rivers continue to be shaped by them.

Born and raised along the Missouri River near Burlington in southeastern Iowa, Knopp naturally engages as an insider to experience and learn the history of the First Americans and immigrants who settled along the river. In an age of expansion, 1,476 steamboats plied the Mississippi and docked at the St. Louis wharf in 1839, but by 1872 only 147 steamboats passed beneath the Burlington Railroad Bridge. Prior to 1890, mussel beds resembled cobblestones on the riverbed; overexploitation by the button industry decimated them by 1900.

In Lewis and Clark's day, the Missouri River was productive and self-sustaining. In spite of an expanding country and early wishful thinking by some that the river should be “tamed,” major floods occurred in 1844, 1881, 1903, 1927, 1937, 1952, 1967, 1978, 1993, and 2011—and will continue into the future. “The Taking” essay about “White Swan” on the Yankton Sioux Reservation is especially acute regarding the Native lifestyle dependent upon the river, including a rich naming of the natural plants and foods supporting the tribal way of life.

The Platte, cutting across the Great Plains region, is the last river the author fell in love with. She asks: Is a river still a river if it has no water? Knopp moved from outsider to insider when she moved to Nebraska. While outsider views tend to be simple, one-dimensional, and acquired through collected rather than innate knowledge, insiders have a long-lived intimacy to perceive relationships and depths. Because of her dual status, she sees the astonishing diversity in the Land of the Platte. The State of Nebraska filed suit and won against the Rural Electrification Association and the Laramie River Power Station on a tributary to the North Platte in Wyoming based on the fact that the sponsor and U.S. Army Corps of Engineers were compromising habitat of endangered species in the central Platte and were in violation of the Endangered Species Act of 1973 and the National Environmental Policy Act of 1969. A major three-state recovery program to return water to this valuable Great Plains river for listed species is presently under way.

EUGENE J. ZUERLEIN
Environmental Service Division
Nebraska Game and Parks Commission


The second, enlarged edition is a timely and necessary revision of the comfortable first edition classic. Tomelleri and Eberle remain true to their initial intent of providing accurate yet readable species accounts and detailed illustrations of Great Plains fishes. Format and style are especially suited for nontechnical audiences (anglers, naturalists, fish enthusiasts), whereas detailed life history accounts, summaries of conservation threats, and an extensive bibliography serve as handy references for natural resource managers and researchers.

Upon first review, the “Revised and Expanded” label may seem suspect: this second edition has 34 fewer total pages. However, revision of taxonomy and addition of species accounts are quickly noticed and appreciated. Two families elevated since 1990 are added along with revised family and genera names. Notable additions are made to Cyprinidae, Ictaluridae, and Percidae. Among cyprinids, several genera (e.g., Hybognathus, Macrhybopsis, Diona) are expanded or added, five new species accounts appear, and illustrations increase from 27 to 71.

Common names are assigned for a few genera, such as singing shiners, tallscale shiners, and finescale shiners. Though seemingly whimsical, these names are phylogenetically sound and morphologically useful for ichthyology students. Addition of several madtoms (Noturus) increases the number of ictalurid illustrations from 10 to 16, and addition of several “roughbelly darters” (Percina) and “smoothbelly darters” (Etheostoma) increases the number of percid illustrations from 12 to 32. Unfortunately, additions of black, silver, and bighead carps are necessary to account for exotic fishes established since 1990.

Except for the omission of plate numbers, the second edition is a flawless and artistic presentation of some of the most memorable and often encountered ichthyofauna of the Great Plains.

TIMOTHY H. BONNER
Department of Biology/Aquatic Station
Texas State University, San Marcos


Oklahoma is home to some 2,500 species of flowering plants. Patricia Folley has captured, in full color, some 200 striking and beautiful wildflowers. From the state wildflower (Gaillardia pulchella) to the state grass (Sorghastrum nutans), this wildflower guide covers plants growing in the Rocky Mountain
foothills in the northwest to the cypress swamps of the southeast and a lot in between.

Each species is illustrated with at least two photos showing the entire plant in its habitat and a closeup of its flower. The text offers a short description, followed by the geographic area of the state where the species grows, flowering time, and typical habitat. Common and scientific names are provided, but not the family name. The organization of the book is taxonomic, with monocots first, then followed by dicots with families (not noted) and genera in phylogenetic order—an arrangement the nonbotanist is likely to find difficult to follow. An organization by flower color would have made using the book for identification purposes much easier. The color index in the back of the book is organized into four color groups, then alphabetically by common name. Unless you know the common name, finding your plant by flower color can take time.

As a native Oklahoman, I was disappointed not to find the state tree (rebad, Cercis canadensis) included. Surely the rebad—with its mass of striking pink flowers—is more colorful and noticeable than Juncus marginatus (grass leaf rush). Looking hard, I couldn’t find the state floral emblem, the mistletoe (Phoradendron serotinum), either.

But if you love wildflowers—and Oklahoma’s at that—then you’ll find The Guide to Oklahoma Wildflowers worthwhile to have in your library and perhaps a second copy in your car.

BARNEY LIPSCOMB
Botanical Research Institute of Texas
Fort Worth, Texas


As we grapple with climate change and pollution, resource scarcity and rising prices, it’s clear we need to make difficult choices about our energy consumption. In the opinion of many, the solution begins and ends with increased investment in renewable energy systems, an investment that will help us cut back on emissions and lower prices—while creating economic opportunity here at home. Oizzie Zehner doesn’t share that opinion. His critique of modern American environmentalism in Green Illusions maintains that many of us could be wrong.

Zehner begins by addressing the seductive nature of renewable energy systems, dissecting popularly circulated solutions, and arguing that we are nowhere close to finding a technology capable of moving us past the fossil-fuel-intensive lifestyle we’ve chosen. From solar panels to wind farms, biofuels to clean coal, he shows that each “solution” isn’t a solution at all. In fact, each is part of the problem.

His deconstruction of the industry helps to make sense of our affinity for renewable energy. He points to popular media and mainstream environmentalism as culprits busy selling the renewable energy ideal to an unversed public while ignoring numerous options that could be far more effective in confronting climate change. He points out that alternative energy production expands energy supplies, placing downward pressure on prices, which spurs demand, entrenches energy-intensive modes of living, and finally brings us right back to where we started—high demand and so-called insufficient supply.

It takes some time to get there, but Zehner eventually begins to spell out a series of options that help us look at energy in a brand new way. He touches on energy-efficient lighting, walkable communities, and suburban sprawl. He offers practical solutions readily available to average homeowners seeking to minimize energy use in their day-to-day lives. He then points to some of the many causes of our energy-intensive lifestyle that aren’t often discussed. Examples include commercials aimed at children, corporate influence trumping citizen representation, measurements of the nation’s health in dollars rather than well being, and media concerned with advertising over insight.

Green Illusions commendably illustrates the importance of energy to our everyday lives. Almost every decision we make—from where we live to where we work, to what we eat and how we seek entertainment—provides an opportunity to choose between an energy-intensive lifestyle and one more mindful of consequences.

Zehner is right to suggest that this problem won’t necessarily be solved by the same productivist mentality that got us here in the first place. But it’s fair to argue that he uses this opportunity to dismiss renewable technologies far too quickly. The need to change the way we think about energy doesn’t alter the fact that we need at least some energy, both now and in the future. And where will that energy come from? Should we give up on renewable resources simply because they won’t by themselves solve our energy problems?

It’s true we can focus on saving energy, or on better policies that will conserve energy, but we can’t pretend that we can quit consumption cold turkey. Our energy has to come from somewhere. Zehner comes dangerously close to implying that as long as we boost efficiency and create policies that lead to less energy use and more conservation, the coal-intensive status quo is acceptable.

But continually burning coal to meet our energy needs is not acceptable. The conversation cannot be about replacing conventional resources wholesale; it needs to be about diversification and moving away from those that are most harmful. We may minimize our need for electricity, but we aren’t going to eliminate it entirely. Though they may not be perfect, renewable energy technologies will play an important role in providing our minimum energy needs. They can be improved upon, but they can’t be dismissed.

In the end, Green Illusions asks more questions than it answers, which is a good thing. It’s imperative that we spend more time considering the energy issues that really matter, not those being foisted upon us through mainstream media and other
facets of popular culture. As a nation, we have hard decisions before us. We need to find actual, tangible solutions that will make a real difference. Our path begins with critical thinking and informed choices. This book helps us get started.

Jonathan Hladik
Center for Rural Affairs
Lyons, Nebraska


Robert Wuthnow, who directs the Center for the Study of Religion at Princeton University, has a distinguished publishing record in the field of American religion and culture. A Kansas native, he has an unmistakable soft spot for the state. He opposes Thomas Frank’s view that Kansans have consistently espoused Republican-centered moral issues at odds with their economic well-being. His central argument, as he clearly states, is that the “Republican Party and the centrist conservatism of the state’s two dominant religions—Methodism and Catholicism—actually deterred radical religious and political movements from gaining much ground during most of the state’s history.” He claims it was President Franklin Roosevelt’s New Deal policies that eventually laid the groundwork for the emergence of a radical right-wing, religiously conservative movement in Kansas.

In general, Wuthnow does an excellent job tracing the development of religious institutions in the state. He draws upon census records, both state and federal, in illustrating the dominance of Methodism and Catholicism and the post-World War II fast-paced growth of Southern Baptists and Evangelical dominations. He accurately portrays the importance of prohibition in Kansas, and how Protestants and Catholics lined up on the side of the state’s two dominant religions—Methodism and Catholicism—actually deterring radical religious and political movements from gaining much ground during most of the state’s history. He claims it was President Franklin Roosevelt’s New Deal policies that eventually laid the groundwork for the emergence of a radical right-wing, religiously conservative movement in Kansas.

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Unquestionably, Wuthnow compiles an impressive array of evidence to illustrate his interpretation. Sometimes, however, it feels as if he stacks the deck. As an example, Jeff Sharlet’s The Family: The Secret Fundamentalism at the Heart of American Power (2008) details the rise of perhaps the most influential Christian fundamental political movement in the country. According to Sharlet, Kansas Senator Frank Carlson, who served for over a decade in the House of Representatives and another 20 years in the Senate by 1969, became an important member of the Family, actively embraced its fundamentalist Christian views, and formulated important national policy along the Family’s theological lines. Reading Wuthnow, one would hardly know that Senator Carlson had much of a role in this regard.

Recently at the state level, the social and economic policies of Governor Sam Brownback (whom Jeff Sharlet once labeled “God’s Senator”) and a conservative Republican state legislature have garnered national attention. Large-scale corporate income tax reductions, new abortion bans, voter ID laws, abolishing the state Arts Commission, and opposition to implementing the national Affordable Care Act all bear testimony to the mixing of religion and politics.

Other states in the Great Plains have similar political histories, but Kansas seems to shine in the spotlight. Undoubtedly, Wuthnow sums it up well in saying that “on many occasions, Kansas did lead the way.”

James E. Sherow
Department of History
Kansas State University


Austin, Texas, by most accounts, is one of the most attractive cities in America. It is said by many people and magazines to be one of the best cities in which to live. Outside of Silicon Valley, it possesses some of the best high-tech companies and the most generous investors in high technology. Young people from across the country attend the University of Texas at Austin—and few of them ever seem to leave. It has become the Urbantopia of our age, the model for the new “creative economy.”

But is it? How much of what we know about Austin is simply its branding, not its substance? This book by Joseph Straubhaar and his colleagues from the University of Texas suggests that all is not perfect in Urbantopia.

For many decades, Austin was simply another college town. But in the 1970s and 1980s several strategic decisions and some luck helped the city become a “technopolis”—a center of high technology in which all its residents, presumably, would have the technical skills and know-how to work and live in a high-tech world. The city council, the state government, and the University of Texas all conspired to attract the new high technology companies in the 1980s. IBM was the first to arrive, and the Microelectronics and Computer Technology Corporation furnished an additional boost in 1983. George Kozmetsky of the Business School at the University of Texas helped invent the term as well as a vision for the technopolis, in addition to providing a good deal of its energy and initial financial resources. Once Michael Dell decided to take early leave from the University of Texas in 1983 to begin his own computer firm, the new and revolutionary directions of the city were in place.

The specific question posed by the collaborators on this book is this: Has Austin as a high-tech, high-wire utopia man-
aged to address the question of inequality, particularly in the ways in which people negotiate and profit in it, or is it a utopia in which only the privileged can live and thrive? The research team addressed this question in two ways: by looking directly at the "digital divide," the division in resources and access to the new technology among people of different races and social classes; and by considering the way in which the cultural, or spatial, geography of Austin plays into the access people have to this new world. A large number of students and a number of University of Texas faculty got involved in the research effort that unfolded over 10 years—among the students, the number was in the dozens. And the research itself was carried out in a very careful and meticulous way, including the novel (and adopted) methodological strategy of actually mapping the location of racial groups in Austin from the early 20th century to its late decades. Ethnographic studies were done of how young people used the libraries as well as the public facilities for access to the Internet; studies were made of the occupational distribution of the local labor market. Indeed, in terms of the research effort and the materials uncovered to examine the digital divide, this study is exemplary.

So what did the team discover? They learned that many local groups and people were well aware that not everyone might have equal access to the new technology. Local entrepreneurs like Dell and new local organizations consequently made a decided effort to try to bridge the digital divide and give disadvantaged groups equal access to high technology. Public venues were established where everyone could have access. Classes were held where students from disadvantaged backgrounds were taught the skills necessary to navigate this world. Classes were even held for adults to equip them with the necessary skills and knowledge to deal with this new world.

Despite all these efforts and the good intentions of many public officials and private figures, the digital divide remains firmly in place today. Poverty itself has actually grown in Austin since the dot-com bust of 2000. And while lower-income adults may have been trained in the skills and know-how of this new high-tech world, they often can find no jobs in it. The various authors argue that the inequalities exist because the cultural geography of access continues to shape Austin—the rhythms and spaces of its public life are today pretty much the same as they were in the early part of the 20th century. In particular, Austin is still divided between East Austin, where the majority of African Americans and Latinos have lived since the 1930s and 1940s, and the rest of the city. Geography is indeed a matter of power.

The overall conclusions are compelling and important, though I have just a few academic quibbles. The book tends to be repetitive, the same arguments made in one chapter after another. The work also tries to use and implement the theories of Pierre Bourdieu, a well-regarded contemporary sociological theorist, but I, for one, did not find the theory nearly as helpful as the actual empirical discoveries made by the research team.

In the end, Austin may be the Urbantopia of today, but one with fundamental flaws and problems.

**Anthony M. Orum**
Visiting Scholar
Center for Urban Research and Learning
Loyola University, Chicago


In some respects, this comprehensive anthology represents the cutting edge in a growing field of study related to urban Aboriginal communities in Canada. With a focus ranging from Toronto to Vancouver, the book contains fascinating new studies, including the experiences of Aboriginal employees at Ontario’s Casino Rama, the rebuilding of Papaschase First Nation in Edmonton, and how Plains culture has been adopted as a form of healing in Vancouver. While the authors acknowledge the absence of voices addressing the Atlantic provinces and Quebec, this is offset by the strength of offerings from the Prairies, which include a textual analysis of media racism, a focus on Aboriginal youth gangs, and an exploration of hip-hop culture. Notably, in a context in which Inuit communities are often ignored, the book includes a study of Inuit communities in Ottawa.

While the introduction covers a range of issues relating to urban Aboriginality, this book is refreshing in its view of urban Aboriginal communities as normative, rather than exceptions to a reserve norm. Indeed, the opening essay by David Newhouse, “Urban Life: Reflections of a Middle-Class Indian,” offers an unapologetic choice to be urban and highlights what cities have to offer urban Aboriginal people, particularly those who are culturally sure of their identities and economically in a position to enjoy the benefits of urban life.

Perhaps this choice to establish urbanity as normative to Native experience is the reason for the lack of focus on the role of residential schooling, the Sixties Scoop (the mass removal of Aboriginal children from their families into the child welfare system beginning in the 1960s), or loss of Indian status in shaping some aspects of urban Native life. Indeed, while the role of class in urban Native experience is well articulated, Indian status to some extent is presented as normative to the urban experience.

Overall, the book’s only real weakness is its tendency to privilege academic voices not rooted in Native communities. Unquestionably, the articles written by Native people about their own communities are among the strongest, while the articles that overemphasize academic disciplinary categories in discussing identity and community-building are the most
disappointing, in general providing us with little opportunity to actually hear the subtle distinctions in how the Native people under discussion understand their own identities. Otherwise, this is a highly recommended collection.

Bonita Lawrence
Department of Equity Studies
York University, Toronto


I don’t know how many times I’ve heard someone say, “Capitalism doesn’t work in Indian Country . . . it’s just not compatible with their way of life.” While I’ve often attempted to counter such misconceptions with my own anecdotal knowledge and experience, Robert J. Miller’s excellent Reservation “Capitalism” thoroughly eviscerates that persistent myth.

The opening chapters offer a comprehensive critique of the antiquated notion of Indians as “forest-dwelling socialists,” detailing how private property rights, wealth accumulation, and entrepreneurial acumen were commonplace throughout Indian Country prior to European contact. Miller proceeds to recount how reservation economies were devastated by European interactions and how the yoke of the Great White Father’s paternalism continues the suppression. He then introduces his core thesis that capitalism and economic activity are consistent with tribal values and culture, although both exogenous and endogenous factors unnecessarily suppress reservation economies. Finally, Miller provides a roadmap for overcoming those deleterious factors and moving Indian Country forward towards self-sustaining reservation economies.

Reservation “Capitalism” is worth reading for the opening chapters alone, but Miller also analyzes modern reservation economies, covering a range of tribes from throughout Indian Country with detailed examination of specific tribes in Oregon, California, and Oklahoma. He also provides a thorough recitation of the rise of Indian gaming as an economic powerhouse.

While many of the reasons for the deplorable economic conditions in Indian Country are exogenous, Miller highlights certain areas under tribal control that also contribute to the challenging economic situation. In his chapters on attracting capital, Indian entrepreneurship, and creating reservation economies, he details several opportunities for tribes to make a substantial difference in their own economic situations that are entirely within their power.

Miller also identifies instances where federal and state governments impede the development of self-sustaining reservation economies and provides suggestions either for change or at least minimization of their negative impacts.

Miller’s ideal reservation economy is one in which revenue is generated on the reservation and then circulated multiple times through several on-reservation businesses and individual entrepreneurs, with the ultimate goal of keeping the dollars earned on the reservation. The reality of most reservation economies, however, is the exact opposite, and Miller uses this problem of “leakage” as a recurrent theme throughout his book. He cites numerous examples, but also several studies, including one from 2000 demonstrating that the leakage from the seven reservations in Montana resulted in a billion dollars of lost economic activity. Miller also points to those examples of tribes actively trying to reverse such leakage, such as the development of a tribal member-owned bank on the Turtle Mountain reservation in North Dakota.

While Miller’s fluid style makes his book accessible to the casual reader, the level of research and its extensive endnotes make this book a viable choice as the primary text for a course on tribal economic development. Although not a legal text, Miller provides an excellent synopsis of the legal history and background necessary to understand the impediments to tribal economic development.

Gavin Clarkson
Department of Finance
New Mexico State University


As one who took an early interest in the water rights of American Indian tribes (American Indian Water Rights and the Limits of Law, 1991), I found this book a welcome opportunity to get current on an enduring yet ever-changing area of western water law. In reading it, I was impressed both by what it is and what it is not.

What It Is. This is primarily a report on the proceedings of a conference that the American Indian Law Center and the University of New Mexico’s Utton Transboundary Resources Center convened on the centennial anniversary of the U.S. Supreme Court’s history-making decision in Winters v. United States. In a stunning example of judge-made western federal natural resource management law, a century ago the high court reasoned that whenever the federal government set aside (reserved) lands in the public domain for some specific purpose (in this case, an American Indian reservation), it also by implication laid claim to however much unappropriated water was needed to fulfill the purposes for which the lands were reserved.

The decision and the federal reserved water rights doctrine (a.k.a. the Winters Doctrine) it spawned essentially lay dormant for half a century, while the surface waters of the West were
allocated under state law. But in *Arizona v. California* in 1963, the Supreme Court reinforced the doctrine with fresh legal and moral authority, by empowering tribes and federal agencies to sue for reallocation to reservations of waters that the Court deemed rightfully theirs, even if those resources had already been given to others.

From that time forward, state and federal courts throughout the West (and the Supreme Court as well) have hosted a steady stream (and at times a seeming flood) of lawsuits brought by tribal governments, associated advocacy groups, and the federal agencies seeking to affirm their water rights under the precedents set by *Winters* and *Arizona v. California*. Dedicated young legal advocates, both Indigenous and non-Native, strove to convert the potential latent in the *Winters* Doctrine into the practice of reserved waters being turned onto the lands for which the federal courts ruled they were intended.

To a remarkable extent, those very same history-makers were the ones who, a generation later, gathered in conference at Santa Ana Pueblo, New Mexico, in 2008. In the intervening time, they had become leaders in state and federal government agencies managing water resources, founders and directors of legal defense funds, and law professors and deans carrying on the scholarly development of the living entity that is the *Winters* Doctrine.

So this is in large part what this book is: a record of reflections, opinions, and recommendations from those who participated in changing the course of the history of western water law. As is the case with such conference proceedings, however, the content tends to be somewhat uneven, partly depending on how much effort the participants put into the preparation of their remarks and written contributions.

Happily, the inevitable gaps are filled in with scholarly research from other contributors. They provide additional historical context and develop a handful of case studies looking at what happens after the courts have issued their decrees (or the parties have reached settlement in the shadow of the court’s authority) and stakeholders have to go about converting “paper water” into “wet water” (i.e., reallocation management regimes).

The result is an edited potpourri of conferee comments, contributions of mixed depth and erudition, and contemporary scholarship on the history and current implementation of the federal reserved water rights doctrine. Historians will like it for the same reasons they like the memoirs and insights of veterans of wars fought a generation earlier.

**What It Is Not.** Paradoxically, what *The Future of Indian and Federal Reserved Water Rights* is not is a book about the future of Indian and federal reserved water rights. Less than 10% of the content of the book is devoted to the subject of its title. Granted, some of the most poignant (and perhaps prescient) writing is to be found here, such as some parting words of wisdom from David Getches, then dean of the University of Colorado School of Law and a legend in both the scholarly literature and the administration of western water law. Fittingly, the book is dedicated to his memory. But the book is simply not what the title promises.

It does a great job of both providing rich historical context and well-developed case studies of the current status of *Winters* Doctrine implementation. Nonetheless, thoughtful consideration of its future appears almost as an afterthought in the book’s last section. A far better title would have been something like “American Indian and Federal Reserved Water Rights: The First Hundred Years,” or “American Indian and Federal Reserved Water Rights in the Twenty-first Century.”

This is a worthy contribution to scholarship on one of the most important doctrines in western water law. Would that its title better conveyed this virtue.

**LLOYD BURTON**

School of Public Affairs
University of Colorado Denver


Lavishly illustrated, beautifully bound, and richly textured, this volume stunningly reproduces the visual culture of the railroad: its maps, brochures, advertisements, broadsides, and pamphlets. Derek Hayes has brought together over 400 maps, ranging from the first railroad survey map drawn in the U.S., filed in 1809, to President Barack Obama’s “Vision for High Speed Rail in America,” published in 2009. This is an impressive compilation, but it is not an atlas in the conventional sense. Hayes considers a “map” to be any printed item with geographical information on it, whatever its genre. Whether a route map, advertisement, or ticket, whether railroad-produced or not, all are considered “maps” and treated without regard to their original purpose or format. For this atlas, moreover, Hayes has produced no new cartography, either representational or analytical.

Hayes has interwoven narrative text on the history of the railroad among the illustrations, and the volume suffers as a result, creating several problems. First, we learn nothing about the workers who built these colossal enterprises, or the tunneling, bridging, and grading operations they undertook. Second, older myths are perpetuated here. The most obvious example is Hayes’s dismissive depiction of the Grangers as cranky obstacles to progress. His treatment of land grants is equally neorevisionist. Hayes suggests correctly that the railroads received less-sizable grants than were often depicted in some hyperbolic maps. But his conclusion, left there, misleads: after all, the federal land grant to the Union Pacific Railroad roughly equaled the square mileage of New Jersey and New Hampshire combined; the Central Pacific got, in effect, Maryland. Native American losses to the railroads go entirely unmentioned.

Third, Hayes’s narrative is unapologetically triumphant and
uncritical, as well as out of touch with the latest scholarship on the railroads in North American history by Richard White, Richard Orsi, Teresa Van Hoy, T. J. Stiles, and Theresa Case. In fact, this atlas leaves out much of North America—neither Mexico nor Central America is included, though Canada is. Hayes downplays the Crédit Mobilier fraud, for example, by explaining simply that the company "took advantage of new limited-liability legislation." The explanation, not entirely accurate, gives the Crédit Mobilier's activities a veneer of legitimacy and respectability they do not deserve.

For Great Plains scholars, this volume will likely both inspire and disappoint. The gorgeous maps, page after page, are mesmerizing, and even the most experienced railroad enthusiast will find new insights. But scholars will have trouble with the glorification and technological determinism at the heart of Hayes's analysis, evident from the first paragraph according railroads singular responsibility for the growth of the U.S. and Canada.

**William G. Thomas**
Department of History
University of Nebraska—Lincoln


At first glance this slender volume appears to be nothing more than a study of one small and seemingly insignificant Ukrainian Canadian settlement located in the harsh bush country of southeastern Manitoba. Appearances can be deceiving. While *Community and Frontier* is most assuredly a case study, it is a brilliant little work—a true gem—that sparkles with intellectual vitality as it broadens our understanding of the entire Ukrainian Canadian experience, particularly in the pioneer phase.

The author, John Lehr, a well-respected historical geographer at the University of Winnipeg and an important contributor to the field of Ukrainian Canadian studies, has in some ways been doing the fieldwork that informs this project for the better part of 40 years—and his familiarity with the Stuartburn district and its people comes through on every page. More to the point, Lehr achieves his goal of using this subregion and its largely Ukrainian-speaking settlers to "demonstrate the complexity of pioneer settlement and community formation on the frontier" and fulfills his desire to illustrate the "crucial role played by geography in the evolution of new societies on the margins of the British Empire, where 'regional' colonies were created within much larger colonies in a hierarchy of dependence." In meeting these rather grandiose objectives, Lehr has employed a broad array of sources, including ethnographic interviews (many of which date back to the 1970s), a host of archival sources, the Ukrainian- and English-language press, and an extensive set of published works, ranging from contemporary government reports up to the most recent scholarship on Ukrainian Canadians.

Organized into nine thematic chapters, and taking a decidedly postmodernist approach to the subject at hand, *Community and Frontier* places the Stuartburn district into several different contexts. The work starts with a well-considered analysis of how Ukrainian-speakers came to Canada at the close of the 19th and beginning of the 20th century and then moves into the specifics of the settling and colonization of the Stuartburn district. It is here that we see Lehr's genius for moving from the general to the specific and back again come to the fore. His appreciation of the preexisting divisions among Ukrainian-speakers—often determined by religion, specific place of origin within the Austro-Hungarian and Russian empires, exposure to nationalist sentiment, etc.—allows him to go well beyond the usual "outsider's view" and see the nascent Ukrainian Canadian community as a diverse and often deeply divided entity in the somewhat problematic process of creating a "Ukrainian identity," even as it was being called upon to adapt to the norms and mores of the dominant British Canadian culture. In Lehr's work there was no singular "old country" tradition at work in Stuartburn; instead, there were several conflicting traditions, all of which competed with each other as the settlers struggled to eke out a living—and a way of life—in a subregion hardly endowed with natural bounty.

What is most refreshing about this work is that Lehr is not looking for heroes or villains: the choice of the Stuartburn district by the Ukrainian-speaking settlers, with its marginal lands, swamp-like conditions, and tree cover, was not the result of the work of heartless agents of the Canadian state, bound and determined to fill up every last square centimeter of western land, nor of unthinking, ignorant settlers. Rather, the district was consciously chosen for its short-term advantages—such as easily accessible supplies of wood and water—and then grew and developed in spite of its long-term disadvantages as a farming district, primarily because of the well-studied phenomenon that is chain migration. Nor does Lehr shy away from aspects of life in Ukrainian communities that shine a less-than-flattering light upon his subjects: alcohol, ether and patent medicine abuse, domestic violence, criminality, anti-Semitism, virulent fights over matters of religious (and secular) affiliation are all dealt with in a manner that shows both sensitivity to the plight of the settlers and a keen appreciation of the cultural baggage that was transported by them to the Canadian frontier.

Most praiseworthy of all, however, is the way in which Lehr manages to surmount the parochialism inherent in so many case studies. While a central part of his argument is that settlements like Stuartburn developed their own unique "social, cultural, and economic resources" through the work of individuals and grassroots organizations, the author never loses sight of the larger picture of the Canadian "corporate frontier," the partially determining effects of environment, the hierarchical relationship of hinterland regions to submetropolitan and metropolitan...
centers, and other such structural factors. Indeed, at the end of the day, some readers will wonder if Harold Adams Innis, and perhaps Marx, have not had just as much an effect on Lehr's analysis as Michel Foucault. But that is a moot point; indeed, I would argue that the perspectives are nicely balanced. What is not debatable is this: John Lehr has produced a work that deserves to be read by every serious student of the settlement process, the "frontier," western Canadian history, ethnic history and—oh, yes—Ukrainian Canadian history. The only factor that demands further explication in this work is the role—often mentioned but rarely discussed in any detail—of the grassroots intelligentsia in the development of the Stuartburn district. This, however, is a minor flaw in an otherwise outstanding piece of work.

Jim Mochoruk
Department of History
University of North Dakota
2014 GREAT PLAINS SYMPOSIUM

The Center for Great Plains Studies announces that its 2014 annual symposium will address the issue of Drought in the Great Plains. The symposium will be a collaboration with the National Drought Mitigation Center and the Robert B. Daugherty Water for Food Institute, both at the University of Nebraska; it is scheduled for Spring, 2014. 2011 and 2012 witnessed two of the worst Great Plains droughts in recent memory, a tragic counterpoint to the damaging floods of 2011 and a return to the stressful times of 1998–2006. Drought is a recurring pattern in this semi-arid region, with severe droughts in the 1890s, 1930s, 1950s, and 1980s. Indeed, using tree ring, lake sediment, and dune records, scientists have documented the periodic return of severe droughts; for example, during a period labeled the “16th century megadrought,” severe drought persisted for up to 20 years. Based on such evidence, some scientists have observed that drought was the dominant feature of climate rather than the exception. Drought has been and will continue to be a normal part of the climate of the Great Plains. Drought or the ever-present threat of it has had a pervasive effect on the region and its people. It has molded the region’s settlement patterns, agriculture, and commerce; stimulated innovation and new technologies; aroused conflict between agriculturalists and environmentalists; and fueled litigation between states in the region. Drought has shaped how the people of the Great Plains think of themselves and their region and influenced the culture, literature, and art they have created. So, too, there is increasing concern as to whether the region will have sufficient water for its future, both for planned development and for sustaining the ecological services the region provides. Scholars from across the full spectrum of disciplines will be invited to share their expertise and perspectives as the symposium explores all aspects, causes, impacts, projections, social and cultural consequences, and ramifications of drought.

CONFERENCES

August 4–9, 2013
The 98th Annual Meeting of the Ecological Society of America will be held in Minneapolis, Minnesota. This meeting’s theme is “Sustainable Pathways: Learning from the Past and Shaping the Future.” Web site: www.esa.org/meetings/.

August 12–14, 2013
“America’s Grasslands: The Future of Grasslands in a Changing Landscape” will bring together researchers, natural resources professionals, farmers and ranchers, policy experts, and conservationists to discuss the conservation of North America’s grasslands and the opportunities and outlook for these vital ecosystems in a changing landscape. The conference is sponsored by Kansas State University and the National Wildlife Federation. For more information, contact John Briggs at jbriggs1@ksu.edu.

November 10–13, 2013
The 61st Annual Meeting of the Entomological Society of America will be held in Austin, Texas. The theme of the meeting is “Science Impacting a Connected World.” Web site: www.entsso.org/entomology2013.
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Article Style. Authors should write simply and in the first person, communicate with a broad interdisciplinary audience in jargon-free language, and avoid sexist, racist, or otherwise biased language or intent.

Title. Article titles should not exceed 10 words (or 82 characters) and should not have subtitles.

(1) Text Headings are left-justified, all caps, and bold: INTRODUCTION, METHODS, RESULTS, DISCUSSION, CONCLUSIONS, ACKNOWLEDGMENTS, REFERENCES. (2) Text Subheadings are left-justified, title caps, and bold. (3) Text Lower Subheadings are left-justified, title caps, bold, no tab, and lead into the paragraph.

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Illustrations. All illustrations including maps should be referenced parenthetically by arabic numbers in the text. For example, "Rainfall increases with elevation (Fig. 1)." Captions for figures should be sent as a separate file and not included or embedded into the figure itself. All illustrations should be sized for 1-column width (3.25") or 2-column width (6.625"), be no more than 9.0" in height, and be sent as separate files as "grayscale" tiff or eps graphic files at 350 dpi, and "line" illustrations should be 1200 dpi. High quality pdf files are acceptable.

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BOOK REVIEWS

NEWS AND NOTES